The Links Between Uncertainty, Variability of Outputs and Flexibility in Manufacturing Systems

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Abstract

This research looks into the relationships between **uncertainty, variability** and **flexibility** in manufacturing systems from an operations strategy viewpoint. After reviewing the literature concerning the three categories, 6 research propositions are defined in order to guide the research. A research method (case-studies with semi-structured interviews) is then selected and field research which encompassed 8 companies, including the ones of the pilot study is described. The field work resulted in 4 in-depth case studies, performed with Brazilian and British companies (2 in each country), all of them belonging to the automotive industry. Based on the conclusions of the literature review and on the results of the field work, the 6 propositions are discussed and an original model is then proposed in order to help managers understand and analyze unplanned change from the operations management's viewpoint. The model proposes two complementary categories which are used by managers in order to deal with unplanned change: **control** and **flexibility**. Control is related to the managerial actions which aim to restrict the amount and level of unplanned change with which the organization will have to deal *ex-ante* the occurrence of the change. Flexibility is related to the managerial actions taken in order to respond to the uncontrolled unplanned change's effects *ex-post* the change. Types and dimensions of control and flexibility are proposed and discussed. A new way to look into the flexibility of the manufacturing structural resources is also proposed, which is based on the presence of the resource **switchability** and on some types of **redundancy** of the resources - of capacity, of capability and of utilization.

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Declaration

No portion of this Thesis has been submitted in support of an application for another degree or qualification from this University or any other Institute of Learning.

Some of the research findings have already been published in conference proceedings (see Correa and Slack, 1991 as referred in the Bibliogrphy).

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Part I - Literature Review

This part consists of 5 chapters and aims at reviewing critically the literature with regard to the main concepts involved in this research work: flexibility, variability and uncertainty in manufacturing systems.

Chapter 1, "Manufacturing Strategy" reviews briefly the increasing interest found in the literature in manufacturing strategy and places manufacturing flexibility in its strategic context. The increasing importance of flexibility as a competitive criteria is discussed and the relationship between flexibility and other important criteria is also analyzed.

Chapter 2, "The Flexibility of the Manufacturing Systems" reviews the literature about manufacturing flexibility as a competitive criterion. The different definitions and taxonomy of flexibility and the justifications for a manufacturing system to develop flexibility found in the literature are discussed.

Chapter 3, "The Flexibility of the Manufacturing Resources" reviews the relevant literature on the development of manufacturing flexibility through the development of flexible manufacturing resources. Three basic resource types are analyzed: Human, Technological and Infrastructural.

Chapter 4, "Uncertainty in Manufacturing Systems", discusses the literature on uncertainty, analyzing the concept of uncertainty itself (e.g. "is uncertainty an objective or perceived category?"), the measurement of uncertainty and its relationship with the concept of flexibility.

Chapter 5, "Variability in Manufacturing Systems" analyzes the scarce literature on variability of manufacturing systems. The reasons for variability to appear in manufacturing systems and the relationship between variability and, costs and flexibility are also analyzed.

Chapter 1 - Manufacturing Strategy

The objective of the first chapter, "Manufacturing Strategy", is to place manufacturing flexibility in its strategic context.

The first part of the chapter discusses the reasons why manufacturing strategy has been one of the most studied issues of recent years in the operations management literature.

The second part discusses the views found in the literature about the manufacturing strategy contents - objectives and decision areas - and process. Manufacturing flexibility is then described as one of the competitive criteria which the organization may pursue in order to enhance its competitiveness.

The role of manufacturing flexibility as a first and as a second order competitive criteria (a "second order competitive criteria" is one which is not a competitive criteria in itself, but an indirect criteria which influences the performance of the organization in terms of other criteria e.g. costs and delivery speed) is analyzed, in terms of helping enhance the organizations competitiveness.

Chapter 1

Manufacturing Strategy

Manufacturing strategy has been increasingly regarded by academics and practitioners as having an important contribution to make to enhanced competitiveness. The growth of literature in manufacturing strategy has matched the growth of interest in the area. Within the literature there are three main reasons identified as being responsible for its newly found importance.

The first of these is the increased pressure due to increasing international manufacturing competitive environment. The second is the increased potential to be gained from the development of new manufacturing technologies and the third is the development of a better understanding of the strategic role of manufacturing. Each of these stimuli will be examined in turn.

1.1. The Changing International Manufacturing Competition

During the last 30 years the relative competitive positions occupied by the leading industrial countries have changed substantially. Some traditional industrial nations have been outperformed by other countries, of which Japan is the most evident example. The United States and the United Kingdom have had their leading positions challenged and in many cases lost them (e.g. in the automobile market, for long dominated by American companies) (Womack et. al., 1990; Hill, 1985).

Buffa (1984), considering the Japanese manufacturing industry, notices that the industries in which they have excelled - motor cycles, domestic appliances, automobiles, cameras, hi-fi, and steel production - had existing already developed markets with established market leaders. According to the same author, Japanese companies would have succeeded, partially because of their Finance and Marketing related skills, but largely because of the high quality and low cost which they achieved through a sharp manufacturing practice which most of the western manufacturers would not have been able to match. Buffa (1984) identifies that the Japanese companies were using the improvements which they had been achieving in Manufacturing as their main competitive advantage, as opposed as the Western companies, which had considered Manufacturing as a "solved problem", focusing their attention on getting competitive advantage through achieving excellence in marketing their products and managing their financial issues.

Not only are Japanese companies on average more cost efficient than most western companies (though there are many exceptions of western companies which have maintained or improved their competitive position in the world market during the last decades), but they are competing and winning based also on their better quality and reliability performance as well as on their better responsiveness to the market needs and opportunities. In the introduction of new products, for instance, Japanese car manufacturers cut their product development times (the period between the earliest stages of design and the manufacture of a new model) to an average of less than four years compared to six to eight years in Europe and America[1] (Womack et. al., 1990; Stalk and Hout, 1990)

1.1.1. The Reasons Behind the Changes

There is in general agreement that (initially, at least) Western companies lacked an effective response to the Japanese challenge. The reasons behind this lack of an effective response by most of the western companies which faced such challenge are various, according to the literature. Hayes and Wheelwright (1984) summarized some of them in 5 main points:

Financial considerations - the assessment of companies and their manager's performance based predominantly on short term considerations (Hill, 1985)(Johnson, 1990) would have induced managers to avoid long term investments which would have resulted in a more effective manufacturing. Managers would not decide to invest in improvements of which results would only show in the long term because they needed short term performance. Kaplan (1984) argues that the traditional accounting methods, developed basically to support mass production, undermine today's production, because of its short termism and inadequacy to support production in the new competitive reality. The new competitive environment would require broader product ranges, faster and more frequent product introductions and products of higher quality levels.

Technological considerations - western managers would have been less sophisticated, imaginative and even interested in dealing with technological considerations than the overseas competitors, focusing attention predominantly on financial and marketing issues (Buffa, 1984; Hill, 1985; Skinner, 1985).

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[1]The Economist, "Teaming with Ideas", February 1988.

Excessive specialization / Lack of proper integration - western managers would have tended to separate complicated issues into simpler, specialized ones to a greater degree than their foreign counterparts without having developed proper integration to pull the differentiated responsibilities together and to be able to deal with the total picture (Skinner, 1985).

Lack of focus - the separating and specializing mentality would have led many western firms to diversify away from their core technologies and markets. They would have tended to adopt the "portfolio" approach, used by stocks and bonds' investors. This approach considers that diversifying is the best way to hedge against random set-backs. Manufacturing however would not be subject only to random set-backs but more significantly to carefully orchestrated attacks from competitors who focus all their resources and energy on one particular set of activities. Focused manufacturing is based on the idea that simplicity, repetition, experience and homogeneity in tasks breed competence (Skinner, 1974).

Inertia - Skinner (1985) observes that most factories in the western world were not managed very differently in the 70's than in the 40's or 50's. Such practices, goes on Skinner, may have been adequate when production management issues centred largely on efficiency and productivity. However, the problems of operations managers had moved far beyond mere physical efficiency. On top of it, managers considered that the production problems were solved (Buffa, 1984), directing attention and resources toward other issues such as distribution, packaging and advertising. There has been a failure, according to Hill (1985), conscious or otherwise, of western industries and the society at large to recognize the size of the foreign competitive challenge, the impact it was having on their way of life and consequently to recognize the need for change.

The result of the concurrence of the 5 factors above would be that western plants and equipments were allowed to age. What one day had been technological advantage eroded by the decline in expenditure and attention to issues such as new products research and development and new process technologies (Hayes and Wheelwright, 1984). Then, Hayes and Wheelwright conclude, "in the beginning of the 70s, US companies found themselves pitted against companies that did compete on dimensions as defect-free products, process innovation and delivery dependability. Increasingly, they found themselves displaced first in international markets and then in their home market as well". This conclusion can also be extended to many non-U.S. western companies.

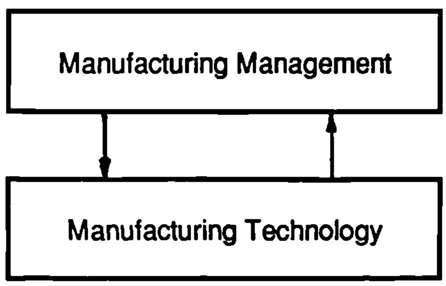
One western country which represents an exception in the loss of competitiveness to Japanese companies is West Germany. In spite of the upward pressure on the Deutsche

Mark during most of the 70s and the economic stagnation and political turmoil the Germans have faced in recent years, the German Economy remains strong in its most important area, the manufacturing sector (Hayes and Wheelwright, 1984). German manufactured exports grew vigorously during the 70s and Germany's productivity growth rate in the manufacturing sector actually increased in the 70s, whereas it dropped in other western industrial countries. The authors reckon that the good German performance is based on factors such as technological strength throughout the company's managerial hierarchy, intense product and customer orientation, orientation toward the growth and stability of the firm, among other manufacturing related factors.

When we contend German and Japanese approaches (Hayes and Wheelwright, 1984) to manufacturing management, some points in common can be found - such as the technological strength throughout the managerial hierarchy - but quite different characteristics can also be noted - like the strong emphasis in the team approach and participative management style, a norm in Japanese firms and less emphasized, in German ones. However the authors in the literature recognize that Japan and West Germany managed to find their competitive way. They were better able to exploit their strengths and mitigate their weaknesses. They showed that there were alternative paradigms to the one in vogue since World War II. This does not mean that their practices are unequivocally good or necessarily superior to practices in other countries. The main point is that their superior performance called the attention of western managers and academics to the need to rethink their own manufacturing practices in order to find their own effective way, one which is adequate to their needs and potential and appropriate to the new reality of the world market.

1.2. The Development of New Manufacturing Technologies

Manufacturing Technology is regarded as one of the most important decision areas within the manufacturing management function (Voss, 1989; Goldhar and Jelinek, 1983). Traditionally, manufacturing management has influenced manufacturing technology to a much greater extent than the other way round.



Changes in the manufacturing technology were for a long time slow and gradual not calling for profound changes in its management methods and techniques. With the new micro-electronics and information handling technology being incorporated into the process technologies, the resulting changes were not gradual and did not follow the usual pattern. A new paradigm was established. Computer controlled flexible machines challenged the one time well established concept of "economies of scale" because they have the potential of making changeover times negligible. The concept of "economies of scope" (Goldhar and Jelinek, 1983) started to gain importance.[2]

The new flexible technology made it possible to produce different products at the same rates which had only been possible with mass production, with single or a few products. The strict one-to-one relationship between product and process life cycles (Hayes and Wheelwright, 1984) would not apply any more (Stecke and Raman, 1986).[3]

According to Voss (1989) the development of new process technologies has been of such proportion that it has "outstripped the ability of people to use it at its full advantage or even understand its potential". The potential capabilities of the new technologies include reducing design-to-production lead times, reducing order to delivery lead times, improving the conformance quality of products, among others. This can change the way organizations compete in the market place. New manufacturing technologies start influencing more relevantly the manufacturing management. Questions such as: "How can the new technologies make us more competitive?" and "How can the new technologies change the way we compete?" become the key questions. The new technological paradigm called for a new management approach.

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[2] Economies of scope (Goldhar et. al., 1987) are said to occur when one production unit can produce a given level of outputs of a variety of products at an unitary cost which is lower than that obtained by a set of separated production units, producing, each one, one product at the same level of output.

[3] Hayes and Wheelwright (1984) propose the representation of the interaction between the stages of the product life cycle and the stages of the process life cycle using the "product-process matrix". The rows in the matrix represent the major stages through which a production process tends to pass going from what they call Jumbled flow (job shop) to the Continuous flow through Disconnected line flow (batch) and Connected line (assembly line). The columns represent product life cycle phases which go from the great variety associated with the product's initial introduction (low volume, low standardization) to the standardization associated with commodity products (high volume, high standardization) passing through intermediate stages. The authors suggest that normally there is a "natural match" between process and product stages in their life cycles, and that normally production systems would be located in the matrix according to "diagonal matches", in which a certain kind of product structure (set of market demand characteristics) is paired with its "natural" process structure (set of manufacturing characteristics) - for instance the Jumbled flow process would naturally be paired with low volumes, rather than with high volumes, high standardized products, which in turn would match the continuous flow process.

Robotics, Computer Aided Manufacturing, Flexible Manufacturing Systems, among other newly available manufacturing process technology labels, are now current terms in the manufacturing environment and they came to challenge some one time well established concepts (e.g. the economies of scale). However, despite the optimism of some authors, there is some evidence in the literature (Poe, 1987; Jaikumar, 1986) that the new process technologies (robotics, FMS - flexible manufacturing systems, among others) have not proved to be as influential as initially thought. These authors argue that the expectations and also the investments with regard to the new technologies were initially high but the results, although considerable, have not followed suit.

The choice of the adequate process technology is more than ever a critical strategic decision. Each choice of process will bring with it strategic implications for a business in terms of: response to the market needs, manufacturing capabilities and characteristics, level of investment required, unit costs involved, type of control and style of management. Traditionally, manufacturing technology has been seen in relatively narrow terms. Specialist engineers have tended to think in technical rather than operating or strategic terms (Skinner, 1985). The availability of the new manufacturing technologies, according to Hayes and Wheelwright (1984) call for at least three kinds of strategic fit: the first is internal to the manufacturing function and relates to coordinating technology activities with operating policies and systems. The second is to do with the consistency between internal and external activities or, in other words, with meshing manufacturing capabilities with the capabilities and needs of the other functions and the firm's overall competitive strategy. The third fit relates to the consistency over time, ensuring that the firm's technology evolves in a directed fashion so that as technological capabilities are renewed and augmented, they reinforce and expand the firm's competitive position. A comprehensive and strategic perspective is thus more than ever necessary to deal with the new manufacturing technologies to ensure an adequate choice and appropriate management so that they actually contribute at their full potential to the business competitiveness.

In summary, without a clear strategic direction with regard to manufacturing, the new manufacturing technologies can become an expensive "solution in search of a problem". In this sense, one of the aims of manufacturing strategy is to give the organization strategic direction with regard to manufacturing issues - technology included - making sure that not only the technologies but also the people and the infrastructure used are consistent with the strategic objectives of the business.

1.3. Development of a Better Understanding of the Strategic Role of Manufacturing

Skinner is one of the authors who first recognized and called attention to the strategic role of the manufacturing function in business and corporate competitiveness. In his early articles (Skinner, 1969, 1971) the author identifies that the acceleration of the foreign competition, technological changes in production and information handling equipment and the social changes in the work force would be calling for profound changes in the manufacturing function management. The potential of manufacturing as a competitive weapon and the concept of using manufacturing as a strategic asset could no longer be overlooked by managers who should abandon a number of old assumptions about manufacturing. A new approach would be necessary, according to Skinner (1985), in order to respond to the new reality. The author makes a number of points, which can be grouped under 4 main headings:

First, manufacturing can be a "formidable" competitive weapon if equipped and managed properly. Manufacturing matters have been a "missing link in corporate strategy" and companies which intend to be *competitive should start to consider* manufacturing in a strategic way.

Second, cost efficiency is not the only contribution which manufacturing can provide to business competitiveness. The assumption that the main criteria for evaluating factory performance are efficiency and cost should be challenged and new criteria should be adopted which evaluated how the firm is competing rather than how efficient it is.

Third, trade-offs must be made and priorities established between manufacturing performance criteria. According to this view, a good factory could not simultaneously excel in all performance criteria such as low cost, high quality, minimum investment, short cycle times and rapid introduction of new products.

Fourth, competitive manufacturing must be focused. Companies should focus each plant on a concise and manageable set of products, technologies, volumes and markets and develop manufacturing policies and supporting services so that they focus on one explicit manufacturing task instead of many inconsistent and conflicting ones.

Since the seminal work of Skinner, a number of authors have addressed the strategic role of the manufacturing function. Hayes and Whellwright (1984) called attention to the need to transform the manufacturing role from being primarily reactive to "proactive", where the manufacturing function contributes actively to the achievement of competitive advantage.

Another point which is made by some authors (Slack, 1990; Fine and Hax, 1985) refers to the fact that the complexity of the manufacturing function calls for strategic management. According to Slack, manufacturing is almost certainly the largest (both in terms of people and capital employed), probably the most complex and arguably the most difficult of all the functions within the organization to manage. Manufacturing strategy would thus involve developing a manufacturing system or a set of manufacturing resources which enable the organization to compete more effectively in the market place.

Hill (1985) argues that the need for a manufacturing strategy to be developed and shared by the business is not only to do with the critical nature of manufacturing within the corporate strategy but also with a realization that many of the decisions in manufacturing are structural in nature. Therefore, unless the issues and consequences are fully appreciated by the business, then it can be locked into a number of manufacturing decisions which possibly will take years to change. Changing them is costly and time consuming, but even more significantly, the changes will possibly come too late.

1.4. Focused Manufacturing: an Increasingly Important Concept

Although the manufacturing function is regarded as one of the most complex to manage within the organization, what creates the complexity is not the technology dimension but the number of aspects and issues involved, the inter related nature of these and the level of fit between the manufacturing task and its internal capability (Hill, 1985). The level of complexity involved depends largely on corporate and marketing strategy decisions, made within the business, where the competitive priorities are established. These competitive priorities are established because a manufacturing system cannot excel in all aspects of performance at the same time. Trade-offs must be made. Different types of performance demand different manufacturing resources organized in different ways (Slack, 1989a). An organization which competes predominantly on cost efficiency, for instance, by manufacturing in high volumes, would need different resources (possibly more dedicated machines) in order to compete effectively if compared to an organization competing on product customization, making products to order (which would possibly call for more general purpose flexible equipment).

This is the rationale behind the concept of focused manufacturing. According to this view, for the effective support of competitive business strategy the manufacturing function should focus each part of its manufacturing system on a restricted and manageable set of products, technologies, volumes and markets so as to limit the manufacturing objectives in which it is trying to excel. This means that if an organization has different products or product groups competing in different ways, then its manufacturing function should reflect this in the way it is subdivided so as to maintain focus on what is most important for its competitiveness in the market place.

If a company competes on a broad range of products, the decision to adopt the concept of focused manufacturing can have the disturbing implication of calling for major investments in new plants and new equipment to break down the present complexity. One alternative approach which helps to avoid major investments is, according to Skinner, a solution that does not involve selling big multipurpose facilities and decentralizing them into small ones. The solution could be the more practical approach of the "plant-within-a-plant", where the existing facility is divided both organisationally and physically into plants within the original plant. Each of them would have its own facilities. Each plant-within-the-plant can this way concentrate on its particular manufacturing task, using its own work force management approaches, production control systems, organizational structure and so forth. Each plant-within-the-plant would quickly gain experience by focusing and concentrating every element of its work on those limited essential objectives which constitute its manufacturing task or focus.

According to Skinner (1974), the idea of focus should thus permeate all the process of formulation and execution of the business and manufacturing strategies. The establishment of competitive priorities and the decision making process should also take the idea of focus in consideration, in order to make sure that the manufacturing function can really excel in what it is expected to.

Although it is intuitive and appealing, having gained a broad support lately among academics and practitioners (Schmenner, 1990; Stalk and Hout, 1990; Hill, 1985), the concept of focused manufacturing still lacks further empirical support[4]. Further research is still needed to test its assumptions and prescriptions.

1.5. The Manufacturing Strategy Process

In general, authors agree on the prime aim of manufacturing strategy which, according to them, is to support the organization's achievement of a long term sustained

[4]Although some empirical evidence can already be found in the literature, e.g. in the work of the Boston Consulting Group, reported in Stalk and Hout (1990).

competitive advantage (Skinner, 1985; Hill, 1985; Slack, 1991; Hayes and Wheelwright, 1984; Buffa, 1984; Fine and Hax, 1985). It is also clear that for most of the authors the development of a manufacturing strategy should follow a top-down approach. Skinner (1985), Hayes and Wheelwright (1984), Hill (1985), Slack (1991) and, Fine and Hax (1985) suggest hierarchical models in which corporate strategy drives business strategies. This in turn drives the strategies of manufacturing and other functional areas within the business unit. Although the dominant approach to formulate a manufacturing strategy is top-down it seems that as long as the manufacturing function reaches more developed stages in Hayes and Wheelwright's (1984) 4-stage classification[5] capabilities developed by the manufacturing function start influencing more and at a certain extent also driving the corporate and business strategies, with a somewhat bottom-up view being aggregated to the dominant top-down approach. The general process of formulating manufacturing strategy can be represented by the figure 1.1.

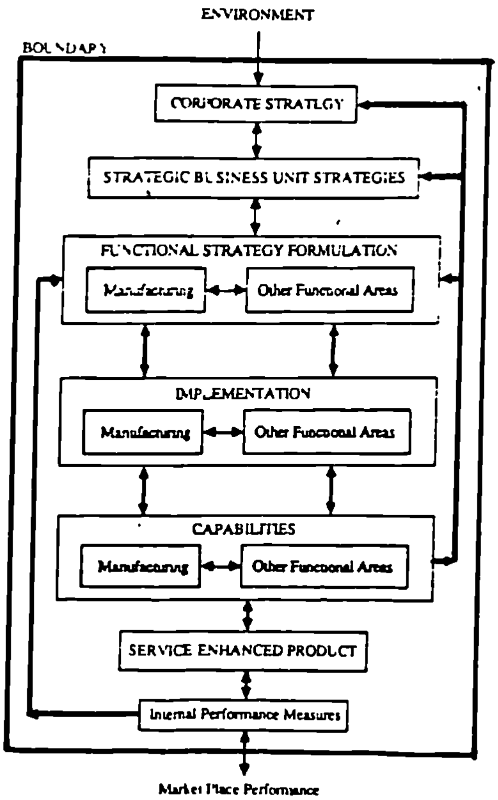

Fig 1.1. - General Manufacturing strategy development process
Font: Leong et. al., 1990

[5]Hayes and Wheelwright (1984) propose a taxonomy for the manufacturing systems in which 4 stages are defined - internally neutral, externally neutral, internally supportive and externally supportive - according to the increasing proactive role played by the manufacturing function within the organisation's corporate strategy.

Summarizing, the authors (Gregory and Platts, 1990; Anderson et. al., 1990; Hill, 1985; Leong et. al., 1990; among others) seem to agree with regard to the basic top-down, break down approach for manufacturing strategy formulation where corporate strategy drives business strategy, which in turn drives the strategies of manufacturing and other function areas within the business unit (Marketing, R&D among others.), breaking down strategies of one level into objectives of the following and so on up to the level of the manufacturing strategy decision areas (defined in the next section).

1.6. The Manufacturing Strategy Contents

The manufacturing strategy "contents" are divided into "objectives" and "decision areas". Each will be discussed in turn.

1.6.1. Objectives

The principal aim of manufacturing strategy is to support the organization's achievement of a long term sustained competitive advantage. Competitive advantage is achieved through manufacturing by managing its resources in order to provide an appropriate mix of performance characteristics or competitive priorities. In general terms, the authors seem to agree about the main objectives which the manufacturing systems should pursue, although the terminology they use varies widely, making it difficult to make accurate comparisons.

Skinner (1978) and Fine and Hax (1985) define the manufacturing objectives as having four broad dimensions: cost, quality, delivery and flexibility.

Wild (1980) divides the objectives into two groups: the ones related to customer service and the ones related to resource productivity. Resource productivity refers to how efficiently the manufacturing resources are utilized. About customer service, three main competitive factors are identified: product specification (design and performance levels), cost (price and expenses levels) and timing (delivery time). Wild suggests that apart from the level achieved, another dimension should be considered for each factor: reliability, which would be the principal direct contribution of operations management.

Slack (1983) extends Wild's analysis and adds volume and mix of output to the factors and flexibility to the dimensions. Volume relates to the ability to manufacture at a particular rate, mix relates to the ability of manufacturing products in a particular mix and flexibility relates to how far and how easily a system could change what it is doing.

In a later work, Slack (1991) summarizes his objectives in five: quality, cost, responsiveness, dependability and, flexibility.

Buffa (1984) sees 4 manufacturing related dimensions which organizations use in order to compete: cost, quality of products and services, dependability of supply (delivery dependability) and flexibility/service which include the ability to accommodate variations in the product or service, availability of spare parts, field services, among others.

Hayes and Wheelwright (1984) identify 5 main competitive priorities: low cost/price, high performance (product features, tolerances and customer services), dependability (product, delivery and field service), flexibility (broad line, customized products, fast response and delivery time) and, innovativeness (new products, latest technology).

Hill (1985) introduces the concept of "order winning criteria" which are the objectives manufacturing should pursue in order to win orders in the market place. The main "order winning criteria" are, according to Hill, price, quality, delivery speed, delivery reliability, product and colour range and, design leadership.

A composite view of the literature results in the following main competitive priorities (with terminology adaptations):

Cost - manufacturing and distribution of the products at low costs;

Cost dependability - meeting required or intended costs;

Productivity - achievement of a better utilization of process technology, Labour and material resources;

Product quality - manufacturing of products with high performance and conformance to standards;

Range of products - manufacturing a broad range of products;

Innovativeness - introduction of new products or processes;

Delivery speed - reacting quickly to customer orders;

Delivery dependability - meeting delivery schedules or promises; and,

Flexibility - changing easily what is being done.

Figure 1.2 below summarizes the competitive priorities of selected authors:

year	Skinner 1978	Wild 1980	Buffa 1984	Hill 1985	Fine &Hax 1985	Hayes et.al. 1988	Slack 1991
Cost	x	x	x	x	x	x	
Cost dependability		x					
Productivity		x					x
Product quality	x	x	x	x	x	x	x
Range of products				x		x	
Innovativeness						x	
Delivery speed	x*	x		x	x	x	x
Delivery dependability	x*	x	x	x	x	x	x
Flexibility	x		x		x	x	x

Fig. 1.2. - Manufacturing competitive priorities according to some selected authors

* Skinner mentions only Delivery

A brief analysis of the Figure 1.2 shows that there are basically 4 competitive priorities which are explicitly present in all the authors' lists: cost efficiency, product quality, delivery speed and delivery dependability.

Flexibility is another competitive factor which is present in most of the authors' lists (5 out of 7). However, although not explicitly, flexibility is also present in Hill's (1985) list as an attribute of other priorities.

Although the authors mention sets of objectives which the organizations should pursue in order to achieve long term competitive advantage, the relative importance given to them vary, according to the particular market in which the organizations compete. However, there are some objectives which, at a certain point in time, gain special and generalized attention.

Since the mid seventies, special emphasis on the objective of Quality has taken place, mainly as a response to the increasing competitive power of some Japanese companies which managed to show the inappropriateness of the assumption that the concepts of quality and cost efficiency are incompatible: they were producing better products at lower costs. Since then, a vast literature has been put out diffusing techniques such as Statistical Process Control, Zero-defect Campaigns, Quality Control Circles, among others. The whole world was mobilized seeking quality improvements (Ferdows and Skinner, 1986).

From the late seventies on, other among the objectives joined Quality as a major concern of managers and academics: Flexibility.

De Meyer (1986), reporting research with large manufacturing companies in Europe, Japan and United States, suggests that while 1975-1985 could well be labelled as an era where manufacturers discovered that there was no trade-off to be made between quality of product and service and efficiency of the production system, 1985-1995 had the potential of becoming an era where manufacturers would discover that flexibility in all its aspects is not necessarily contradictory with the pursuit of cost efficiency. De Meyer argues that Japanese companies are leading this tendency and justifies such leadership by arguing that these companies' current performance in terms of quality gives them sufficient lead over American and European competitors to concentrate their efforts on the trade-offs between flexibility and cost.

Stalk and Hout (1990) suggest that "time" will be the next source of competitive advantage. According to this view, the companies which manage to reduce the time span of their processes will take the lead in the near future. Since flexible systems tend to respond quicker to the market needs, it seems that flexibility and "time-based competitiveness" are somehow linked as manufacturing objectives. This point will be further discussed in section 1.8. "Manufacturing Strategy and Flexibility".

1.6.2. Decision Areas

Hayes and Wheelwright (1984) and, Skinner (1978) characterize manufacturing strategy as a consistent pattern of many individual decisions that affect the ability of the firm to achieve long term sustained competitive advantage. Because the manufacturing function is complex, these authors and others have categorized the individual decisions in strategic *decision areas*[6] and provide a framework to analyze and shape a pattern for the decisions which should be consistent with the organization's objectives. The problem of lack of standard terminology makes it difficult to compare the various categories proposed by the authors. However, it is possible to envisage that there is some level of agreement amongst them with regard to the decision areas, as it can be seen in figure 1.3. below:

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[6] Decision areas represent sets of decisions which relate to a specific aspect of the manufacturing function

Wild (1980) - design and specification of the process and systems, location, layout, capacity and capability, design of work and jobs, scheduling of activities, quality, inventory, maintenance, replacement of facilities, and performance measurement.

Buffa (1984) - capacity/location, product/process technology, workforce and job design, operating decisions, supplier and vertical integration, and positioning of system.

Skinner (1985) - plant and equipment, production planning and control, organization and management, labour and staffing, and product design and engineering.

Hill (1985) - choice of alternative processes, trade-offs embodied in the process choice, role of inventories in the process configuration, function support, manufacturing systems, control and procedures, work structuring, and organizational structure.

Fine and Hax (1986) - capacity, facilities, vertical integration, process/technology, scope and new products policy, human resources, quality management, manufacture infrastructure, and vendors relations.

Hayes et. al. (1988) capacity, facilities, technology, vertical integration, work force, quality, production planning and control, new product development, performance measurement, and organization.

Slack (1989a) - design of the manufacturing system, management of product response, management of materials flow, long term capacity, management of demand response, and manufacturing control system.

Fig 1.3. - Decision areas in manufacturing strategy according to some selected authors.

A composite view of the manufacturing strategy decision areas in the relevant literature, provided the adjustment of terminology, converges to the following 10 main decision areas:

Capacity - amount, type, timing, responsiveness;

Facilities - layout, size, location, specialization, maintenance policies;

Technology - equipment, automation, linkages, capability, flexibility;

Vertical integration - direction, extent;

Work force - skill levels, wage policies, employment security;

Quality - defect prevention, monitoring, intervention, standards;

Material flow - sourcing policies, decision rules, role of inventories, responsiveness;

New products - focus, responsiveness, frequency;

Performance measurement - priorities, standards, methods; and,

Organization - centralization, leadership style, communication, decision making.

1.7. Manufacturing Strategy - Conclusions

Considerable progress has been made in the concept of manufacturing strategy since Skinner's early conceptual work. The most appropriate way to define manufacturing strategy currently seems to be a composite view of some of the researchers in the field:

Manufacturing strategy can be defined as a framework (Hill, 1985) with the central task of enhancing long term sustained (Fine and Hax, 1985; Roberts and Russell, 1990) competitiveness (Buffa, 1984) by organizing manufacturing resources (Slack, 1989) and shaping its functional decisions (Hayes and Wheelwright, 1984) so as to provide an appropriate mix of desired performance characteristics (Slack, 1989a).

It seems that a general agreement exists in the scarce literature about the process of developing manufacturing strategy, which is summarized by Figure 1.1. Leong et. al. (1990) notice that process research has been relatively neglected conceptually and almost totally neglected empirically by the literature. The proposed model seems to be reasonable, but empirical research work is still needed in order to validate the model. Another important question is whether the approach is appropriate for the current and future competitive environment. Many authors, for instance, agree upon a top-down approach for the manufacturing strategy formulation process. At the same time, they also agree that it is desirable that the manufacturing function has a proactive role rather than only reactive within the organization. This suggests that a bottom-up component should be incorporated to the dominant top-down approach. However, apart from some overlooked feed-back loops, this bottom-up component is not present explicitly in any of the frameworks found in the Literature. Most of the frameworks also suggest that the manufacturing strategy replanning process should be triggered by time, with a replanning period which generally varies from six months to one year. However it seems that with the increasing turbulence of the markets, the frameworks should also consider a formal means for the replanning process to be triggered by relevant events whenever they happen. One year or even 6 months appear to be too long a time for a company to wait to redirect its strategy in case some relevant aspect of the environment changes substantially. The competitors, subject to the same changes, can develop more responsive systems and therefore react to them quicker, what can be an increasingly important advantage in times of "time-based competitiveness" (Corrêa and Gianesi, 1992).

About the contents of manufacturing strategy, which are by far more explored in the literature than the process, there seem to be agreement, at a certain extent, among the authors, about the approach they adopt. Most of them divide the overall problem into two main content areas: the set of manufacturing strategic objectives, which are sometimes called competitive priorities (Leong et. al., 1990) or order winning criteria (Hill, 1985) and the decision areas. Leong et. al. notice that empirical work on the contents of manufacturing strategy have been produced substantially more than on process. However, such empirical work, according to the authors, would tend to be predominantly descriptive. They suggest that time has come to move on to testing bigger ideas and building new theory (such as the manufacturing focus concept, broadly discussed and reasonably accepted but still lacking empirical evidence).

The literature points out 5 main manufacturing objectives: Cost, Quality, Delivery Speed, Delivery Dependability and Flexibility. About them, some general trends can be observed throughout the years. In the 40s and 50s, cost efficiency appears to have been the key manufacturing competitive priority. From the mid-60s on, quality also started to be considered a top priority. From the 80s on, as a general view, there has been a trend that flexibility joins cost efficiency and quality in the top rank of the competitive priorities of manufacturing companies. Some authors argue that the 90's will bring time (delivery speed, quick product introductions and so on) into the scene as another top ranked criteria to many markets.

A more detailed analysis of manufacturing objectives, particularly flexibility, and their inter relationship can be found in the next section.

1.8. Manufacturing Strategy and Flexibility

In most of the quoted manufacturing strategy work, Flexibility seems to be regarded (at least implicitly) as having an important role in the organization's manufacturing strategy in at least in two ways:

Firstly, as a response to an increasingly turbulent environment, flexibility could be seen as one of the most valuable features a company can possess regardless the position which the company occupies in Hayes and Wheelwright's (1984) 4-stage classification (see footnote 4 in section 1.5. "The Manufacturing Strategy Process") in which the company is. If the company still has its manufacturing function playing a purely reactive role, good and quick reaction to changes in marketing needs, environmental and internal unexpected set-backs and so on is what matters. If, on the other hand, the company's manufacturing function has a more proactive role, fast response to environmental changing conditions will lead to shorter response times, which has been considered by a number of authors (Stalk and Hout, 1990; De Meyer, 1986) as one of the most important features for the next decade's competitive battle.

Secondly, flexibility is very pervasive and can influence the performance of other organization's competitive criteria. Slack (1989) argues that flexibility would be a second order competitive criterion in the sense that a company would not win orders based on its flexibility as such, but based on other criteria (such as delivery time, reliability, cost or quality). The virtue of flexibility would be to support the achievement of the other, first order, competitive criteria. Slack's point is only partially right for although flexibility can have an important role in supporting and influencing the achievement of the other competitive criteria, it can also be a first order competitive criterion. As an example to illustrate this point, suppose that a hypothetical car manufacturer is developing a new model. If the approach adopted is that of simultaneous development (Womack et. al., 1990), the company will have suppliers involved at the very early stages of the product development process, frequently even before the definitive specification of the parts are completely defined. If this is the case, changes in the preliminary specification tend to become a norm and it is likely that the hypothetical car manufacturer prefers to choose a supplier on the grounds of its ability to respond effectively to such specification changes or in other words, based on the supplier's flexibility. This is an illustrative example, although hypothetical, of the potential of flexibility as a first order competitive criteria.

A brief analysis of flexibility as a second order criterion or, in other words, how flexibility can influence the other organization's competitive criteria follows.

Generally, the performance criteria can be considered at both levels - at the manufacturing system level and the resource level[7]. The relation between the level of performance of the particular resources and the level of performance of the system as a whole, regarding the same criteria, is not direct. That is because the effect of the interaction between the resources has also to be considered. The performance of a system in terms of a particular criterion is the aggregated effect of a) the performance of its particular resources and b) the interaction between the resources, with regard to the particular criterion:

quality - there is the level of quality which a machine can provide such as the tolerances it can work within and the scrap levels it normally produces and, there is the level of product quality provided by the whole system which is a function of the quality built along the whole process, including design, material supply, transformation process, assembly, among others.

cost efficiency - there is the level of productivity a particular machine can provide and there is the level of productivity the whole system can provide which results in how costly are the products which the system manufactures. A system with very productive machines can have overall low productivity caused, for instance, by the operator's absenteeism, lack of skills or excessive levels of stocks.

manufacturing speed - there is the level of speed a particular machine can provide, with fast set ups and fast processing times and there is the speed which the whole system can achieve which is reflected by how short are their production cycle times. A system with very fast machines and operators can have long lead times if its production planning system is inadequate, for instance, working with large lot sizes, causing queues to build up and causing throughput times to lengthen.

dependability - there is the level of dependability of the particular resources, e.g. given by a very low mean time between fails of a machine or low absenteeism level of a worker, and, there is the level of dependability of the whole system, reflected, for instance, by the delivery lead time dependability. A system with very dependable resources can have problems with dependability if it can not promise the delivery dates accurately or if it can not manage priorities properly in the plant, in case something goes wrong - what is inevitable. On the other hand, a firm can achieve high levels of dependability if it develops system's robustness (what includes contingency plans for

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[7]The system's level is defined here as the level of the production units, or the set of manufacturing resources which interact having general common objectives, as opposed as the resource level which is defined here as the level of the specific individual resources, e.g. an individual machine or a worker.

unexpected set-backs, for instance) even though the individual resources are not extremely reliable.

flexibility - there is the level of flexibility of the particular resources, given by the variety of tasks which they can perform and ease with which they switch between tasks and, there is the level of the flexibility of the system as a whole, reflected by the effectiveness with which the system as a whole is able to change what is being done.

In order to change the levels of the various manufacturing system's performance criteria an organization can adopt two main approaches:

a) improve directly the level of the performance criteria of the main individual resources involved, for instance, by training people to "make right the first time" (aiming at quality improvements) or implementing a new machine which produces faster (aiming at improving delivery speed); and,

b) improve the level of some performance criteria indirectly. Increased flexibility, particularly, can influence the level of the system in terms of dependability, cost, speed and quality:

Dependability can be enhanced by flexibility because a flexible operation helps to cope with unexpected interruptions in supply and process (Mandelbaum, 1978; Stecke et. al., 1986). As examples, a wide range of in-house processing capability allows the operation to produce the part internally if the vendor's response is slow or interrupted. Labour flexibility, which allows the transfer of people between departments, can compensate for temporary shortages. Processes with broad capability can more easily accommodate products being re-routed away from a machine which is broken down.

Costs are improved by better utilization of process technology, labour, or material resources. Flexible operations contribute to that by helping overcome such problems as long process changeover times, excessive work in progress, fluctuating demand between product groups and so on. All of these reduce resource utilization and therefore increase cost. In addition, fast changeovers reduce batch sizes therefore reducing inventory and working capital (Slack, 1990a, Schomberger, 1986; Shingo, 1985, Womack et. al., 1990).

Speed, meaning fast delivery, fast development of new products, or fast customising of products can be improved by a flexible operation (Stalk and Hout, 1990). Flexible changeovers give small batches and fast throughput, and processes with a wide range of capabilities can accommodate new products without costly and time consuming new investments. (Slack, 1991).

Quality can be affected by flexibility. If a manufacturing system is flexible and responsive in design in the sense that the design function is performed quickly and accurately, it allows time for the process design team to choose and/or develop the appropriate manufacturing process ensuring higher probability of quality conformance since the developed process is more likely to be suitable for the product introduced (Womack et. al., 1990; Stalk and Hout, 1990).

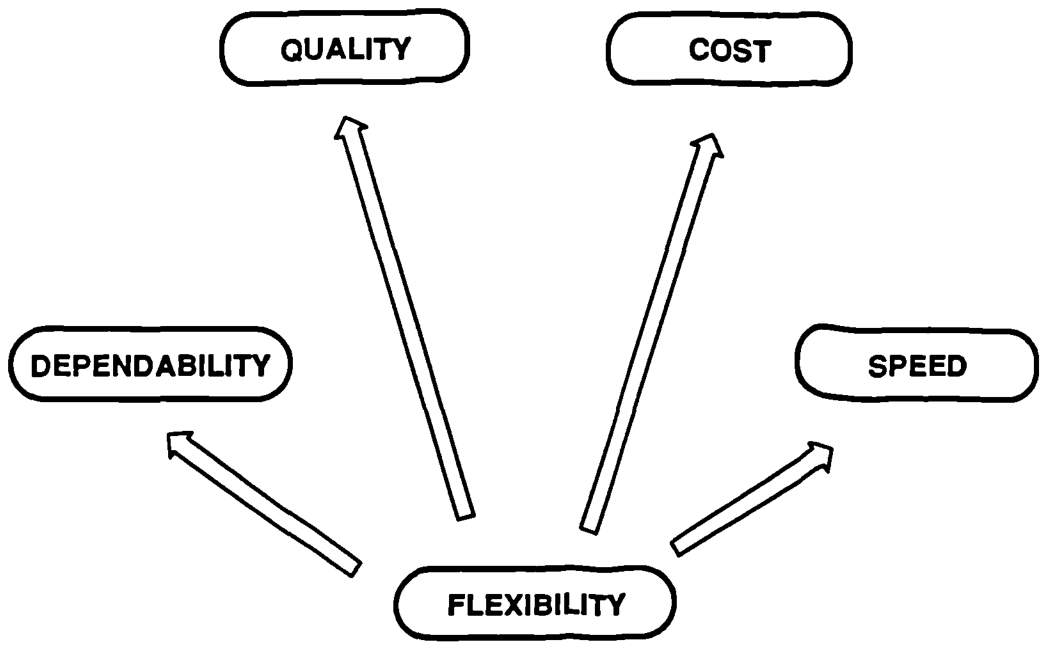

Fig. 1.4. Flexibility's influence on other objectives

Flexibility thus deserves special attention firstly because its strategic importance as a first and as a second order competitive criterion is growing and also because the amount of research on the strategic aspects of flexibility have not matched its growing importance. The remaining of this research is dedicated to flexibility. The main aspects announced in this chapter with regard to flexibility will be further exploited in the next chapters, particularly chapters 2 and 3. The underlying assumption behind the remaining of this work is that the main reason for an organization to seek manufacturing flexibility is to enhance its strategic competitiveness.

Chapter 2 - The Flexibility of Manufacturing Systems

The objective of the chapter 2 - "The Flexibility of Manufacturing Systems" is to discuss the most relevant views of the authors in the literature about flexibility at the manufacturing system's level. The manufacturing system is the level of the set of inter - related manufacturing resources which form the production units, as opposed as the level of the individual resource types which are dealt with in chapter 3.

Initially, chapter 2 deepens the discussion initiated in chapter 1 about the reasons why manufacturing flexibility has been increasingly regarded by academics and practitioners as an important competitive criterion for the present and future markets.

The recently published relevant material which discuss manufacturing system's flexibility is summarized and critically reviewed. The following aspects are specifically addressed:

The objectives of manufacturing system's flexibility - the reasons why organizations should or should not develop manufacturing system's flexibility, according to the literature.

The nature of manufacturing flexibility - several definitions and classifications of manufacturing system's flexibility types and dimensions found in the literature are critically compared.

The methods of assessment - some methods for assessing flexibility which are proposed by various authors are discussed.

The development of manufacturing flexibility - the ways, according to the literature which the organizations can use in order to develop manufacturing system's flexibility are briefly discussed. Further discussion on the issue can be found in chapter 3.

Chapter 2

The Flexibility of Manufacturing Systems

2.1 Introduction

Several management research areas e.g. Organizational Behaviour and Industrial Management have dealt with the concept of Flexibility in recent years. Each of them approaches Flexibility in a different way, depending on their scope. Each of them also uses different analytical tools, consistent with each approach. The Organizational Behaviour researchers are mainly concerned with the flexibility of the human resources within the organization and in this sense they use tools such as Behavioural Theory, Psychology and Sociology of Work, as can be found, for instance in the work of the IMS - Institute of Manpower Studies of Sussex University. In Industrial Management one can also find a vast literature about flexibility, mainly of the equipment involved in the production process, generally under the label "FMS" - Flexible Manufacturing Systems, with a quite technical approach which focuses on issues like task sequencing or dispatching disciplines.

Although possibly useful for the solution of short-term area-specific problems, the kind of localized approach exemplified above seems to be inadequate for a more strategic and comprehensive understanding of manufacturing flexibility such as the one needed by the managers of the manufacturing processes. The approach adopted in this chapter is comprehensive rather than partial, contemplating the set of inter-related manufacturing resource types, rather than predominantly one or some.

2.2 The Importance of Flexibility

From the early 80s on, a new emphasis has been given to the importance of Flexibility for the competitiveness of manufacturing systems. This new concern is based on some factors, identified by several authors and summarized below (Slack, 1987)[1]:

[1]See Chapter 1 for a detailed discussion on manufacturing objectives.

a). The environment in which the manufacturing companies have had to act has been extremely turbulent - Competitors have been more and more competent, the market has demanded an increasing variety of products with shorter life-cycles, and the suppliers not always accomplish desirable levels of product quality and service level as well as prices, because they are struggling with their own difficulties in the same turbulent market. These conditions lead to a situation of limited stability and predictability and therefore demand an increasing capability to respond well to changing circumstances or, in other words, to develop flexibility.

b). The development of new process technologies - The development of new process technologies has been of such proportion that the rate of technology development may have outstripped the ability to use it to its full advantage or even understand its potential (Voss, 1989). The result of this lack of balance would be the underutilisation of the new technologies (Jaikumar, 1986), which potentially "offer" technology flexibility to any organization who can manage to transform "potential" into actual flexibility. Great effort has been put by manufacturing organizations in trying to work out how to do it effectively.

Beside these two main factors, Slack (1989) identifies a third one which is the fact that the managers have been constantly told that flexibility is important. Publications, equipment suppliers, etc., with varied interests, would be, in part, responsible for the shift towards a greater concern about flexibility.

Maybe influenced by the development of the new process technologies - flexible automation, numerically controlled machines (either stand alone or integrated), automated material handling systems, pattern recognition systems and the FMS - "Flexible Manufacturing Systems", the concept of flexibility is frequently associated with technological resources, when discussed in the literature. However, although recognizing the importance which technology may have in the effort to achieve more flexible manufacturing systems, it is important to bear in mind a broader perspective. Manufacturing systems consist of a *set of resources*, which apart from technology, include people and infrastructural systems (organizational systems, supply systems, among others).

The emphasis on technology flexibility is reflected by the work of some authors (e.g. Gupta and Goyal, 1989) according to whom, the introduction of flexibility into a manufacturing system requires high initial capital investment in flexible technology. A number of authors (Schomberger, 1986; Shingo, 1985; Blackburn and Millen, 1986) disagree with that. They argue that a system can achieve flexibility by using simpler and cheaper machines as long as they are properly utilized, e.g. if their set-up times are sufficiently reduced.

Some authors have called attention to the risks involved in the myopic reduction of the broad concept of flexibility to the concept of flexible automation. Jaikumar (1986) reports the results of research realized with American companies which adopted FMS and concludes that most of them are actually inflexible because of lack of appropriate supportive managerial systems. On the one hand, it would not be enough, according to this view, to have flexible automation to ensure the achievement of manufacturing system flexibility. On the other hand, Flexibility is not a characteristic which is exclusive of the automated FMS. Some authors, like Poe (1987), argue that when real flexibility is needed, the tasks have to be assumed by people. As an example, he mentions the final assembly line in the automobile manufacturers where only 10% of the tasks would be possible/viable to be automated.

Bringing these two ideas together, it may be important to be aware, when analyzing production systems, that although flexible automation may have an important role to play, it is not enough and in many cases, not even necessary for the achievement of system's flexibility. It is necessary that the whole set of structural (technological and human) and infrastructural (systems) resources (see chapter 3 for a discussion on the manufacturing resources' flexibility) are considered on a systematic rather than on a partial basis in order to develop a more comprehensive understanding of the flexibility of manufacturing systems.

Numerous papers about flexibility of manufacturing systems have been published during the last 10 years. The ideas contained within the relevant literature can be broadly divided in 4 principal groups, based on the main focus they consider:

Focus on the objectives of Flexibility - papers largely concerned with why the production process should be flexible

Focus on the nature of Flexibility - papers which try to define and classify flexibility in categories and identify flexibility dimensions in an attempt to enlighten a concept so far only partially explored.

Focus on the assessment of Flexibility - papers which propose methods to measure flexibility.

Focus on the development of Flexibility - papers which prescribe ways for the organizations to develop flexibility.

The 4 groups are discussed in turn below.

2.3. *The Objectives of Manufacturing Flexibility*

The authors identify a number of reasons for the organizations to seek more flexible production systems. These factors can be separated in three principal groups.

a) *factors related to the output side of the manufacturing system* (consumers and competitors)

b). *factors related to the input side of the manufacturing system* (suppliers)

c). *factors related to the production process*

2.3.1. Objectives Related to the Manufacturing System's Outputs

These are the most mentioned factors in the literature. The markets would be becoming increasingly fragmented, demanding more variety of products with shorter life cycles. This would be happening in parallel with an increasing need for more efficiency of the processes and overall effectiveness of the manufacturing systems. The managers would be facing the most turbulent market environment in many decades (Slack, 1987). The lack of predictability of the demand would be motivating companies to develop the ability to cope with this turbulence and to respond to it effectively (or, in other words, to improve their flexibility) as one of their main objectives.

The utilization of flexible resources is generally more costly than the utilization of dedicated ones (Slack, 1988). However, in a market which tends to demand diversification rather than mass production, a concept gains importance: that of the "economies of scope"[2] (Goldhar and Jelinek, 1983).

The scarce resources which the organizations have available to develop flexibility make the resource allocation a problem of main importance. More than ever, it is important that the managers understand the concepts involved in such decision process in order to be able to identify the most effective ways to invest in flexibility development.

[2] Economies of scope are said to occur when one production unit can produce a given level of outputs of a variety of products at an unitary cost which is lower than that obtained by a set of separated production units, producing, each one, one product at the same level of output. Another aim of developing flexibility of manufacturing systems is to make it possible that economies of scope happen resulting in a cost effective ability to deal with the variety of outputs which the new market reality demands.

2.3.2. Objectives Related to the Manufacturing System's Inputs

Swamidass (1985) claims that "the competitive value of manufacturing flexibility is its ability to neutralize the effects of demand uncertainties". This claim does not seem to be confirmed by research work realized with a number of American, European and Japanese manufacturers (De Meyer, 1986): one of the findings of the researchers is that the American and European companies would not be adopting FMS - Flexible Manufacturing Systems in order to be able to change their product designs quickly as it is broadly believed, but in order to accommodate the variability of their inputs. This tendency seems to be less evident with Japanese companies because the relationship they have developed with their suppliers would allow them to establish long term contracts and effective technological cooperation.

In environments where the supply market is less developed, the possible lack of reliability of the suppliers with regard to delivery time and, raw material and component quality would be motivating the development of more flexible production systems, which can cope with such imperfections.

In a similar way, in some markets, the supply of Labour at the required levels of skills and quantities is uncertain. Companies seem to be trying to develop more flexible manpower structures (Atkinson, 1984) in order to be able to cope more efficiently with this kind of uncertainty through quick and easy redeployment and adjustments of manpower levels. (For further details see chapter 3)

Another factor related to the supply of inputs is the development and availability of more flexible process technologies at lower costs. The development of these technologies would be pushing the market to utilize them, either because these technologies represent the effective solution for an unresolved problem or because the non adoption of these technologies might result in loss of future competitive power. The cost of "not acting" has been pointed out as an important consideration when a company analyzes the adoption of new process technologies (Blackburn and Millen, 1986). Traditional analysis techniques such as discounted cash flow, return over investment and others have been considered insufficient to perform these analysis largely because they are unable to consider such strategic costs.

2.3.3. Objectives Related to the Production Process

Flexibility would also be developed as an "insurance" (Carter, 1986) against process uncertainty mainly in the short term (Stecke and Raman, 1986). Equipment breakdowns and Labour absenteeism are examples of uncertainties regarding the structural resources of the manufacturing process.

2.4. The Nature of Manufacturing Flexibility

Throughout the literature, the authors seem to agree that Flexibility is a concept which is not fully understood as yet. Several definitions are found, as well as several classifications of dimensions and types of flexibility.

2.4.1. Concept and Definitions

One of the most mentioned definitions of Flexibility is Mandelbaum's (1978): "...the ability to respond effectively to changing circumstances". Despite of being too vague and of limited practical use, this definition can be used in an attempt to understand the difficulties involved in treating the concept of Flexibility by doing a brief analysis of its semantic elements.

The first element of Mandelbaum's definition is "the ability of..." what gives flexibility a character of a "potential". This makes the task of measuring the flexibility of a given system both difficult and controversial. Analyses of the system's historical data are of limited use and do not give anything but an idea about its ability to respond to changing circumstances. The system's past performance may be close to the limit of its ability but it may also not be. The system could possibly be able to cope with more and/or more dramatic changes than it has done in the past. These aspects make measuring flexibility objectively a very difficult and controversial task (see section 2.5. "The Measures for Manufacturing Flexibility" for further details on the discussion on flexibility assessment).

The second element is "...to respond...". Response generally means reaction or adaptation to some sort of change, given that the change has already occurred.

The third element of Mandelbaum's definition is "... effectively..." , what suggests a link between the concept of flexibility and the concept of overall system's performance. In other words, keeping (despite the change) or improving (responding to the stimuli of the change) its overall performance.

The last element in Mandelbaum's definition is "...changing circumstances...". Behind this element there are two concepts: uncertainty and variability. On the one hand, if the circumstances are changing but the steps of the change are perfectly known (therefore without uncertainty) although one could have more time to plan the means to cope with the change, the more broadly the circumstances change the more flexibility is demanded from the system in order to cope with them. On the other hand, if the circumstances are recognized as changeable or changing but one does not have perfect information about the result or the steps of the change (or in other words, if there is uncertainty with regard to the change), then it is necessary that the organization has the ability to identify what is the extension of the possible future uncertain changes, with what part of this range and how effectively the organization intends to be able to cope with.

The possible uncertainty behind the "changing circumstances" adds difficulties to the treatment of flexibility. When one discusses uncertainty regarding the market or Labour behaviour, for instance, the statistical and mathematical analytical tools, frequently used to model and analyze some types of uncertainty become of very limited use. Other methods, some of them borrowed from the Social Sciences may have to be used.

There are a few other definitions of flexibility in the literature which are conceptually different from Mandelbaum's. Ferdows and Skinner (1986) propose a different approach: according to Ferdows and Skinner' view, flexibility should be seen as a relative variable. A flexible system would be more able to react quickly and at lower costs than the competitors to the market changes. This view does not seem to be appropriate because it means to mix a variable itself and its value. It may be useful to understand and analyze a system's flexibility independently of its relative position when compared to their competitors. Although it may be very important competitively, a company does not compete only based on its flexibility but on a set of criteria which would include cost, quality, and delivery performance among others. A company may, for instance, choose to be less flexible than the competitors, provided that its level of flexibility reaches the minimum (qualifying) level required by the market, preferring to compete in other terms such as design leadership. In this sense, it would be more appropriate to consider flexibility as an absolute concept as opposed as relative. Slack (1990) also seems to believe that flexibility is not a relative concept since he argues that "the flexibility of the operation as a whole is determined exclusively by the flexibility of its constituent resources and systems."

2.4.2. Dimensions and Types

Some authors argue that Flexibility is a multi dimensional variable. Slack (1983) defines two basic dimensions: range and response. Range flexibility would be the "ability of the system to adopt different states". A production system would be more flexible than another on a particular aspect if it can handle a wider range of states, for instance to manufacture a greater variety of products or to produce at different aggregate levels of output.

However, adds Slack, the range of states a manufacturing system can adopt does not totally describe its flexibility. The ease with which it moves from one state to the other in terms of costs, time and organizational disruption is also important. A production system which moves quickly, smoothly and cheaply from one state to another should be considered more flexible than another system which can only cope with the same change at greater cost or/and organizational disruption. The way the system moves from one state to another would define the other Slack's flexibility dimension, "response flexibility".

Although range and response are clearly two different dimensions of flexibility, it is important to notice that they are not independent. Systems tend to be more responsive to small changes and less responsive to big changes (Slack, 1989).

Time is another dimension which is mentioned by some authors as an important consideration in order to understand flexibility. Carter (1986) believes that different kinds of flexibility impact the production system in different time frames: very short term, short term, medium term and long term and as a consequence, different kinds of flexibility should be sought in order to achieve the different time frame objectives.

Stecke and Raman (1986) also consider time in their analysis regarding the relationship between Flexibility and Productivity and propose that, in the short term, production flexibility enables the system to maintain its production in face of unforeseen events, such as machine breakdowns.

With regard to the long term, Stecke and Raman propose that production flexibility would be related to the inter-dependence between the process and product life cycles. Flexible systems in the long term would tend to cause a relaxation in the one-to-one relationship which the conventional production systems would represent. For details of this relationship, see Hayes and Wheelwright (1984), chapter 4.

Another dimension identified by Gerwin (1986) as a basic issue in defining manufacturing flexibility is the level at which it is to be considered: the individual machine or manufacturing system; the manufacturing function such as forming, cutting or assembling; the manufacturing process for a single product or group of related ones; the factory or the company's entire factory system. At each level, says Gerwin, the domain of the flexibility concept may be different and alternative means of achieving flexibility will be available.

A company which intends to be flexible in the introduction of new products in the market place (at the highest level, that of the company's entire factory system) should take different actions than a company which intends to make a machine more flexible by developing jigs and fixtures in order to make the time spent with set-ups shorter (lowest level, of the individual machine). In the former for instance it is essential that the flexibility of the product design team is developed. In the latter the flexibility of this team is possibly less relevant.

Gupta and Buzacott (1986) define three dimensions of manufacturing flexibility: sensitivity, stability and effort. With respect to each change, sensitivity relates to the magnitude of the change tolerated before there is a corrective response.

Stability relates to the size of each disturbance or change for which the system can meet expected performance targets. Whereas sensitivity and stability determine whether a system responds to a change or not, effort relates to how well a system responds to a change. Effort depends on such factors as the time to respond to a change, cost of response, among others.

Dooner and De Silva (1990) propose dimensions which are similar to Slack's. According to these authors, flexibility would have three dimensions: range, switchability, and modifiability. Range, similarly to Slack's range, relates to a set of states a machine or a set of machines can adopt to do useful work. Within a given set, transitions can be made between states. The general ease in which this takes place is called switchability. Modifiability would relate to taking up a new set of states, which may or may not include those individual states belonging to the set of states prior to the modification.

Mandelbaum (1978) defines two basic dimensions of manufacturing flexibility: action flexibility and state flexibility. Action flexibility would be the "capacity for taking new action to meet new circumstances" that is, leaving options open so that it is possible to respond to change by taking appropriate action. State flexibility would be the capacity to continue functioning effectively despite the change, i.e. the system robustness or tolerance to change.

Figure 2.1. below summarizes the different dimensions of manufacturing flexibility according to selected authors

Mandelbaum	Slack	Gupta/ Buzacott	Stecke/ Raman	Carter	Gerwin	Dooner et. al.
1978	1983	1986	1986	1986	1986	1989
action	range	sensitivity	time	time	organizational level	range
state	response	stability				switchability
		effort				modifiability

Fig. 2.1. - Dimensions of manufacturing flexibility according to some selected authors.

The different flexibility dimensions found in the literature have some similarities and differences. Gupta and Buzacott's "effort" seems to be quite similar to Slack's "response". Slack's concept of "response" is divided by Dooner and De Silva into "switchability" and, "modifiability" which refers to changes in the resources capabilities.

Slack's and Dooner and De Silva's "range" are also similar. Slack's "range" is similar to Gupta and Buzacott's "stability" but their "sensitivity", as a flexibility dimension, is somewhat arguable. Considering "sensitivity" as a dimension of flexibility is arguable, mainly if we consider flexibility as the ability to respond to change. *Sensing* the changes depends on the ability of the system to *monitor* the changes rather than on the ability to respond to the changes (which is proper flexibility).

Stecke and Raman's and Carter's "time" dimension and Slack's, Dooner and De Silva's and, Gupta and Buzacott's dimensions do not seem to be independent. Short term considerations seem to be associated to "response", "effort" and "switchability" whereas long term considerations seem to be more associated to "range", "sensitivity" and "stability" and, "modifiability" because they are more related to structural changes such as the resources and their capabilities.

Gerwin's "organizational level" considerations seem to be very important in order to define the boundaries of the system which is being analyzed. One of the difficulties one finds in analyzing the literature on flexibility is exactly the fact that not always the authors define the scope or the organizational level which they are considering.

With regard to the flexibility types, the classifications found in the literature vary according to the approach which each particular author adopts. All of them seem to agree that classifying flexibility in different types is important. This suggests that different kinds of flexibility would be obtained by different means (possibly developing the different resources in different ways) or would be appropriate to deal with different conditions or types of change.

Buzacott (1982) defines two types of manufacturing system's flexibility, based on the change the system has to cope with: "job" and "machine" flexibility. *Job flexibility* would be the ability of the system to cope with changes in the jobs to be processed by the system. *Machine flexibility* would be the ability of the system to cope with changes and disturbances at the machines and the work stations.

Zelenovic (1982) proposes two types of flexibility: "design adequacy" and "adaptation" flexibility. *Design adequacy* is the probability that the given structure (machines, handling equipment, measuring equipment, storage and control devices and plant layout) of a production system will adapt itself to the changing environmental conditions and to the process requirements within the limits of the given design parameters (of the given structure). *Adaptation* flexibility is the ability of the system to transform/adapt from one to another job task at minimum value of time. Zelenovic's "adaptation" seems to be similar to Slack's "response" dimension.

Slack (1988) suggests 4 types of manufacturing flexibilities which would be achieved through the development of flexible resources. Each of them is defined below:

> *Product flexibility* - the ability to develop or modify products and process to the point where regular production can start. If range is considered, this is similar to Zelenovic's design adequacy.
>
> *Mix flexibility* - the ability to produce a, or change the mix of products within a given time period.
>
> *Volume flexibility* - the ability to change the absolute level of aggregate output which the company can achieve for a given product mix.
>
> *Delivery flexibility* - the ability to change delivery dates effectively.

Dooner and De Silva (1990) consider 4 types of manufacturing flexibility:

Machine flexibility - the ability of a machine to accommodate different tasks.

Mix flexibility - the ability of a system to accommodate different types of part design which are able to be manufactured simultaneously.

Part flexibility - the ability of a system to accommodate new or modified part designs.

Volume flexibility - the ability of a system to accommodate variations in the production rate.

Gerwin (1986) defines several types of flexibility of production systems as part of his attempt to establish guidelines to the relationship between different types of uncertainty to which the organization is subject and the types of flexibility which the company should use in order to cope with them. Gerwin's flexibility types are:

Mix - the ability of a manufacturing process to produce a number of different products at a certain point in time.

Changeover - the ability of a process to deal with additions to and subtractions from the mix over time.

Modification - the ability of a process to make functional changes in the product.

Re-routing - the degree to which the operating sequence through which the parts flow can be changed.

Volume - the ease with which changes in the aggregate amount of production of a manufacturing process can be achieved.

Material - the ability to handle uncontrollable variations in the composition and dimensions of the parts being processed.

Sequencing - the ability to rearrange the order in which different kinds of parts are fed into the manufacturing process.

Although similar to Gerwin's in many aspects, another way to classify the flexibility of production systems in types was proposed by Browne et. al. (1984). Stecke and Raman (1986) use this classification in order to analyze the relationship between the flexibility of production systems and its productivity. This classification is as follows:

Machine - the ease with which the operations of a given set of part types can be performed at a given machine.

Process - the ability of the manufacturing system as a whole to manufacture a given set of part types in several ways.

Routing - the ability of a system to maintain its efficiency in the face of breakdowns.

Operations - the ease with which the sequence of operations for each of the given part types can be inter changed.

Volume - the system's capability to be operated profitably at different volumes of the existing part types.

Product - the ability of the given manufacturing system to changeover efficiently from a particular set of part types to a different set.

Expansion - the manufacturing system's capability to be built and expanded modularly.

Production - the cumulative result of the seven previous flexibilities.

Most of these classifications do not seem to consider all the resources involved in the production process with the same emphasis or importance. The resource Technology seems to deserve a much greater attention in their analysis than the resources Systems and Labour.

There is no standardization in the terminology about flexibility matters in the literature. Mix flexibility, for instance, means different things to Slack (1989) and Gerwin (1986). That makes it difficult to make comparisons between the authors' classifications. Another factor which was highlighted by Gerwin (1986) and is in general not explicitly stated by the authors who propose the different classifications is the organizational level they are considering. Some classifications in the Literature mix flexibility types of two or more levels. Browne et. al.'s (1984), for instance, includes "machine flexibility" (individual resource level), "process flexibility" (manufacturing system level) and "expansion flexibility" (company level).

There are some similarities between the authors' flexibility types. Figure 2.2. shows 5 authors' flexibility types. Types which bear some similarity are shown in the same row. Zelenovic's (1982) "design adequacy" and "adaptation" seem to be flexibility dimensions rather than types, therefore they are not shown in Figure 2.2.

Figure 2.2. shows the lack of consistency between the selected authors in terms of terminology and approach. Slack's seems to be the classification which is more directly associated with the manufacturing system's strategic objectives, since the four types which he suggests are consistently at the manufacturing system's level and refer directly to the system's demand. Its only flaw, possibly, is to focus exclusively on the system's demand, neglecting the flexibility component which can be used to overcome process and input's set-backs, mentioned by a number of authors (e.g. Stecke, 1986 and Carter, 1986) and therefore having possible strategic implications.

Buzacott (1982)	Browne et. al. (1984)	Gerwin (1986)	Slack (1988)	Dooner/ De Silva (1990)
	product	mix changeover	mix	mix
		modification	product	part
	volume	volume	volume	volume
		sequencing	delivery	
machine	routing	re-routing		
	machine			machine
		material		
	process			
	operations			
	expansion			
	production			
job				

Fig 2.2. - Types of manufacturing flexibility according to some selected authors.

2.5. The Measures for Manufacturing Flexibility

One of the difficulties found by the authors who study the flexibility of manufacturing systems is on measuring it. Two main streams can be identified among the papers. There are the ones which seek to define objective measures and the ones which prefer to assess the flexibility based on the perception of the people involved in the process.

Some authors (Slack, 1988; Swamidass, 1987, among others) seem to prefer perceptive measures while others (Stecke, 1986; Zelenovic, 1982; Gerwin, 1986) seem to prefer the objective methods. All of them agree however that it is important to have a procedure in order to assess the flexibility of a system or, at least, the flexibility needs of a system and that this assessment should be done periodically in order to face an increasingly dynamic environment.

2.5.1. Objective Measures

One of the main difficulties in the development of objective measures of flexibility is its characteristic of a potential (Tidd, 1991): flexibility would be an ability, a "potential" to realize things rather than something measurable with hindsight, such as performance, for example.

Gerwin (1986), for instance, suggests that, in order to measure "modification flexibility" one should reckon the number of design changes done during a period in one component. This does not seem to be appropriate because the number of design changes which have been made may mean that the market demanded only such number, rather than that the number of the design changes was limited by the ability of the system to realize them. Thus one could say that the ability of the system to realize design changes is at least equal to the number of changes realized in any one period but no one can assure that the system could not have realized more design changes than the number reckoned at the end of the period.

Another operational problem with regard to objective measures of flexibility is that when one talks, for instance, about "number of design changes made" one is levelling the treatment of changes which might be completely different from each other in terms of magnitude or complexity.

Two different hypothetical production systems could realize, during the same period of time, the same number of changes (which could even be similar in magnitude and complexity). However, if one of them performs the changes more easily (with less cost, time or disruption) than the other, it seems to be reasonable to consider it more flexible than the other (Slack, 1987). Based on Gerwin's measure both systems would show the same flexibility level. Schmigalla, reported in Zelenovic (1982), proposes an index to measure flexibility which has the same operational problems as Gerwin's and is restricted to machine flexibility. The index uses for example a variable "K_{ei}" which represents "the effective capacity of machine 'i'". However, it would be difficult to decide what effective capacity to use in the index, for flexible machines are able to manufacture several different products and, in many cases, the capacity of a machine varies according to the product it is currently performing.

Kumar (1987) proposes a method to assess flexibility using the concept of entropy. The method is based on the alternative choices which a system has available and on the "reliability" of each choice. Reliability in the case is a measure of the relative preference which the different choices would deserve. The bigger the number of possible choices and the more similar the preferences between them are, the higher the flexibility indicator will show. Again, the problem with this kind of indicator is that it requires that the preferences of the possible choices are quantifiable.

Kumar's method is interesting and possibly useful in order to compare the flexibility of sets of machines, for example. However, with regard to assessing manufacturing systems' flexibility as a whole, where there is a concurrence of several different types of resources, it is difficult to rank preferences or even to identify and quantify possible choices. Beside, the measures based on entropy are not able to capture the responsiveness of the systems: two systems can have the same number of options available with the same set of relative preferences. They would be given the same flexibility indicator value. Yet, one system could, with the same set of choices, be more responsive than the other, being therefore more flexible.

The authors who try to find objective methods to measure flexibility contribute to enlighten a not sufficiently explored subject. However, when one seeks to develop models in order to support the decision making regarding production systems, oversimplified indexes and measures can be dangerously not adherent to the modelled reality. The most serious problem about these oversimplified measures is that, once the index is defined by one author, people who will apply it, sometimes do not seem to pay enough attention to the hypothesis assumed when the index was developed. Sometimes, in production management environments, a decision seems to gain an overrated "legitimacy" when it is, and just because it is, based on a mathematical, quantifiable expression. Its use sometimes becomes indiscriminate and in this case, the resulting decisions may be wrong.

2.5.2. Perceptual Measures

For the reasons discussed in the previous section, in terms of measuring complex variables such as the flexibility at the manufacturing system's level, the methods which use the perception of experienced people involved in the process, when well conducted, can have advantages over the quantified, hard data-based ones.

Slack (1988), based on Fine and Hax (1985), proposes a method to assess the flexibility of production processes which is based on the perception of the managers involved. The method uses scales which consider the relative position of the assessed system among competitors. For each type of flexibility - product, mix, volume and delivery, and for each of the dimensions - range and response, the production system is classified in:

+++	Very much better than the nearest rival in industry
++	As good a capability as the best in the market
+	Better than average capability
E	Industry average
-	Marginally below average capability
--	Not many rivals with worse capability
---	The lowest capability in industry

The manager's scaling is then compared with another scaling where the managers point out the capability levels considered important to the competitiveness in the market. The gaps between the actual capabilities and the important capabilities guide the decision making of the managers. The answerers should be experienced people capable to develop a global rather than partial view of the organization.

Complementary techniques can be used in order to get to a consensus assessment rather than to an "average" one. The answers should, as much as possible, be based on data (objective as well as subjective) which then should be provided. Slack (1988) suggests the use of accessory tools such as the range/response curve, in order to help the assessment of product flexibility, for example. This way, no information would be overlooked and on the other hand, the analysis would not be restricted to the numerical data available.

2.6. The Development of Manufacturing Flexibility

One of the most discussed aspects of the Literature about flexibility is exactly how to develop it. The development of manufacturing system's flexibility is achieved through the development of some specific characteristics of the manufacturing resources - people, technology and systems. The authors seem to agree that developing flexibility is in general desirable. Adler (1987) though warns: flexibility is a characteristic which people have tried to develop in production processes in order to make them able to cope with unstable and/or unpredictable situations. However, if the next decade brings, what seems plausible, new and more stable configurations of supply and demand, some flexibility efforts may prove to have been myopic over-reactions. In other words, if the reasons to be flexible are eliminated, why to be flexible?

Although Adler's point is worth considering, to a certain extent, the present preoccupation of managers and academic researchers about flexibility can be justified: one the one hand, different countries and even different production systems are in different stages of development, in terms of the relations between the organizations and the market. While, for instance in Japan the efforts to reduce the uncertainty of the relationship supplier-customer (e.g. through long term contracts and cooperation) seem to be on an advanced stage, the same does not seem to occur with regard to most of the western countries and, particularly with the developing countries. In such matters, although the tendency seems to be that companies are trying to reduce their uncertainties, a cooperative, stable and predictable environment cannot be achieved overnight. In the meantime, the companies must develop ways to cope with their uncertainties and developing flexibility is one of such ways (Swamidass, 1987).

On the other hand, Adler's caveat seems to be more suitable for the uncertainties and instabilities related to the supply market. About the consumer market, most authors agree, there is a tendency that, in the future, it will demand an increasing variability of products with shorter life cycles *(Slack, 1990a; Gupta and Goyal, 1989; Gerwin, 1986).* This, together with an increasingly competitive environment would for itself justify the present efforts for the development of flexibility. Further and detailed discussion on the development of the flexibility of the manufacturing resources can be found in chapter 3 - "The Flexibility of Manufacturing Resources".

2.7. Summary and Conclusions

The authors in the literature seem to agree that flexibility is not a fully understood concept as yet, surely deserving further research. The amount of recent articles discussing the concept of flexibility and its classification in types and dimensions attest this fact. However, flexibility has been considered by most of the authors in the literature as one of the most important characteristics of the manufacturing organizations in today's and tomorrow's market. The literature identifies 2 mains reasons for this newly found importance: firstly, the environment in which the manufacturing companies have had to act has been extremely turbulent demanding an increasing ability of the systems to respond to changing circumstances. Secondly, the development of new process technologies has increased the availability of machinery which embodies features such as flexible automation.

However, it is important to be aware that although flexible automation may have an important role to play, it is not enough and in many cases not even necessary for the manufacturing systems to achieve flexibility.

The literature can be divided under 4 main headings, according to the main focus they consider with regard to manufacturing flexibility: focus on the objectives, on the nature, on the assessment and on the development of flexibility.

In terms of objectives, the authors consider that flexibility is developed mainly in order to cope effectively with uncertain and variable changes, be them environmental or internal, be them either related to the inputs, to the outputs or to the manufacturing process. However, the literature lacks proper contingency models which relate what types of flexibility should be used in order to cope with what types of uncertainty, and variability.

With regard to the nature of manufacturing flexibility, several authors propose ways of classifying flexibility in types and dimensions. There is still lack of commonly accepted terminology in the literature regarding the different types and dimensions of flexibility. One of the basic issues in terms of flexibility dimensions seems to be the level of analysis at which flexibility is to be considered.

In terms of measures for manufacturing flexibility, two main approaches can be identified in the literature. The first approach seeks to find objective, numerical measures whereas the second prefers to assess flexibility based on the perception of the people involved in the process. In terms of assessing the flexibility of the manufacturing system as a whole, the perceptual measures seem to be more appropriate because of the risks of oversimplification which the hard data-based, quantified measures run.

The development of manufacturing system's flexibility is done based on the development of the three basic types of resources considering their inter-relationships - Human, Technological and Infrastructural. The flexibility of each of the three types of resource is discussed in details in chapter 3.

Chapter 3 - The Flexibility of the Manufacturing Resources

Chapter 3 - "The Flexibility of the Manufacturing Resources" discusses flexibility at the level of the particular resource types: structural (technological and human) and infrastructural (infrastructural systems).

In terms of technological resources, two basic approaches are addressed: flexible automation and methodology-based flexibility.

With regard to the flexibility of human resources, the views of the literature about methods to manage, analyze and improve Labour flexibility are reviewed and criticized.

Finally, in terms of the infrastructural resources, two important infrastructural systems are discussed, with regard to flexibility: *the supply network system* - internal and external to the organization, which encompasses the relationship with external suppliers and the production planning and control systems and, *the work structuring system*, which is related to the way in which the work is organized, e.g. style of leadership, direction and, responsibility and authority delegation.

Chapter 3

The Flexibility of Manufacturing Resources

3.1. Introduction

The classification of the manufacturing resources in "structural" and "infrastructural" is proposed by a number of authors in the literature (Hayes and Wheelwright, 1984; Hill, 1985; Slack,1989; among others). However, not all the authors agree on which resources should be considered as structural and which should be considered as infrastructural.

Hill (1985) defines infrastructural resources as the set of structures, controls, procedures, systems and communications combined with attitudes, experience and skills of the people involved with the manufacturing system and structural resources as the technology, equipments and facilities of the manufacturing system. Hill (1985) thus includes characteristics of human resources as part of the infrastructural resources. He considers organizational issues (the role of specialists, the number of layers, team-work approach, the structure of work, among others) and control issues (control of quality, inventory and manufacturing) as the main issues about infrastructural resources.

Hayes and Wheelwright (1984) also consider work force as one of their four infrastructural decision areas - Work force, Quality, Production Planning and Materials Control, and Organization. They consider these decisions more tactical and easy to reverse than the ones which they consider as structural (Capacity, Facilities, Technology and Vertical Integration). This view is arguable, since the work force, for instance has increasingly been regarded by many authors as the most important asset of the organizations and reversing decisions concerning people's attitudes, commitment to the company's objectives and motivation, have generally proved to take long time and a considerable amount of organizational effort. Even considering the criteria of reversibility, therefore, the work force seems to be more adequately classified as a structural resource.

According to Slack (1989), infrastructural resources include only the systems, relationships and information couplings which bind the operation together, supporting the functioning of the structural resources - Labour and Technology. He considers the systems which supply resources to the production system (the supply systems) and the systems which control the production operation (the control systems) as being of particular relevance to flexibility issues.

In this research, the following classification (based on Slack, 1989) of manufacturing resource types will be adopted: the manufacturing system is a configuration of interacting individual resources which can be classified in: Structural resources (Technological and Human resources) and Infrastructural resources. Each of them is defined below:

-*Technological resources* - the facilities and technology or the hardware side of the manufacturing system.

-*Human resources* - people in the manufacturing system.

-*Infrastructural resources* - the systems, relationships and information couplings which bind the operation together.

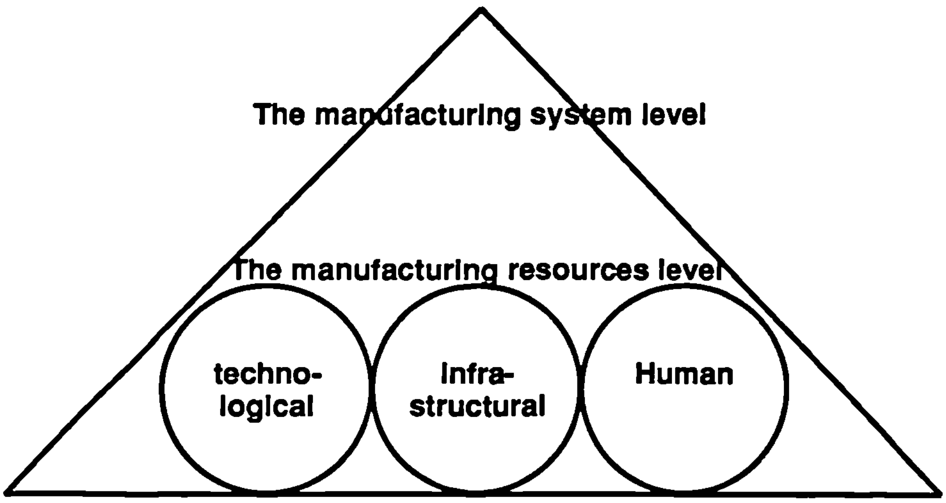

Fig. 3.1. The level of the manufacturing system and the level of the manufacturing resources

In an attempt to understand manufacturing flexibility better at the flexibility building blocks' level (the individual resource types level), ways which can be used in order to develop the flexibility of the three basic resource types are discussed below.

3.2. Flexibility of the Technological Resources

In order to understand the flexibility of the technological resources of a certain production process it is important to understand the concept of Economies of Scale. Economies of Scale are said to occur when the marginal cost of the production of a specific product is decreasing or, in other words, when the total production costs increase is less than proportional with the quantity produced. This happens because of the so called fixed costs in the cost structure of the process. A simple example can illustrate the concept more clearly. Be, to keep it simple, the following the parameters of a specific production process:

TC = total production costs

AVC = aggregate variable costs

FC = fixed costs

n = number of units produced

UC = unitary total product cost

UVC = unitary product variable cost

UFC = average fixed cost (per unit)

where $TC = AVC + FC$

but $AVC = n \,.\, UVC$

and then $TC = n.UVC + FC$;

$$UC = \frac{TC}{n} = \frac{n.UVC}{n} + \frac{FC}{n} = UVC + \frac{FC}{n}$$

In order to calculate the variation in the costs per unit with the production of one additional unit we can do (assuming for simplicity that the function is continuous as opposed as discrete):

$$\frac{d\,UC}{d\,n} = \frac{d\,UVC}{d\,n} + \frac{d}{d\,n} \cdot \frac{FC}{n}$$

but $$\frac{d\,UVC}{d\,n} = 0$$

because UVC is fixed in relation to the amount of units produced.

then $$\frac{d\,UC}{d\,n} = -\,FC \cdot \frac{1}{n^2}$$

or, the cost per unit varies inversely with the production of an additional unit.

When n assumes a very high value, the economy of scale tends to its maximum and we have:

$$UC \sim UVC$$

because $\frac{FC}{n}$ would tend to approach zero.

This situation can happen when the number of units produced is very large. However, the same situation can also happen if the term "FC", fixed cost, is made very small.

At a time when competition was based mostly on cost effectiveness, companies tended to perform large runs (or, to make "n" very large). Nowadays, it is not enough to be only cost effective to be competitive. A company must be able to produce and deliver small quantities of a variety of products and on top of it, at competitive prices.

This means no more long runs (or no more high values for "n"). The term "FC", with regard to equipment, stands for the set-up costs, fixed for any quantity produced in the run. One of the ways for a company to achieve the required cost effectiveness together with the required variability lays on the term "FC" which should thus be reduced at a minimum level.

Therefore, mainly when costs or productivity are especially relevant considerations, the cost of the equipment setup - in general a function of the setup time - is a very important factor to be taken into account when considering the equipment flexibility. Reducing the setup times of the equipment is thus one of the ways to achieve higher levels of equipment flexibility, mainly in terms of its response.

The literature can be divided in two different and important streams when it comes to discuss the means to reduce changeover times (the time necessary for the process to change from one product to another).

One stream suggests that flexible automation (such as computer controlled machines) is the principal way to achieve equipment flexibility. The other stream, more linked to the Japanese thought, suggests an approach which could be called methodology-based in this research. The methodology-based approach is based more on the concepts of organization, methods and rationalization of the use of conventional equipment. Both approaches will be discussed in turn.

3.2.1. Flexible Automation or the "Technology-Based" Approach

Some authors found in the literature consider that the key aspect for a manufacturing system to achieve high levels of flexibility is *technology*, or, in other words, "flexible automation". Zelenovic (1982) argues that "... increased flexibility of the production elements (work centres and assembly lines, materials handling equipment, buffers and storage, measurement and checking devices and control systems) can be successfully achieved by changing the production elements structure to more highly automated concepts enabling the maintenance of optimal levels with changing products and process conditions ...".

Stecke and Raman (1986) add that "... while the one-to-one correspondence between respective stages of the product and process life cycle could possibly be established for the conventional manufacture, flexible automation tends to de-link the product from the process..."[1], making, this way, the manufacturing process more flexible as a whole. This way, not only some of the processes (e.g. the conventional job-shops) would be flexible but even the most cost effective processes (e.g. the assembly lines) could also be flexible, being able to produce a variety of products rather than only one or a few.

In this respect, Hill (1985) argues that the numerical control (NC) base (the heart of flexible automation) of these [new] processes brings with it a level of flexibility which is far greater than the inherent with non-NC alternatives. This would mean therefore that

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[1]For details of the product / process life cycles relationship, see Hayes and Wheelwright (1984), chapter 4

the new processes are more able to cope with a wider range of products and also to handle product mix changes over time.

The new production processes which appeared as a result of automation would, according to Hill, be hybrid systems, having characteristics of more than one of the five conventional process life cycle stages adopted by Hayes and Wheelwright (1984) and others: Project, Job Shop, Batch, Assembly Line and Continuous Flow. Some of these hybrid systems and their impact over Technology Flexibility are described below, based on Hill (1985).

Numerically Controlled (NC) Machines (stand alone): - A numerical control system describes a process which automatically performs the required operations according to a detailed set of coded instructions. As mathematical information is the base used, the system is called numerical control. Compared with conventional equipment, NC machines offer increased accuracy, consistency and flexibility, even with the need to meet very complex manufacturing requirements. Changes and modifications in the task being performed are executed via change of instructions (actually change of magnetic or paper tape) reducing thus dramatically the setup times involved as all instructions for it are contained in the tapes.

Machining centres: - Machining centres combine NC operations previously provided by different machines into one machining centre. With tools changing automatically, controlled by instructions on the tape and carousals holding up to 120 tools or more, the underlying rationale for this development is to maximize the combinations of operations completed at a single location. In this way, a machining centre changes the pattern of work-in-progress inventory, because the stocks between operations performed by the machining centre are eliminated. With the reduction of work-in-progress inventories, the flexibility of the process increases because semi-finished products, many times, are committed with specific final products.

Flexible Manufacturing Cells (FMC): - Machining centres with automatic loading and unloading are called Flexible Manufacturing Cells (Voss, 1989). They can perform a variety of parts and can be left unmanned for one or more shifts. With the reduction of the required labour, the FMC tend to be more productive than the machining centres, however without a substantial alteration in terms of equipment flexibility (Hill, 1985)

Flexible Manufacturing Systems: - Flexible Manufacturing Systems are a combination of standard and special numerically controlled (NC) machines, automated material handling and computer control in the form of direct numerical control (DNC). FMS's are designed around families of parts which take part in the same assembly operation, similar products, similar operations or sizes, for example. The "philosophy" of FMS is the same as that of machining centres, i.e. maximizing the combination of operations completed at a single location with fast changeover between operations. The even further reduction of work-in-progress inventory and the ease with which the products being manufactured are changed make the FMS the automated system with the highest level of technology flexibility (Hill, 1985).

Figure 3.2. below illustrates and summarizes the spectrum of the main automated production systems.

	conventional	stand alone NC	machining centre	FMC	FMS
1. move piece to machine	M	M	M	M	A
2. load and affix workpiece to machine	M	M	M	A	A
3. select and insert tool	M	M	A	A	A
4. establish and insert speeds	M	A	A	A	A
5. control cutting	M	A	A	A	A
6. sequence tools and motions	M	M	A	A	A
7. unload part from machine	M	M	M	A	A
8. movement between machines	M	M	M	M	A

A=automatic; M=manual operation

Fig. 3.2. - Spectrum of automated production systems.
Based on Voss, 1989

3.2.2. Trade-offs Involved With Flexible Automation

The most visible of the trade-offs of increasing equipment flexibility via automation is the high level of the necessary capital investment. A full FMS can cost as much as 5 million pounds sterling (Bessant, 1986) what is a high investment for most of the companies.

Another problem faced by the companies, regarding the adoption of flexible automation is proving its economical viability by using traditional techniques such as discounted cash flow and pay-back methods. Kaplan (1984) proposes that the new flexible technology should be considered in a broader way. The long term, strategic benefits to the overall competitiveness of the company, brought about by the new technologies should also be taken in consideration rather than only the benefits resulting from its increased productivity (Adler, 1987), what would be only a marginal benefit. Meredith (1989) emphasize the strategic costs of "not adopting" the new technologies. The conventional techniques used to analyze project investments alone can not take these costs into account and, as such costs can be relevant in this kind of decision, they would not be sufficient to analyze the new flexible automation.

With regard to the benefits of flexible automation, there is no consensus as yet about how to assess the value of the flexibility of production processes. This represents additional difficulties to the viability analyses involving such technology. Although the difficulty in performing economical analysis is one of the most visible problems, it is not the only and perhaps not even the most important one regarding the use of flexible automation.

Another risk associated with adopting expensive flexible automation is highlighted by Tidd (1991). According to him, case studies suggest that in many cases firms are investing in FMS in an attempt to overcome what are essentially organizational shortcomings. As a result, some users have adopted inappropriate technologies and have failed to improve their flexibility (Bessant and Haywood, 1986).

A report of NEDC (National Economic Developing Council) on FMS reads in this regard:

> "The limited flexibility of a Flexible Machining System can, of course, be a disadvantage unless the system and the parts that it is to make have been carefully chosen... In general, a company installing an FMS must be prepared to re-organize its manufacturing procedures if the full potential of the system is to be realized... The drawback is not the capital cost, it is the flexibility itself...Planning and understanding are crucial because in one way the system is inflexible, as most of the options should be planned at the beginning" (NEDC, 1984).

Jaikumar (1986) performed research aiming to compare the adoption of FMS in companies in Japan and USA. The author concludes that the USA is visibly loosing the battle of using the new technologies to achieve competitive advantage.

The crucial point would not be related to investing more in equipment. In today's manufacturing environment, Jaikumar argues, what matters is how the equipment is used. The author presents some figures, as results of such research. Some of them are transcribed below:

	U.S.A	Japan
types of parts produced per system	10	93
annual volume per part	1,727	258
number of new parts introduced per year	1	22
utilization rate	52%	84%

Fig 3.3 - Some figures comparing FMS adoption in USA and Japan
Source: Jaikumar (1986)

Since the physical systems (the hardware) utilized in USA and Japan are not substantially different in average, the critical point seems to be in the way the organizations in both countries are using them.

The reasons behind these differences, says Jaikumar (1986), are mainly the management and the qualification of the Labour. What happens is that getting more qualified and committed work force and more competent managers require substantially different (and probably more difficult to achieve) efforts than simply buying equipment.

Adler (1987), analyzing the factors which can be critical with regard to the adoption of flexible automation, highlights three of them as the most important ones: the management of change, the implementation and the human aspects involved. The process of change should be managed bearing in mind its strategic nature, with all the implications it brings to the organizational structure. The adoption of flexible automation should be dealt with by planning carefully for effective implementation, instead of considering implementation just as a residual task. Finally, the human factors should receive a very careful consideration because the success of the change process will depend basically on them. The management of change itself has been the object of intense research effort and the literature about it is vast. This fact demonstrates how managers and researchers have been concerned about the issue and in a way, how important it is.

The technological change represented by the adoption of flexible automation is not a minor change. Carnall (1989) argues that "managing technological change turns less on issues of technology and more on questions of attitudes and experience". These changes affect the contents of the tasks to be performed, the level of Labour skills required and, as a consequence, the way Labour should be managed:

> "They (the changes) generate uncertainty, anxiety and stress. Moreover, changes which have a big impact on people's work will affect the self esteem and this will affect performance... To manage change effectively involves the ability to create a new synthesis of people, resources, ideas,

opportunities and demands. The manager needs skills rather like of an orchestral conductor. Vision is essential and creativity paramount. Yet the capacity to create systematic plans to provide for the logistics of resources, support, training and people is central to any change program. People must be influenced and departmental boundaries crossed or even "swallowed up". New ideas must be accepted and new ways of working embraced. New standards of performance and quality must be achieved.

The politics of the organization are crucial. Support must be mobilized, coalitions built, oppositions handled and bargains struck. The program must be maintained, teams built and supported. People need help to cope with the stress, anxiety and uncertainty of change. Continuity and tradition must be overturned, in part, as the old is replaced by the new, yet continuity and tradition provide people with stability, support and meaning and should not be needlessly destroyed. The effective management of technological change demands attention to all of those somewhat conflicting issues and challenges." (Carnall, 1989)

Carnall suggests that in order to successfully overcome the problems mentioned above, it is essential to encourage aspects such as people's creativity, the risk taking attitude and continuous learning. These factors would help people restore self esteem and performance. Therefore, leadership, motivation, organizational structure, training, rewarding systems, among others, should be designed consistently with the three above mentioned aspects.

Gerwin (1982) emphasizes the need for the participation of all the people affected in the decision process with regard to the adoption of flexible automation. Participation is also crucial, according to Di Martino (1989) who says that as the complexities [of the new technologies] increase, there is a growth in the level of risk relating to unforeseen events and therefore an increased need for special expertise in dealing with such events and, as a consequence, for a greater participation.

The process of changing to flexible automation is not trivial. The effort to reduce the risks of failure requires large amount of resources in training programmes, reorganization, personnel substitution, efficiency reduction due to the learning process and so forth. The material costs involved in the implementation can surpass by far the 5 million pounds represented by the equipment cost itself. Beside this, the risk of failure is not irrelevant.

Schonberger (1986) points out some other aspects which can be disadvantages of large scale automation: due to the high volume of capital involved in the acquisition of flexible automation, there would be a risk that management would tend to avoid idleness even at a high cost, resulting in the build up of stocks which according to the author are highly undesirable not only for the capital costs involved but also because stocks hide process inefficiencies.

Another problem, goes on Schonberger, with what he calls "super machines" is the lack of modularity, making it difficult to increase process capacity gradually, according to the demand requirements. In other words, the flexibility of the system to change output volume would be reduced with the large automated machines. Finally, the lack of mobility of large equipment can make it difficult for the process to make alterations in layout such as setting up and changing manufacturing units (such as cells).

Schonberger is one of the authors who advocate the development of flexibility of manufacturing systems through other and simpler means, rather than flexible automation. In this respect, Blackburn and Millen (1986), for example, say that "recent evidence from Japan and elsewhere indicates that flexibility can be achieved at a little or no investment in equipment ... what has been invested [in the companies which support their conclusions] is line and staff personnel time to find the causes of inflexibilities".

Dimsdale and Cox (1989) seem to agree. They argue that "Proposed acronym-based solutions (a la CIM) to the nation's [USA] manufacturing problems have soared but results have not followed suit. We have tended to rely on newer and more sophisticated equipment and methods for possible solutions. Instead, what is needed is a recognition that all the pioneers of management are not wrong. Their ideas just need to be updated for use in today's environment".

The next section comments on this kind of approach: the ways which can be used in order to achieve flexibility other than flexible automation.

3.2.3. Methodology-Based Flexibility Development

The importance of lead time reduction for the development of equipment flexibility has already been stressed in an earlier section of this chapter. Based on this assumption, much effort has been spent, initially in Japan and later all around the world, in order to find ways and develop techniques to reduce equipment setup times. Shingo (1985), the originator of the SMED (Single Minute Exchange of a Die) System has contributed in this effort. Reductions to 1/18 in average of the time previously spent in the setup of equipment are reported in his book (Shingo, 1985) and attributed to his method which is based on the principles of the "scientific management" analysis, originated by Frederick Taylor in the beginning of the Century.

To help the analysis, Shingo proposes the identification of 2 types of setup operations:

Internal Setup (IED): operations which can be performed only when the machine is stopped, such as mounting and removing dies.

External Setup (OED): operations which can be conducted while the machine is in operation, such as transporting old dies to storage or conveying new dies to the machine.

The steps for one to perform the reduction of the setup times are, according to Shingo:

1. To separate Internal and External setups, making a "scientific" effort to treat as much of the setup operations as possible as external setup. Then, the time needed for internal setup could, according to Shingo, be cut some 30% to 50%.

2. To convert internal to external setup, re-examining operations to see whether any steps are wrongly assumed to be internal and finding ways to convert these setups to external. Still according to Shingo, this kind of analysis caused reductions in the setup time of a machine, manufacturer of screws, from 8 hours to 55 seconds, at Toyota company.

Schonberger (1986) also suggests some forms of increasing equipment flexibility without using flexible automation. About flexibility, he agrees with Shingo and claims that the important point is the reduction of setup times. He also highlights some desirable characteristics of equipment such as modularity and transportability which could contribute not to the flexibility of the specific machine but to the flexibility of the manufacturing system. If a specific machine has, for instance, small capacity and size, low cost and simple setup operations, then, even to face a large demand, it would be preferable, according to Schonberger, when compared to bigger machines. The reason is that the production system could add equipment capacity the same way it adds people. The system's capacity would follow closely the growth of the demand. In working with large capacity machines, capacity could only be added in large jumps (given by the capacity of each machine).

When capacity addition occurs in a system which uses large machines, two are the possible outcomes: in one case, the additional machine would be bought in before the demand grows sufficiently to fully occupy its capacity, resulting in idleness and thus underutilisation. In the other possible case, the additional machine would be bought in after the demand have grown sufficiently to fully occupy its capacity. This means that the system remained with its capacity limit below its demand level for at least the period it took the demand to grow of an amount equivalent to the capacity of the new machine.

During this period, the system probably either served the market poorly or lost sales to competitors, what can possibly have important strategic consequences.

The transportability of the equipment would make the system more flexible because it would be easier to rearrange the machines into new configurations, more appropriate to new situations which the system has possibly to face.

3.2.4. Trade-offs in the Development of Methodology-Based Flexibility

According to the approach proposed by authors such as Shingo and Schonberger, who suggest the use of more conventional and universal machines, the task of "being flexible" has to be performed by people rather than by machines. These authors see people as the most critical factor for a system to be flexible. Commitment, participation, skills and adequate management are concepts which become critical. To develop them, the authors say, it is necessary to change the organizational culture, and in many times, to change it considerably.

To change an organizations' culture, it is necessary to take a series of major measures, possibly including extensive training, new rewarding systems and methods for motivation, new management style, among others. Performing these alterations is not a trivial task and it certainly requires considerable organizational effort and top management's commitment, left alone the tangible costs.

It is not only a matter of identifying other companies' successful experiences and transplanting the models and "recipes". In the literature, many examples can be found of failure in attempts made by American companies to simply transplant the so called "Japanese model" of management. It is necessary that one takes into account the whole context in which the system is to work, the cultural background of the people involved, the Capital-Labour relationship history of the company and a series of subtle companies' particular details if the desired "cultural changes" are to be successful.

3.2.5. The Flexibility of Technological Resources - Conclusion

In terms of technological resources, or equipment, flexibility (at least in terms of response), the costs, time and effort spent in order to perform changeovers seems to be most relevant considerations.

The literature is divided in two main different and important streams with regard to the ways to achieve better levels of performance in terms of machine changeover: one stream suggests that flexible automation is the principal means to develop technological resources flexibility. The benefits of this approach are changeover speed and consistency, achieved in general through numerically controlled machines, either stand alone or integrated. The main disadvantages of this approach are the high capital costs involved in equipment acquisition and implementation, and, the lack of modularity and transportability of the equipment. There is still great difficulty to prove investments with flexible automation viable by using conventional financial analysis techniques and indicators.

The other stream is an approach which advocates the use of conventional and modular equipment of which the setup times should be reduced basically by *methods* such as the SMED method. The main disadvantages are the need for change in people's attitudes and the greater dependency on people's skills which are necessary. In order to change people's attitudes and level of skills, a considerable amount of organizational effort and capital have to be spent in training, changing the relationship organization-labour, the style of supervision and others.

The two main general approaches to technological resources flexibility - methodology-based and technology-based do not seem to be and should not be considered mutually exclusive (Hayes et. al., 1988). Probably no manufacturing system could achieve high levels of flexibility by relying exclusively on one of the two approaches (at least for the near future). A certain amount of both approaches may be necessary in any case and the more or less emphasis on one or on the other seem to depend on the specific contingency. If a hypothetical organization, for instance, intends to develop the flexibility of its technological resources but lacks the capital necessary for the adoption of flexible automation (as it seems to be the case of some companies in developing countries, for instance), it appears to be plausible that it should seek to emphasize the methodology-based approach. In another hypothetical situation, it also seems to be plausible that the firms which have problems with Labour Unions in terms of making their work force more flexible tend to adopt flexible automation, in which possibly less multi-skilled flexible workers are needed, since the flexibility is "embodied" in the machines. It seems to be important therefore that the decision makers consider both approaches as non mutually exclusive and that they adopt a "mix" of both (Schomberger, 1990), which should be consistent with the particular contingency which the organization is currently facing.

The next section deals in more detail with the development of the flexibility of the work force.

3.3. Flexibility of the Human Resources

In this section, the flexibility of human resources is discussed. Some ways to develop Labour flexibility and some related managerial aspects are also presented and discussed, based on the relevant literature.

3.3.1. Flexible Work force

According to Atkinson (1984), the best way to achieve greater flexibility from the work force is by changing the organization of work. The author proposes a model which would help the development of labour flexibility which he named "The Flexible Firm". The model would be, according to the author, a breakthrough in relation to conventional hierarchical forms of structuring the work force. Completely different policies would be applied to different groups of workers. Figure 3.4. below illustrates the model:

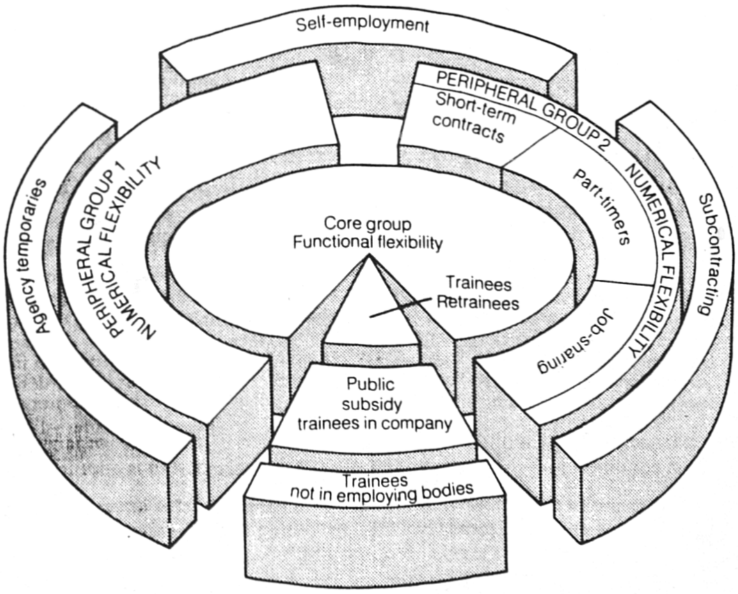

Fig.3.4 - The Flexible firm
source: IMS (Di Martino, 1989)

The basic division would be between jobs which are specific to a particular firm from those involving only general skills. The specific jobs would be, for instance, those of production manager or maintenance technician while jobs with general skills would be computer programmers or drivers, for example. The model includes a class of workers with weaker links with the company (first and second peripheral groups), around a more numerically stable group, responsible for the key activities of the company.

The emphasis of this stable group would be more in the functional flexibility (sought so that employees can be redeployed quickly and smoothly between activities and tasks).

The emphasis of the peripheral group would be more in numerical flexibility (sought so that at any time the number employed / working exactly matched the number needed). When the demand expands, the periphery group expands. When the demand contracts, the group contracts accordingly.

The stable group would be isolated from these short and medium term fluctuations while the periphery group would be more exposed to them. The relationship between the company and both groups would be accordingly different.

The workers in the core are full time employees and their employment security would be won at the cost of accepting functional flexibility both in the short term as well as in the long term, via development of multi skilled abilities, reduced job demarcation, changing of carrier and retraining. Pay systems should reward the acquisition and development of new skills and they should be, at least partially, based on performance assessment. The central characteristic of this group is that their skills can not be readily bought-in.

The workers in the first peripheral group would be also full time employees but enjoying a lower level of job security and having less access to carrier opportunities. They would be offered a job, not a career. They might have clerical, supervisory, component assembling and testing occupations. The key point is that their jobs would be "plug-in" ones, and not firm specific.

As a result, the firm would look to the external labour market to fill these jobs and would seek more numerical flexibility through a more direct and immediate link to the external labour market. A lack of carrier prospects, systematization of job content around a narrow range of tasks all tend to encourage a relatively high level of labour turnover which itself would facilitate easy and rapid numerical adjustment to product market uncertainty.

A second peripheral group would be used if the firm needs to supplement the numerical flexibility of the first peripheral group with some functional flexibility. They are contracts of employment designed to combine the two. Part time work is probably the best example of this - the jobs having all the characteristics of those in the first peripheral group with their deployment often structured to match changing business needs.

Job sharing, short term contracts, public subsidy trainees and recruitment through temporary contracts all perform a similar function - maximizing flexibility while minimizing the organization's commitment to the worker's job security and career development. This not only would permit numerical flexibility but would also encourage greater functional flexibility than in direct employment.

Pollert (1987) criticizes Atkinson's (1984) model's prescriptive aspect in various points. She observes that the concept of core and periphery are too fragile and that the model does not help understand the relationships between labour flexibility and the flexibility of the production system as a whole.

Another aspect to be observed is that the creation of an insecure and unskilled labour (the case of the first peripheral group) is not presented by Atkinson (1984) as something with which the management should be concerned about. This seems to be contradictory with the views of a number of authors in the field (e.g. Hayes et. al., 1988 and Womack, 1990). They, in general, consider that creating a motivated and committed work force is something very desirable, whether they perform a key function or not. The broadly accepted concept of "Total Quality Control" (TQC) for example, assumes that even a worker who performs a non firm-specific task like simple assemblies and tests has his parcel of contribution to the final product quality or service level offered by the company.

In this aspect, Pollert (1987) says that the "Flexible Firm" model gives excessive emphasis to labour cost control rather than to the achievement of effective labour flexibility. This would thus be a myopic approach, according to Pollert, which would divert attention from long term training needs by providing an excuse to shift them to the periphery -"after all, what cannot be bought in?".

Other authors seem to agree with Pollert. Hayes, Wheelwright and Clark (1988) suggest that superior competitive performance depends primarily on the people involved in the production process. To develop its potential - skills, discipline, ability to solve problems, capacity for learning - would be in the heart of high performance manufacturing. Some characteristics which would be desirable, according to the literature, for the work force to possess in a company aiming to achieve higher levels of flexibility are discussed below:

Multiple and better skills: (Adler, 1987; Kohler, 1989; Grey and Corlett, 1989; Hayes et. al., 1988) - The larger the range of skills of a worker, the more flexible he is, either in terms of mix of products changes or in terms of inter changeability of workers between work stations, useful in order to cope with absenteeism and temporary shortages. With regard to flexible automation, Adler (1987) found "a surprising degree of convergence in a series of studies conducted in numerous countries, all pointing to advanced automation's new and higher skill requirements".

Ability to make decisions/ solve problems (Kohler, 1989; Hayes et. al., 1988) - This is a specially important characteristic in order to obtain quick responses to changing circumstances. It allows decentralization of decision making and therefore avoids that time is wasted awaiting decisions otherwise always dependent on upper echelons.

Ability to work in teams (Womack et. al., 1990; Kohler, 1989) - Integration is important in order to achieve product flexibility. Multi-functional task forces or teams are being increasingly used when a company needs to launch a new product or change an existing one. Design engineers, for instance, need to have close contact with the production team so that manufacturing problems can be foreseen at the design stage, avoiding future waste of time and effort. This kind of interaction should happen between all the areas involved and team work seems to be the most appropriate approach.

Communication capability (Kohler, 1989) - To achieve integration, efficient communication intra and inter areas is essential. The more this communication is practised, the easier it becomes. Some areas of the company have their own jargon which should be standardized or at least understood by the other areas with which they interact. This way misunderstanding is minimized and doubts can be solved quickly and effectively.

Ability to understand the process as a whole - The good understanding of the process as a whole helps understand the consequences of the decisions made. It makes the decision making process easier, faster and the decisions become more consistent, avoiding decisions which would lead to undesirable consequences as well as making it possible to identify decisions which lead to consequences which are desirable to other stages of the process (Skinner, 1978).

Ability to adapt to new situations - This helps avoid resistance to change which can jeopardize flexibility. The acceptance of change as an intrinsic part of the production process rather than an exception is important for the development of the abilities in order to deal with changeable or unpredictable environments (Hayes et. al., 1988).

Ability / disposition for continuous learning: This point is stressed by Hayes et. al. (1988) as essential for the creation of what they call the "learning organization". This characteristic is a condition for the creation of an effective capability of the system to adapt to new circumstances. At least partially, the resistance to change is a result of fear of the unknown, caused, many times by lack of information. If there is the predisposition to learn, then the barriers of resistance are more easily broken.

The creation of the favorable conditions to allow the development of the above characteristics can be considered predominantly as management's responsibility. It is necessary that the managers have an attitude which is consistent with the flexibility objectives of the organization. This way they can select appropriate managerial techniques and styles to organize, direct, motivate, provide training and perform the other activities involved with the managerial function. The role of the management in the achievement of work force flexibility is briefly discussed below.

3.3.2. The Management of the Flexible Work Force

Adler (1987) contrasts the concept of flexibility with the one of stability. Stability would be a fundamental value, whereas flexibility would be more difficult to manage and, *ceteris paribus*, more costly. The managerial question would be not simply how to reduce rigidities but how to find the right mix of stabilities and flexibilities. According to Adler (1987), the deliberate introduction of some stabilities in the process would be the necessary baseline for the development of flexibilities. The stability of a consistent and explicit manufacturing strategy creates the conditions for the management to be flexible in local innovations; the job stability would generate the necessary disposition in the work force to learn, make decisions and adapt to change.

Some characteristics which would be desirable for the management to create conditions for labour flexibility development are, according to the literature:

Emphasis on team work: the conventional approaches based on specialization and centralized decision making can be counter productive in dynamic industrial environments. This has not only led to problems of high absenteeism and labour turnover, with a consequent increase in the direct costs of recruitment and training but also to a lack of flexibility (Grey and Corlett, 1989). The answer to these problems is the change in the emphasis of the work organization, from the "individual" to the "team work". The objective is to achieve a multi skilled work force with more responsibility and autonomy at the shop floor level. Individual problems become group problems. This way, a high degree of Labour flexibility is achieved with faster communication and group multiple skills.

Greater work satisfaction is obtained with group organization for the worker can see clearly the links between his task or his objectives and the objectives of the group. The change towards work groups, which adds a managerial dimension (decision making, work planning and control) to the operational dimension of tasks (Hayes, Wheelwright and Clark, 1988) requires substantial alterations on the way the work force has to be managed because it possibly changes the distribution of power within the organization. It could be counter productive to give the worker opportunities to participate (or even demand participation from him) of the decision making process without training him/her properly before. The same way it may be counter productive to delegate the control function to the worker without providing him/her with the feedback information of the actions he/she takes.

Supervision: The shift in emphasis to group work on the shop floor has had profound implications for the nature of the supervisory role. This role, according to Grey and Corlett (1989), has always been particularly subject to conflict and ambiguity, but with the emergence of increased shop floor responsibility, participation and team work, the situation is exacerbated. Aspects concerning interpersonal relationship gained increased importance because the role of the supervision is one of a "team consultant" or "team adviser" rather than a directive one. The supervisors should now establish the group objectives clearly, push for quality and motivate their workers with timely and accurate feedback, coach them when necessary and share information with them. According to Klein and Posey (1986), good supervisors tend to take responsibility for the actions and outcomes of their units, know how to get the right people involved in the problem solving process, and take the initiative to do so. They can also look beyond their immediate areas to understand the plant and the company as a whole.

Payment : The method of payment employed should be consistent with what the organization expects from the work force. "A group incentive method is probably the most suitable to effective team functioning. Any method of individual incentive payment is likely to be counter productive for a number of reasons. Such payment systems are based on the "scientific management" approach which regard a worker to be in business for him/herself, not for the team, and certainly not for the company. Operators will always want to work only on the jobs which they are used to so that they can earn a higher bonus, and will resist to any suggestion of job rotation." (Grey and Corlett,1989).

Training: Training is of fundamental importance for a company to achieve work force flexibility. Training should not be based solely on individual job content. It should serve the dual purpose of enabling people to perform daily operations as well as creating the conditions for people to participate in the design and development of their working environment in the broadest sense (Hayes et. al., 1988). While management would still see skill variety as desirable in that it produces flexibility, shop floor workers may see this as nothing more than an erosion of their demarcation lines and traditional practices (Grey and Corlett, 1989). Training for flexibility should therefore include the abilities necessary for the job contents of the flexible organization: problem solving techniques, planning and control techniques, among other managerial tools. Training for technical excellence should not be neglected either.

The literature discusses the new skills which would be required to fulfil the new flexible automation needs. However, the subject is still controversial. It is not generally agreed as yet that the new flexible automation brings, as a consequence, increased skill requirements. However, lately, the position of a number of authors seem to be that in order to utilize the best advantage of the potential for flexibility inherent in the new technology, a flexible, multi skilled well qualified work force will be needed (Kohler, 1989).

Kohler studied the alterations on the work content of several types of professionals with the introduction of flexible automation and concludes that new skills such as responsibility taking, decision making and cooperation will be demanded for a great many more employees than in the traditional situation. With regard to the technical skills, the new job contents tend to carry on having the same level of demand or even to demand an increase of them.

Job structuring : Flexible production systems seem to demand less structured jobs. Definitions and precise demarcation of the job contents, for instance, seem to be less adequate to situations which demand high flexibility and multiple skills from the workers. (Kohler, 1989).

3.3.3. The Flexibility of the Human Resources - Conclusion

It seems to be necessary to abandon some classical managerial concepts in order to develop a flexible work force. One of them is the complete separation between planning/controlling and executing the tasks. These tasks are not any more the old simple, repetitive ones, designed by the management based on "scientific management's" principles. The new reality demands flexibility and flexibility requires decentralized decision making, skills to solve non repetitive problems, planning and self control skills of who performs the job, or in other words, managerial skills beside technical excellence.

To develop this kind of ability and skills, it is necessary to give workers special conditions, for which the idea of team work seems to be an important building block. These conditions are given largely by the way the workers are managed, basically regarding *supervision* which should change from directive to supportive; *continuous learning,* not only on technical aspects but also on managerial aspects; and finally, the *forms of reward* which should also be based on the group performance and skill levels of the worker rather than solely on individual performance.

Many authors (Hayes et. al., 1988; Womack et. al., 1990; Schonberger, 1990; among others) seem to agree that the human resources are and should be considered as the most valuable asset of the organization in the present and future competitive realities. It is now generally agreed, for instance, that total quality programs should focus and rely predominantly on people within the organization, after a period in which quality had been considered more a function of the quality control information systems (e.g. statistical quality control systems).

Without a committed and well educated work force, it is now broadly accepted, total quality will not happen even with good quality information systems in operation. Quality systems, although possibly necessary, do not seem to be sufficient to ensure high product quality levels. Something similar appears to be happening in terms of flexibility. After the results of the "flexible automation revolution" have proved to be far more modest than anticipated (at least up to the present), it seems that a flexible work force is increasingly important for a firm which intends to achieve high levels of manufacturing flexibility. Some degree of flexibility of the technological resources, although important and possibly necessary do not seem to be sufficient to ensure the achievement of high levels of manufacturing flexibility.

3.4. Flexibility of the Infrastructural Resources

Beside structural resources (Equipment and Labour), companies use infrastructural resources to achieve their objectives. Slack (1989) is one of the few authors who discuss the role of infrastructural resources in the achievement of manufacturing flexibility. Slack (1989) defines two dimensions - range and response for each of his two types of infrastructural flexibility - supply systems flexibility and control systems flexibility:

Supply systems flexibility

(range) - the range of supply potential, both in terms of quantity and type, of materials, labour or any other input resource.

(response) - the time necessary to change from one supply position (quantity and type) to another.

Control systems flexibility

(range) - the range of states for which the system can effectively respond.

(response) - the time necessary to reorganize or re-plan operations.

Although Slack's classification may be useful as a general guide-line to understand the relationship between infrastructural resources and flexibility, the author does not go further in analyzing the specific characteristics which would be desirable in particular systems in order to make the manufacturing operation more flexible.

Tidd (1991) briefly analyzes two infrastructural resource types in terms of its influence on manufacturing flexibility: work organization and production planning and control. In terms of work organization, he argues that there is a trend in the UK, set by Japanese companies, of negotiating flexibility deals with the work force, which includes flexibility and mobility of employees both within departments and inter different departments, employees' training for work as required by the company and so on.

In terms of production planning and control systems, Tidd (1991) argues that decisions regarding capacity primarily affect passive flexibility (defined by the author as the ability to function well in more than one state) whereas production and inventory control systems determine the active flexibility (the ability to respond to change by taking appropriate action) of the manufacturing system. The point the author makes seems to be arguable since there are important components of inventory control which can influence Tidd's "passive flexibility" such as the build-up of stocks in order to buffer against faulty supplies, and there are also important components of capacity decisions which can influence active flexibility, such as keeping some excess capacity in order to be able to introduce a new product line.

According to Berry and Hill (1988), manufacturing planning and control systems represent a critical part of the manufacturing infrastructure and support functions and their design is closely linked to decisions regarding a firm's manufacturing strategy and choice of process. They argue that the way in which companies win orders differs within different segments (with more or less emphasis on flexibility, for instance) and that this, in turn, needs to be reflected in relevant infrastructure investment.

According to Hayes et. al. (1988) certain types of organizational structures are characterized by favouring high flexibility, others encourage efficiency and tight control, and still others promote dependability. They suggest that the organization's flexibility is influenced by the choice of organization structure.

The viewpoints expressed by the literature point out to some aspects regarding infrastructural resources which seem to be of relevance for the flexibility of the manufacturing systems: manufacturing planning and control systems, supply systems and organization structuring issues.

The two first aspects - manufacturing planning and control systems and, supply systems - are in fact elements of a broader research area which is the organization's supply chain (or network) management. Some aspects regarding both organization structuring and supply chain management are discussed below.

3.4.1. Flexible organization structuring

As the aspects concerning work design and structuring within the manufacturing function (e.g. team-work and the role of the supervision) were discussed in a previous section, here predominantly the aspects concerning the relationships between the functions involved in the manufacturing process will be discussed.

De Meyer and Ferdows (1990), reporting the 1990 European Manufacturing Futures Survey, conclude that "The leading European manufacturers are focusing increasingly more in establishing closer links between production and the other functions in the company as well as with suppliers, customers, and others outside the company. This is done partly by technology, partly through inter-functional teams, and partly by modification of procedures. The goal is to *remove the organizational barriers* to free the flow of information, goods, and people to and from the factory.", allowing for more flexible manufacturing. This point is also made by a number of authors (Womack et. al., 1990; Slack, 1991; Campbell and Warner, 1989, and Hayes and Wheelwright, 1984)

As discussed in chapter 1, some of the interfaces between manufacturing and other functions have historically been conflicting areas and removing the barriers which have been built as a result of the past conflicts is in general an exacting task for the management. The literature suggests some ways of breaking the barriers and increasing flexibility through appropriate structure design characteristics:

Flexible job definitions - Hayes and Wheelwright (1984), describing aspects of the elite Japanese organizations, argue that the management training programs and organizational structures adopted by Japanese companies add to their flexibility. Broadly trained managers who operate without rigid job definitions in a mutually cooperative environment would, according to the authors, communicate better and find it easier to make the adjustments necessary during periods of rapid change.

Less hierarchical structures - Campbel and Warner (1989) argue that, if one can generalize about the shape being taken by organizations in the context of changing technologies and markets, one can say that there is now much greater emphasis on communication across the hierarchy, in a structure far more closely integrated through shared data bases and computerized work-flow. Organizations, according to the authors, have to become more open and less hierarchical.

Effective inter-functional project teams - Womack et. al. (1990) emphasize the importance of the inter-functional team work for the "lean manufacturers", a term they use to refer to the companies which they consider as the best automobile manufacturers in the world. In terms of the product design process of the elite lean manufacturers, who, according to Womack et. al., are clearly more flexible in introducing and changing products than the competitors, they argue that the project teams in these companies are formed by employees who come from different functional departments of the company - market assessment, product planning, styling, advanced engineering, production engineering, and so on. They retain ties to their functional departments but for the life of the project they are clearly under the control of the team leader, who judges how they perform in the team, what in turn, will influence their next assignments. By contrast, according to the authors, in most Western companies a development project team consists of individuals, including the team leader, who are on short-term loan from a functional department. Commitment to the team is therefore not enforced by the organizational structure. Key evaluations will come from the head of the employee's functional division, who wants to know: "what did you do for my department?". Effective teams are related to Hayes et. al.'s (1988) second principle of business organization - responsibility equals authority. They argue that as far as possible, a manager's responsibility should equal his or her authority. Slack (1991) also suggests that project-based organization, although it can take several forms, is appropriate to encourage both overlapping problem solving and bridging between functions.

Schonberger (1990) argues that the 4 main functional groups - design, marketing, accounting/finance, and operations - have scarcely been able to talk to one another. Discussing ways to break the communications barrier, the author suggests that only a super-ordinate goal is able to make the barriers fall - **serving the customer**. The underlying assumption here is that everyone has a customer - at the next process. Linkages from process to process would then form a chain ending at the end at the final paying customer. Each operation would just be one node in a complex network. This is the principle behind the concept of supply network, analyzed in the following section.

3.4.2. Flexible Supply Network Management

Supply networks, according to Slack (1991), can be viewed at three levels. The *immediate network*, encompassing the relationships between the company and its immediate suppliers and customers, the *internal network*, within the organization itself - flows of materials and information between departments, cells or sections of the operation and, the *total network*, which includes the internal network, the immediate network and all the other suppliers and supply relationships beyond the immediate network up and downstream. In this section two of these levels will be analyzed with regard to flexibility: the internal network and the immediate network.

Internal supply network management - the systems in charge of supporting the management of the internal supply network are normally called manufacturing planning and control (MPC) systems.

Manufacturing Planning is basically a pre-operational activity, i.e. the determination and the arrangement of all the facilities for the future operations. Manufacturing Control is essentially a during-operation activity involving the implementation of a pre-determined operations plan or policy. Control derives from the process of monitoring activities and the comparison of actual and intended states (Wild, 1989).

"The need for exercising control derives from the fact that rarely is it possible to ensure in advance that certain things will happen in a particular way at a particular time. Control thus is necessary because of the existence of uncertainty. A purely deterministic situation is unlikely to necessitate control since, in such circumstances planning itself is sufficient. In practice, such determinate situations will rarely exist and thus control is an essential link in the circle or cycle which begins with planning and involves monitoring, action and correction, and possibly revision of planning for future events" (Wild, 1989).

In earlier sections, flexibility was considered the "ability to respond effectively to changing circumstances". It seems therefore that the control systems play an important role when a company seeks to achieve flexibility, mainly in the short term. Borrowing Mandelbaum's (1978) classification, control systems seem to be very important to achieve "state flexibility", or the "ability to continue functioning effectively despite the change".

On the one hand, the planning systems become more complex when a company aims to increase its flexibility because, instead of planning for a specific desired situation, it is necessary to plan for a range of future possible situations, with which the company intends to deal. We can thus say that planning systems, in its broadest sense, are also important in terms of achieving flexibility, since it is necessary to determine and arrange all the facilities needed for the range of future operations which the company intends to deal with or, in other words, to achieve a desired range flexibility. On the other hand, control systems are critical for the company to perform short term corrections, adjustments and change either to continue functioning despite the environmental change or to trigger the actions needed to move between states within the planned range or in other words, to provide response flexibility.

The analysis which follows focus in more detail on how three of the most important Manufacturing Planning and Control Systems - MRP II (Manufacturing Resources Planning System), JIT (Just in Time) and OPT (Optimized Production Technology) can contribute to the company's system flexibility.

Flexibility of the Manufacturing Planning and Control Systems

When analyzing different manufacturing management systems, it is important to make the distinction between the general ideas, objectives and assumptions - or the "philosophy" - that lie behind them and the actual manufacturing planning and control system which they use. The literature does not always succeed in making this distinction clearly. A typical example is the use of the term Kanban (a flow control and scheduling technique) referring to the broader concept of JIT or Just in Time which comprises a series of ideas, objectives and assumptions and usually uses the card-based flow control technique (usually called a Kanban system). Figure 3.5 below summarizes the distinction between the philosophy and the MPC used by the three systems analyzed in this section:

MANAGEMENT PHILOSOPHY	USED MPC SYSTEM
JIT (generally explicit) assumes high conformance qual.; assumes certain excess capacity; assumes short set-up times; assumes high machine reliabil.; assumes team-work/participat.; assumes that inv is undesirab; assumes a definite and balanced work flow; assumes schedule stability; assumes line or cell type layout; assumes certain level of work force multi-skills.	**characteristics** card-based (kanban) pull logic; visual scheduling technique; local schedul. decisions; decentralized decisions; intermediate WIP between work stations.
MRP (generally implicit) assumes that low inventory and meeting due dates are priorities; assumes that capacity utilizat. variation is inexpensive (or certain excess capacity); assumes fixed lead times (or a relatively stable mix).	**characteristics** computer-based push logic; centralized decisions; backward scheduling; lead-times are input; all resources treated equally; batch quantities are input; transfer and process batches are equal; infinite capacity scheduling.
OPT (generally explicit) assumes that objective is to simulation- make money by simultaneously increasing throughput reducing inventory reducing operating expenses; assumes that bottlenecks govern both throughput and inventories and should be treated especially (to maximize their utilization).	**characteristics** computer based push logic centralized decisions; bottlenecks are starting point for scheduling; forward and backward scheduling depending on the resource; lead times are output; allows for process and transfer batches to be different and variable; finite capacity scheduling

Figure 3.5 - Differences in assumptions and in the MPC system used by 3 manufacturing management "philosophies" - JIT, MRP II and OPT (based on Corrêa and Slack, 1991)

Here, the potential, constraints and flexibility of the Manufacturing Planning and Control systems embodied in each of the management "philosophies" rather than the "philosophies" themselves will be analyzed.

The types of manufacturing flexibility used in the analysis are those proposed by Slack (1989) (see chapter 2 for details). The analysis are based on Corrêa and Slack (1991) and Slack and Corrêa, 1992).

The Kanban System - Within the JIT manufacturing management philosophy, the most celebrated of the Japanese "pull" manufacturing control systems is the Kanban system. Visual scheduling and control is one of the most important features of a Kanban system. Work cycle times are balanced by having workers perform many different tasks.[2]

The performance of the Kanban system in terms of the 4 types of manufacturing system's flexibility is briefly analyzed below.

Kanban and Flexibility

New product flexibility - With regard to the use of Kanban systems, the introduction of very novel products can be difficult if the new product has a different set or sequence of operations. The Kanban system assumes a relatively defined and stable production flow between work stations which different product flows would disrupt. Within a fixed range of products, changing an existing product is reasonably simple. There is however a discontinuity in the level of flexibility. The response level becomes very poor for the introduction of products which require different production flows.

Mix flexibility - Kanban System do not seem to suit companies which compete on variety. Intermediate stock levels would be too high since output stocks are maintained after each operation, for each part. However, changes in the mix of products are easy to perform once the changes are within the predefined and relatively narrow range. The workers decide what to produce next based on the number of kanban tickets no matter whether it is the same as the one just made or not. In general, one of the assumptions of Kanban systems is to have short set-up times what helps to achieve mix response flexibility.

Volume flexibility - Although some excess capacity is often a feature of JIT manufacturing management philosophy, the volume range flexibility of Kanban systems seems to be more a matter of having excess process capacity (or ability to provide capacity via extra shifts or overtime) than a matter of the system's ability to deal with changes. Large increases in the overall production volume can cause a problem in the supply of materials and components, though. If the supplier chain is integrated with the Kanban system, once more it is a matter of the ability of the suppliers to provide extra

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[2]See Schomberger (1982) for a detailed discussion on Kanban system.

capacity. If they are not integrated the suppliers ability to make quick increments in the supply volume will bound the volume range flexibility of the Kanban system.

Delivery flexibility - To anticipate orders delivery dates may mean giving some orders priority. Nevertheless, in Kanban systems the dispatching system is not centralized so it is not straight forward to inform the whole plant or even only the operations through which the very important order will pass in order to give it priority. Priority in Kanban systems is based on local need and changing it is not very easy. Kanban requires frozen and reliable schedules for a considerable period ahead, varying from weeks to months, according to the particular system, what seems to be a serious restriction to large delivery date anticipation. Kanban systems cope badly with delivery date changes partly because Kanban systems alone has no simulation capability. Furthermore, such changes are directly contrary to JIT philosophy.

The MRP II System - MRP II allows the calculation - normally using a computer - of the precise quantities and moments on which the materials are required, in order that the product delivery due dates are met, with minimum build up of stocks. The system uses an extensive data base, which includes purchase and manufacturing lead-times for every part, detailed product structures, resource utilization for each part, among others (Vollmann et. al., 1988).

The following section is a brief analysis of the performance of MRP II systems in terms of manufacturing system's flexibility.

MRP II and Flexibility

New product flexibility - MRP II systems deal well and quickly with introduction of new products and modifications of existing ones. In general it is only necessary to include the new product structure, possible new parts and new process routines when the product is being developed. From then on, the system will issue orders concerning the new products exactly in the same way it issues orders for current products. Some attributes of the new products nevertheless have to be assumed such as the parts lead times with a risk of assuming lead times which are not real and therefore some problems could arise regarding the system performance.

Mix flexibility - Major mix changes are as easy to perform as minor mix changes when the system regenerates the schedule. A problem which can arise with big mix changes is that when the mix changes substantially, the queues of the system are likely to change accordingly. When the queues change, the lead times possibly change. In general authors, e.g. Vollmann et. al. (1988) consider that data accuracy is of paramount importance for MRP II systems to work properly. Poor data means that the system's performance deteriorates.

Volume flexibility - It seems to be a matter of having extra process capacity or ability to provide it rather than a matter of the system's capability to deal with volume flexibility. Operationally MRP II deals well with volume changes. But when demand nears capacity a problem may arise since it does not consider capacity constraints while generating the schedule. Other modules of the software package can do the check comparing the capacity to the utilization which results from the schedule. That means that sometimes the current plan cannot be performed because there is not sufficient available capacity. The system does not help the planner with this decision, i.e. **how** to change the plan. Its results are thus dependent on the particular ability and experience of the planner.

Delivery flexibility - Changes in due dates are easy to perform in MRP II systems, when time fences are respected. If the new delivery time violates the time fences, requiring expediting of purchasing or production orders, the main MRP II software systems still can support them by allowing for lead-time changes for particular orders. Nevertheless, when utilization nears capacity and priority is given to an order, other orders will obviously have to be delayed. The decision about the changes in other order's dates is totally dependent on the planner. The support the system provides is only at the descriptive level and at a certain extent it can work as a simulating tool, helping test the effect of changes in order's dates.

The OPT System - OPT is still a proprietary method. It is a method which, like MRP II systems, uses an extensive data base requiring a considerable capacity of data processing. It is however intrinsically different from MRP II in the way it organizes and uses information. MRP II is an infinite scheduling technique, in the sense that it does not take into account the capacity constraints of the resources while scheduling. OPT, on the other hand, is a finite capacity scheduling technique. Also according to OPT principles, bottlenecks are resources which should be treated on a special way in the plant. Everything possible should be provided to enhance the capacity of these resources (Goldratt, 1988). On the other hand, non constraint resources can be treated on a less precise way.

OPT and Flexibility

New product flexibility - As MRP II, OPT seems to deal well with the introduction of new products. The new product structure and possible new parts should be entered to the system as well as the new routing and resource consumption. The system's response to the introduction of new products is good. It is a matter of typing in the new information about the new structure possible new parts and their attributes and new routing. The lead times however do not have to be assumed in advance because in OPT lead times are a result of the process of scheduling rather than an input of the system.

Mix flexibility - In terms of day-to-day operations changes in the mix are dealt well and easily by OPT no matter the magnitude of the change. It is only a matter of changing the demand records and run the system. As the lead times are a result of the process of scheduling rather than an input, unlike MRP II, the possible changes in lead times should not affect the system's performance. The problem which can actually arise is in case of substantial changes in the mix which make the capacity constraints to change. Periodically, the system has to be monitored to make sure that the system "knows" what resources are the bottlenecks.

Volume range flexibility - Big volume changes can affect queuing times which in turn affect lead times. In OPT the system simulates the production process and finds out the new queue times. It seems that OPT deals well with volume changes no matter whether they are small or big, once again being a matter of the process' capacity.

Delivery flexibility - Delivery due date changes do not seem to be a problem for OPT systems. Actually, anticipation means priority to the anticipated orders. In OPT everything is dictated by the bottleneck. Giving priorities to orders in the bottleneck is giving priority to them in the whole system. The bottlenecks are sequenced based on due dates and other considerations, therefore an anticipation in the due dates is directly reflected in the order issues at the plant level. Summarizing, let us try to compare the flexibility characteristics of the 3 MPC systems using the Figure 3.6.

	Kanban/JIT	MRP II	OPT
product range	low	med-high	high
product response	med-high	med	med
mix range	low-med	med	med
mix response	high	high	high
volume range	med	med	high
volume response	high	high	high
delivery range	low	high	high
delivery response	low-med	high	high
decision level	operation	system	system

high=high flexibility
med=medium flexibility
low=low flexibility

Figure 3.6 - The flexibility of 3 selected MPC systems.

Immediate supply network management

The issue here is the customer-supplier relationship with which the company has to deal directly. According to Slack (1991), for most industries - mainly the ones subject to fierce competition - these relationships have changed substantially over the last decade. Traditional customer-supplier relationships based on arms length, price based, involvement broke down by competition and recession. What would have emerged is the idea of "partnership" with suppliers, based on openness, trust, shared destiny and long-term development with fewer suppliers, simpler networks and a "richer" relationship This view is shared by a number of authors (Womack et. al., 1990; Schonberger, 1990). Slack (1991) sees the new model as advantageous for the organization's flexibility, since it will mean integrated activities where longer term development is achieved through integrating expertise and closer matching between supplier and customer output levels.

Schonberger (1986, 1990) also sees advantages in the emerging model of customer-supplier relationship, but mainly in terms of reliability, quality and cost, not mentioning explicitly flexibility. Womack et. al. (1990) also do not mention explicitly the advantage of the new relationship in terms of mix or delivery flexibility, for example, but they do mention the closer relationship as one of the reasons why lean manufacturers are more flexible in introducing and changing products.

Hayes and Wheelwright (1984) see the Japanese companies and their suppliers as able to respond quickly to product mix changes and to the introduction of new products, but mainly because of the shorter production cycle times of both customer and supplier companies, developed in cooperation and not specifically because of the new model of relationship.

3.4.3. The Flexibility of Infrastructural Resources - Conclusion

Few authors have analyzed specifically the flexibility of infrastructural resources. The literature signalizes to some aspects with regard to infrastructural resources which seem to be of relevance for the flexibility of the manufacturing systems: manufacturing planning and control systems, supply systems and organization structuring issues.

In terms of organization structuring issues, some aspects are highlighted by the literature as important for the development of manufacturing systems flexibility: in order to achieve higher levels of flexibility, organizations should pursue structures with more flexible job definitions, less hierarchical structures and effective inter-functional "project teams" or task forces. One concept which seems to gain importance in the achievement of flexibility is the emphasis on team work as opposed as individual.

In terms of manufacturing planning and control systems, the recent literature has focused on three basic systems: MRP II, JIT and OPT, although few authors analyzed the flexibility aspects of them.

These three MPC systems are more flexible and similar in terms of response than in terms of range flexibility. It means that it seems to be easier to choose between systems when the main criterion is range flexibility.

Generally speaking, OPT seems to have the best flexibility performance of the control systems analyzed. Kanban is always less or equally flexible than any other. MRP II appears to have a flexibility performance which is in an intermediate position between Kanban and JIT. The most discriminating flexibility types are product flexibility (Kanban is less flexible than the others) and delivery flexibility (Kanban is less flexible than OPT and MRP II). With regard to volume and mix flexibilities none of the systems analyzed seems to be clearly better or worse than the others.

It is interesting to note that there seems to be a correlation between the general level of system flexibility and the degree of centralization of the decision making process of the control systems. The dominant decision making level of Kanban/JIT is the operation. OPT and MRP II, on the other hand, make decisions mainly at the system level using large data bases. It seems that the more centralized the decision making (toward the system level) the more system flexibility the control system is able to provide. If it is possible for the system to handle information on all the orders and operations simultaneously it can more easily change priorities, routes, orders (in quantity, date etc.) and so on, in terms of range. Within the pre specified range with which the system can cope, there seems to be no clear difference between the performances of the centralized and decentralized systems in terms of response flexibility. This analysis however still lack further empirical support.

The analysis of the flexibility of MPC systems seems to suggest that contingency models can be developed associating levels of flexibility needed, for instance, and the adequate type of MPC system. Certainly more research work is needed in the field.

In terms of the supply systems, for most industries, the relationship customer-supplier have changed substantially. The idea of "partnership" emerged from competition and recession replacing traditional relationships based on arms length and price-based involvement. This tendency, according to a number of authors, seems to favour the development of more flexible manufacturing systems in terms of its supplies.

Chapter 4 - Uncertainty in Manufacturing Systems

The objective of chapter 4 is to discuss the views found in the literature with regard to uncertainty affecting manufacturing systems.

Initially, the concept of uncertainty is discussed and an important issue is addressed: is uncertainty an objective or a perceived category?

A discussion follows on the methods of assessing uncertainty found in the literature, with regard to both approaches: perceptual and objective.

The implications of the current literature for this research are also discussed.

Chapter 4

Uncertainty in Manufacturing Systems

4.1. Concepts

Environmental uncertainty is one of the main reasons for a firm to seek Flexibility (Swamidass and Newell, 1987; Gerwin ,1986; Slack, 1989)

Uncertainty is a term which is used daily in a variety of ways. This everyday acquaintance with uncertainty can be seductive in that it is all too easy to assume that one knows what he is talking about. However, the concept of uncertainty which is necessary in developing useful tools in order to better cope with it has not been a consensus among the authors who have dealt with this complex and important subject. Gifford et. al. (1979) reviewing the literature on uncertainty, identifies considerable diversity in the terminology used by various authors, but they found two general concepts which characterize the various approaches - information load and pattern/randomness.

The first, information load, is related to the complexity of the decision situation. The second general category of uncertainty concepts has at its core the distinction between patterns and randomness of events or cues. The classical definition of risk as the ability to assign probabilities to outcomes and of uncertainty as the inability to assign these probabilities (Luce and Raiffa, 1957), according to the authors, is based on differing perceptions of the existence of orderly relationships or patterns. The two concepts are not necessarily independent. Considered together, these two concepts imply that uncertainty will be low if data are available at the time needed and if the decision maker discerns a pattern of regularity among the cues that makes the data become useful information.

Lawrence and Lorsch (1969) suggest that environmental uncertainty is composed of three elements: lack of clarity of information, general uncertainty of causal relationships between decisions and the correspondent results, and time span of feedback about results of the decision made. All the uncertainty elements seem to refer to information which could help predict future events and/or trends. It is important to notice that even high coefficients of variation of the future events and trends do not necessarily indicate that the firm cannot predict them. It is the deviation from the expected which is important in regard to uncertainty and not the size of the range of events or the trend itself (Downey et. al., 1975).[1]

However, the existence or non existence of information itself, resulting from stimuli from the environment, is not the only factor to influence the level of uncertainty under which an organization operates. The set of stimuli lacks meaning or information value until it is perceived by an individual. Perception refers to the process by which individuals organize and evaluate stimuli (Secord and Backman, 1964). According to Huff (1978) the more one considers the notion of relative definitions of reality, individual values and experimental learning, the more important it is to look at the **respondent** to uncertain environments.

This is a very important point because it represents a controversial subject in the literature: is uncertainty perceived or objective?

4.2. Uncertainty: Perceptual vs. Objective

Some authors propose objective measures for uncertainty based on physical attributes of the environment such as technological factors, number of product changes or research and development expenditures as indexes of uncertainty. However, depending on the previous level of knowledge of the individual and his cognitive process, the same set of stimuli from the environment can foster different levels of perceived uncertainty in different individuals. This is the reason why certain entrepreneurs can predict, for instance, the market behaviour more accurately than others (many times, based on similar data), and therefore work under less uncertainty. What is certain to one person is uncertain to another (Huff, 1978). Environments, therefore are neither certain nor uncertain but are simply perceived differently by different organizations (Perrow, 1967).

Restriction of uncertainty to a perceptual concept does contain the inherent problem that some variations in perceived uncertainty are related to characteristics of the individual. It does not, however, preclude the expectation that uncertainty also is related to certain environmental attributes. In this sense, Downey et. al. (1975) argue that specific attributes of physical environments tend to elicit similar perceptions of uncertainty by individuals. However, according to the authors, these similar perceptions of uncertainty

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[1] This is one of the reasons why in this research work, uncertainty is treated explicitly separated from variability.

by individuals stem from similarities in individual perceptual processes rather than from the existence of uncertainty as an attribute of the physical environment . Downey and Slocum (1975) propose that perceived uncertainty can be expected to vary with: *Perceived characteristics of the environment, Individual differences in cognitive processes, Individual behavioural responses repertoires, and, Social expectations for the perception of uncertainty.*

Perceived characteristics of the environment - Duncan (1972) tried to establish relationships between the managers' perceptions of uncertainty and some characteristics of the environment. He characterized environments along two dimensions - *complexity* and *dynamism* which he defines as follows. *A dynamic environment* is one in which the relevant factors for decision making are in a constant state of change. *A complex environment* is one in which the number of interactive relationships relevant for decision making require a high degree of abstraction in order to produce manageable mappings by the individual.

Assuming that the perception of complexity/dynamism in the environment can be expected to be positively related to the perception of uncertainty, Duncan developed an instrument to measure environmental uncertainty and concluded that individuals in decision units with dynamic-complex environments experience the greatest amount of uncertainty in decision making and that the static/dynamic dimension of the environment is more important contributor to uncertainty than the simple/complex dimension.

Individual cognitive process - Different individuals process stimuli from the environment in different ways. Duncan (1972) suggests for example, that individuals with a tolerance for ambiguity may perceive situations as less uncertain than do individuals with lower tolerances.

Behavioural response repertoire - The individual's capacity to display appropriate behavioural responses to given environmental characteristics. Such capacities do not include an individual's innate qualities such as those which might influence individual cognitive processes but rather capacities stemming from the individual's acquired experience. The basic proposition might be that a greater variety (not necessarily duration) of individual experience will increase the behavioural repertoire of the individual.

Social expectations - A socially learned component in the individual's tendency to perceive uncertainty. For example, the degree of discretion defined for a position might be considered as an indicator of the organization's expectation of that position regarding uncertainty. Stated differently, if an organization expects a position incumbent to display little discretion, it can be assumed that the organization also expects the occupant to perceive little uncertainty.

4.3. Measurement

Many authors have tried to develop ways in order to measure perceived uncertainty. Lawrence and Lorsch (1969) pioneered the effort developing a nine-item questionnaire designed to measure uncertainty in the three sub-environments of marketing, manufacturing and research within organizations: the respondent is asked three questions about each of the sub-environments. The response to each question is evaluated using a Likert-type scale[2]. The questions and response categories determine the extent to which each sub-environment is perceived as uncertain according to the following characteristics: *lack of clarity of information, general uncertainty of causal relations*, and *long time span for feedback of results.*

Tosi et. al. (1973) tested and analyzed the Lawrence and Lorsch's instrument. In general, the result of the analysis did not reflect favourably in Lawrence and Lorsch's instrument. Replying the criticism in a later article, Lawrence and Lorsch, although regretting not being enthusiastic about the contributions of Tosi et. al.'s article, admit that there remains a need for methodological improvements in characterizing and measuring the environmental uncertainty of organizations.

Duncan (1972) tried to develop another instrument seeking to measure uncertainty on the basis of three characteristics:

a) the lack of information regarding environmental factors associated with decision making situations.

b) the lack of knowledge about the organizational consequences of a decision if the decision is incorrect.

c) the ability or inability to assign probabilities as to the effect of environmental factors on the success or failure of the organization performing its function.

The first dimension, lack of information regarding environmental factors, is measured by six Likert-type questionnaire items. The second characteristic, lack of knowledge about the organizational consequences of a specific decision in case that it is incorrect is

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[2] See chapter 7, footnote 3 for a brief description of Likert-type scales.

measured by another five Likert-type questionnaire items. The last part is measured by a single two part questionnaire items.

Each of the parts is scored in a specific way and the scores on the three characteristics are summed up to derive a total uncertainty score.

Downey, Hellriegel and Slocum (1975) studied 51 managers of a U.S. conglomerate in order to examine the conceptual and methodological adequacy of Duncan's and Lawrence and Lorsch's uncertainty scales.

Both methodologies were applied, compared and confronted with some criterion uncertainty measures. The principal findings of the author were:

First, there appear to be a lack of commonality between the two uncertainty scales which were presumably designed to measure a similar, if not the same, concept.

Second, the total uncertainty scales did not correlate highly with any one of the 4 criteria uncertainty measures except for one. Some reasons are pointed out for the lack of correlation, the principal of them being:

- The uncertainty sub-scales may not meaningfully lead to a total uncertainty scale caused, for example, by inappropriate conceptualization of the uncertainty multidimensionality.

- The criterion uncertainty measures may not be appropriate indicators of perceived environmental attributes.

- The relationship between specific behavioural environmental elements and specific characteristics which are usually considered as uncertainty sub-dimensions may be better understood than relationships between the global concepts of environment and uncertainty.

The authors add that if the latter reason is accepted, the analyzed instrument is of little explanatory or predictive value and should be restricted to more pedagogical purposes. Downey, Hellriegel and Slocum (1975) suggest, that considerable care should be exercised in selecting existing instruments for uncertainty measurement. The researcher should be sure that the uncertainty concept implicit in the selected instrument is consistent with the uncertainty conceptualization, either implicit or explicit, which is guiding the research.

4.4. Set-backs of Perceptual-Based Measurements

When considering perceptive measures - as opposed as objective ones - one should be aware of some of the mechanisms people generally use to make judgement under uncertainty. Tversky and Kahnemen (1989) analyzed the way people make judgement under uncertainty and showed that when trying to assess the probability of an uncertain event or the value of an uncertain quantity people rely on a limited number of heuristic principles which reduce the complex task of assessing probabilities and predicting values to simpler judgmental operations. These heuristics, although generally quite useful, can sometimes lead to severe and systematic errors.

4.5. Conclusion

Considerable diversity can be found in the literature in the terminology used with regard to uncertainty.

One of the most controversial points in the literature is the discussion whether uncertainty is a perceived category or an objective one. Some authors propose objective measures for uncertainty, which are based on attributes of the environment as indexes of uncertainty. However, it is argued in the literature that depending on the previous level of knowledge of the individual and his cognitive process, the same set of stimuli from the environment can foster different levels of perceived uncertainty in different individuals. According to this view, the set of stimuli lacks meaning or information value until it is perceived by an individual.

It seems to be reasonable to assume that uncertainty should be considered a perceptive rather than an objective category for the purposes of this research work for some reasons:

First, a lack of correspondence between publicly available objective indicators of environmental change and managers' reports of perceived uncertainty has been noticed (Gifford et. al., 1979).

Second, the environmental changes represent stimuli which are the cues or messages that are potentially available to the decision makers. In laboratory situations the term objective uncertainty is useful in describing stimulus conditions that are under control of the experimenter, such as the stated probability of winning a gamble. Outside of a carefully controlled laboratory situation, the nature of the cues used by decision makers cannot be easily specified, and there appears to be little value in the use of the term objective uncertainty (Gifford et. al., 1979).

Environmental uncertainty is seen by a number of authors in the literature (Swamidass, 1987; Gerwin, 1986; Slack, 1989; among others) as one of the main reasons for a firm to seek flexibility. However, few of them have actually delved into a detailed discussion on the relationship between, for instance, different types of uncertainty and different types of flexibility. Some of these authors seem to avoid discussing uncertainty in more detail, maybe because of the difficulties involved in dealing with such complex category. In fact, the Organizational Behaviour theorists, who seem to be responsible for most of the research on the environmental uncertainty categorisation and measurement produced results of little use for the manufacturing management field.

As a result, surprisingly, in an increasingly turbulent environment such as today's competitive market, little research work can be found in the literature on manufacturing management, which considers environmental uncertainty explicitly. Certainly, more research work is needed in the area.

In terms of the objectives of this research and for the sake of simplicity, the most appropriate approach seems to be that of Gifford (1979). According to this author, considered globally, uncertainty will be low if data are available at the time needed and if the decision maker discerns a pattern of regularity among the cues that make the data become useful information in order to *predict* future events or trends. The idea of uncertainty, according to this view is broadly associated with that of *predictability*. Predictability seems to be a concept which is less controversial than uncertainty and also closer to the jargon normally used in industrial environments and therefore probably more easily understood by subjects in such environments during the eventual field work stage (see chapters 6 and 7 for further details on the field work methodology).

Chapter 5 - Variability in Manufacturing Systems

Chapter 5 discusses the second category which, as the literature suggests, is another reason for manufacturing systems to seek flexibility: the variability of the outputs.

The benefits and also the costs which are incurred by a manufacturing system which pretends to provide high levels of variability to its customers are discussed, based on the literature. The reasons for product proliferation are also discussed and an important reference on marketing is analyzed and criticized because of its partial view of the problem.

Chapter 5

Variability in Manufacturing Systems

When analyzing the variability of outputs of manufacturing systems, at least two different dimensions can be envisaged: one is the actual variety of outputs which refers to the range of different products the system produces, and the other one is the variation of the system's outputs along the time, not only in terms of how the range of products varies (e.g. product introductions or changes and, breadth of the product range) but also in terms of how the volume - aggregate and per product, the mix and the timing of the demanded output vary along the time.

5.1. The Costs of Variability

The costs of an organization are in general very sensitive to the amount of variety. According to Miller (1988), the cost of variety is greater than the accounting system reports it to be. Variety would create a cost burden throughout the company:

-The purchasing department, the materials management, the vendor control and assessment, the incoming inspection, and the stock of incoming materials.

-The production lines, which can not get up to speed to establish learning curve rhythms or obtain dedicated machinery to optimize the runs.

-The quality assurance function which must develop separate standards and procedures for different processes and products.

-The increased investment required for both process and finished inventories.

-The warehousing operations and the distribution systems which have to hold higher levels of inventory.

-The administrative functions and systems support, which must develop complex and detailed accounting procedures to track separated batches.

Although it is arguable that all the mentioned costs would increase with product variety, mainly considering the new flexible technology, it is clear that some of them would.

Let us draw from Stalk and Hout (1990) and imagine the simplest of organizations - an organization which manufactures only one product for only one customer at constant quantities. One product made day in and day out. This factory would probably be very simple to manage. Since there would be no changeover, production time lost to set-up would be negligible. Since there would be only one product, each step of the process would have matched capacities and be operated in unison. Quality costs would probably be low, since the process would remain unchanged and the quality problems would have been worked out. Inventories would probably be very low since purchased items could be brought in regularly, work-in-process kept to a minimum, and finished goods shipped immediately to the customer. Management costs would be low because everything would be almost perfectly stable. Womack et. al. (1990), when describing Ford Model T factories, provide a good illustration of this point:

> "Ford dramatically reduced set-up time by making machines that could do only one task at a time. Then his engineers perfected simple jigs and fixtures for holding the work piece in this dedicated machine. The unskilled workers could simply snap the piece in place and push a button or pull a lever for the machine perform the required task. This meant the machine could be loaded and unloaded by an employee with five minutes' training. (Indeed loading Ford's machines was exactly like assembling parts in the assembly line: The parts would fit only one way, and the worker just popped them on).
>
> In addition, because Ford made only one product, he could place his machines in a sequence so that each manufacturing step led immediately to the next. Many visitors to Highland Park felt that Ford's factory was really one vast machine with each production step tightly linked to the next. Because set-up times were reduced from minutes - or even hours - to seconds, Ford could get much higher volume from the same number of machines. Even more important, the engineers also found a way to machine many parts at once. The only penalty with this system was inflexibility. Changing these dedicated machines to do a new task was time consuming and expensive."[1]

[1] The Ford's case is illustrative, although we have to consider that nowadays the car manufacturers are under a completely different technological paradigm. Toyota Takaoka factory today, for instance, is able to change over in a few days from one type of vehicle to the next generation of products while Highland Park was closed for months in 1927 when Ford switched from the Model T to the new model A.

Unfortunately, all this start changing with the introduction of additional products to satisfy additional customer needs (this transition, it is some times arguably advocated, cost Ford its leading position in car manufacturing to General Motors). It is difficult to maintain production of a single product at a constant rate when demand for the others must also be satisfied. Production schedules for each of the products now must be created and managed. Now there will be changeovers that require both scheduling and people to manage them because different products share and compete for the same facilities. Time will be lost to set-up. Quality will probably become more expensive, since with each changeover, the process has to be brought into tolerance. Additional process steps are likely to be required. Because it is much more difficult to match the capacities of each step of the process, it is very unlikely that the processes can be operated in unison. Inventories also will now be more difficult to manage. A greater variety of purchased items will be needed to be handled - in what is now an irregular pattern - to meet the production schedules. Work-in-process inventories are expected to increase as inventories are built up to enable the many parts of the process to continue operating. Finished goods inventories will possibly increase because while one product is being manufactured, stocks of other products have to be maintained to satisfy the demand for them. Customer priorities must be weighed against the priorities for smooth operation of the factory. As a consequence, the process is rarely in balance. In this factory almost nothing is perfectly stable and even predictable. So management costs are going to be much higher than those of the factory that manufactures only one product for only one customer. (Stalk and Hout, 1990).

Blackburn and Millen (1986), also referring to the findings of George Stalk in a previous study, reports "tremendous impact of increased products and processes variety on indirect costs or overhead which includes costs with schedulers, expediters, inventory trackers, space requirements, set-up personnel and so on. These people and systems have been introduced because of the complexity caused by multiple products, parts, process sequences and tasks." In an example referring to a lift truck manufacturing plant in Japan, an increase of approximately 30% in the overhead/unit cost was reported for every time the number of product families produced doubled (within a range between 6 and 20 families).

The disadvantage of excessive variability is also behind Skinner's (1974) concept of focused factory: "A factory that focuses on a narrow product mix for a particular market niche will outperform the conventional plant, which attempts a broader mission.

Because its equipment, supporting systems, and procedures can concentrate on a limited task for one set of customers, its cost and especially its overheads are likely to be lower than those of the conventional plant ... (which) ... attempt a complex, heterogeneous mixture of general and special purpose equipment, long and short run operations, high and low tolerances, new and old products, off-the-shelf items and customer specials, stable and changing designs, markets with a reliable forecast and unpredictable ones, seasonal sales, short and long lead times, and high and low skills. That each of the contrasting features generally demands conflicting manufacturing tasks and hence different manufacturing policies is typically not well understood. One of the rationales for the decision of adding new products into the existing mix in the same plant is usually that the plant is operating at less than full capacity. Thus the logic is: "If we put the new product into the present plant, we can save capital investment and avoid duplicating overheads". The result, according to Skinner, is complexity, confusion, and worst of all a production organization which because it is spun out in all directions by a kind of centrifugal force, lacks focus and a "doable" manufacturing task. Skinner argues that focus (as opposed as indiscriminate variability) not only provides punch and power; it also provides clear goals that can be readily understood and assimilated by members of an organization. It also provides a mechanism for reappraising what is needed for success. Excess variability of outputs would not only jeopardize cost efficiency but more broadly speaking, competitiveness.

One implicit assumption present in the aforementioned points is the trade-off - a relationship in which any increase in variety implies a reduction in cost efficiency. The trade-off was formalized in the 70's by Skinner (1974) although in recent years it has been questioned since some world class companies are evidently successful in improving in all fronts. Slack (1990a) proposes a different view of the trade-offs between variety and cost efficiency. He proposes that flexibility is the pivot which determines the relative state of, on one hand, the various types of variety, and on the other, the cost efficiency of the operation. The more flexibility, then, an operation has or develops, the closer the pivot gets to the cost-end of the seesaw. Therefore, more variety would be traded-off by less cost-effectiveness reduction.

Slack also relates types of variety to types of flexibility which he considers appropriate to deal with them:

Variety types	Flexibility types
product variety	mix flexibility
new product introduction	product flexibility
output variation	volume flexibility
schedule/due date changes	delivery flexibility

Table 5.1 - Variety and corresponding flexibility types (Slack, 1990a)

So, according to Slack, flexibility is a way to achieve variability of outputs cost-effectively. The relationship variability-flexibility is further discussed in chapter 9.

5.2. The Reasons for Product and Parts Proliferation

Some reasons which favour the companies' decisions to increase the product and parts proliferation can be identified in the Literature:

The first reason is related to traditional cost accountancy system procedures. According to Johnson and Kaplan (1987), the practice of using direct labour rates to allocate overhead costs to products have caused, among other problems, the distortion of product costs and introduced unintended cross subsidies by shifting costs from less labour-intensive products to more labour intensive products. That would cause that products with relatively low direct labour content - e.g. low-volume, jobs that require special set-ups, handling and quality control - have their variable overhead costs (which some times vary with other drivers than labour) shifted onto products with high direct labour hours. Costs, therefore would be shifted from small-volume, frequent set-up jobs onto long-running, infrequent set-up standard products that require no special handling or attention. In this situation, the factory would, according to the authors, start to take on a broader product line (becoming a "full-line producer") which includes more low-volume products requiring frequent set-ups, and so on. Thus, the mature, high volume infrequent set-up, stable products become "more costly" as the firms expand its product line and offer special features. The mature products subsidize the firm's product proliferation activities through the aggregation and averaging effects of a direct labour cost allocation system.

The second reason for product proliferation is the pressure from marketing and sales functions in order to have a broader or more complete range of products to offer to the customer (this issue is further discussed in section 5.3. "The Benefits of Product Variety").

A third reason can still be identified and is related to parts rather than product proliferation. According to Neal and Leonard (1982), designers are expected to produce part designs which are simple, interchangeable and easy to manufacture. However, possibly caused by indecisive management pressure, lack of status, time, information or training, they attempt a design solution which is new and interesting but which tends to be non-standard and complex.

5.3. The Benefits of Product Variety

The benefits of variety are generally linked to the market. According to Womack et. al. (1990), companies that have mastered lean design[2] are taking advantage of their strength in the market place, offering a wider variety of products and replacing them more frequently than the competitors. The authors suggest that is one of the reasons for the successful performance of the Japanese auto industry across the world in the 1980's.

Given that the advantages of product variety are linked to the market, let us try to understand how the Marketing function regards product lines management by analyzing how a widely adopted Marketing textbook (Kotler, 1991) approaches the issue.

Kotler defines *product mix* as "the set of all products and items that a particular seller offers for sale to the buyers". A product mix would have a certain breadth, length, depth and consistency. The breadth refers to how many different product lines the company carries. The length refers to its total number of items and the depth refers to how many variants are offered of each product in each line. Consistency of the product mix refers to how closely related the various product lines are in end use, production requirements, distribution channels, or some other way. These 4 dimensions of the product mix would then support the company's strategic planners' decisions in defining the company's product strategy. The company, according to Kotler, can expand its business in 4 ways: adding new product lines or broadening its product mix; lengthening each product line with more products per line; deepening its product mix, with more variants per product and, altering (increasing or reducing) the product-line consistency, depending upon

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[2] The wasteless agile design and development method that successful Japanese and western companies are using which is based on a strong leadership, emphasis in team-work, effective communication and simultaneous (as opposed as sequential) development of the various design and development phases and which allowed such lean companies to shorten substantially the time and amount of resources spent in launching a new product.

whether it wants to acquire a strong reputation in a single field or participate in several fields.

A *product line* is defined as "a group of products that are closely related because they perform a similar function, are sold to the same customer groups, are marketed through the same channels, or make up a particular price range" (Kotler, 1991)

In order to decide about product line issues, according to Kotler, managers need two types of information. First they must know the sales and profits of each item in the line. Second they must know how their product lines compare with competitors' product lines. A high concentration of sales in a few items is considered as "line vulnerability" and these items should be closely monitored and controlled. On the other hand, the manager could also consider dropping the slow-selling (items representing a low percentage of sales and profits) items from the line. The importance that cost accounting practices have in this kind of decision and the risk of using inappropriate cost accountancy procedures were stressed in the last section.

In deciding about length, the issue would be influenced by company objectives. Companies seeking high market share and market growth will carry longer lines. They are less concerned when some items fail to contribute to profits. Companies that emphasize high profitability will carry shorter lines consisting of carefully chosen items. Kotler (1991) goes on saying that product lines tend to lengthen over time and that excess manufacturing capacity puts pressure on the product line manager to develop new items and also the sales force pressures for a more complete product line to satisfy their customers. This "line-stretching" can happen upwards (towards the more sophisticated end of the market), downwards (towards the less sophisticated end of the market) and two ways. There is also the possibility of line-filling, which is the line lengthening by adding more items within the present range of the line. Line modernization and product featuring are other reasons for introducing new products. According to Kotler, the two reasons for a company to eliminate products are when the product line includes "deadwood" that is depressing profits and when the company is short of production capacity.

Another way of generating product-line variety is through packaging. Physical products require packaging decisions to create such benefits as protection, economy, convenience, and promotion.

In terms of manufacturing operations, not always the variety of different final products is directly translated in additional parts, product routes and so on because many different products use common parts. On the other hand, small differences in terms of marketing, such as packaging, can represent different processes, machines, and so on, translating into large variety for manufacturing.

It is somewhat preoccupying that such a broadly adopted and referenced Marketing text book, in its 7th edition, published in 1991, still makes such little reference to manufacturing issues when discussing the company's product line-related decisions. Kotler (1991) still almost completely ignores the issues raised by a number of authors (Skinner, 1985; Hayes and Wheelwright, 1984; Hill, 1985; among others) regarding the need for a closer relationship Marketing-Manufacturing in deciding matters such as product line stretching, deepening, and so on. It does not seem to be advisable that companies nowadays adopt such a top-down approach for strategy designing, leaving little space for the bottom-up, proactive role which the other functions (including manufacturing) should have. The consideration of the manufacturing current and potential abilities, for instance, considered by a number of authors as crucial for a good decision making on product line managing is not mentioned in the whole chapter on "Managing Product Lines, Brands and Packaging" of Kotler's (1991) book. Focusing is not mentioned, either, as a reason for product-line breadth reduction, although a number of examples can be mentioned of companies which set up policies in order to reduce variety and increase focus. Variety is still justified by Kotler in terms of increasing excess capacity utilization, disregarding the now broadly accepted fact that badly utilizing a resource can be even worse for the company's competitiveness than not utilizing a resource (Skinner, 1974; Goldratt, 1988).

Despite these flaws, possibly still due to a lack of effective communication and understanding among different company's functions, Kotler's approach to product variety was included in this review because it reflects the way a number of companies still approach the problem. It is intended, therefore to highlight once again the problem represented by the inter-functional communication barriers within the organization.

5.4. Conclusion

At least two different dimensions can be envisaged when analyzing variability of outputs: one is the actual variety of outputs which refers to the range of different products which the system produces, and the other one is the variation of the system's outputs along the time.

The costs of an organization are in general very sensitive to the amount of variety. Excess variety generally causes impact on indirect costs or overhead which includes costs with schedulers, expediters, inventory trackers, among other people and systems, introduced because of the complexity caused by multiple products, parts, process sequences and tasks. According to Slack (1990a), flexibility is a way to achieve variability of outputs cost-effectively.

The main causes of product proliferation mentioned in the literature are: the traditional cost accountancy system procedures, which favours the proliferation of products, and the pressure from marketing and sales functions which tend to try to have a broader or more complete range of products to offer to the customer. The benefits of variety are generally linked to offering more alternatives to the market.

Variety of outputs (both of products and of volumes) is regarded by a number of authors (Slack, 1989; Stecke and Raman, 1986; Zelenovic, 1982, Goldhar and Jelinek, 1983) as one of the main reason for an organization to seek manufacturing flexibility. As today's and future markets appear to become increasingly segmented, and at the same time, the product life cycles tend to be shorter, the ability to produce a highly variable output tends to become an increasingly important competitive feature for manufacturing companies. However, excessive or unnecessary variety should be avoided in order to help keep manufacturing focus and also because, as discussed earlier in this chapter, variety unvariably causes increasing costs and organizational disruption. A flexible system can, according to the literature, soften this negative effect of variety.

Part II - Methodology

Part II briefly reviews and highlights the most relevant points of part I - "Literature Review" and based on them, defines the research question and 6 research propositions in order to guide the development of this work. It also reviews the literature on research methods for organization studies, describes the selection process for the research method to be adopted and also describes the investigation procedure to be used. Part II consists of two chapters.

Chapter 6, "Methodology" initially describes the research question and the six research propositions for this research work, based on the literature reviewed in Part I. It also discusses the various possible macro approaches and research designs for research in organizational research found in the literature, defines criteria for the selection and describes the selection process for the research method to be used in this research.

Chapter 7, "Research Micro-Design", draws from the conclusions of chapter 6 and describes in detail the procedure to be used in order to design and perfect the research instrument, the number of cases-studies, the level of analysis and the research procedure used in the field work, which is described in part III.

Chapter 6 - Methodology

This chapter discusses the methodology used in this research.

It evaluates the two broad approaches to management research, qualitative and quantitative, and concludes that the qualitative general approach is the most appropriate for the objectives of the research described here.

The chapter also evaluates the most relevant alternatives of research design: experimental research, survey research, qualitative research / case study and active research and concludes that the "case study" design is the most adequate design for this research.

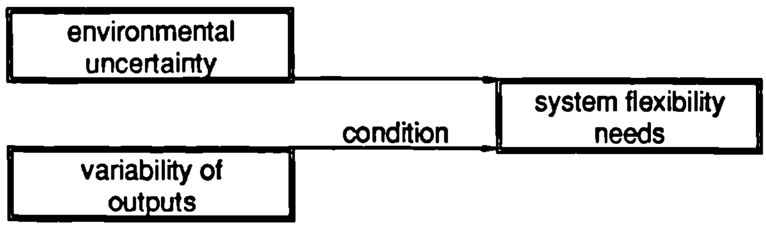
Three other important aspects are also discussed in this chapter: the organizational level of the analysis, the number of cases to be studied and the criteria for choosing the organizations to be studied in the research described here.

Chapter 6

Methodology

6.1 Overall Research Direction

Although a number of authors in the literature suggest that the environmental uncertainty and the variability of outputs are the main reasons for an organization to seek manufacturing flexibility, little empirically supported research work has been found which explored the mechanisms behind these relationships. Trying to fill this gap, the overall objective of this research is to understand and explore the relationships between "variability of outputs", "environmental uncertainty", and "flexibility of manufacturing systems". The attainment of such an objective involves exploring further some propositions drawn from the literature which suggest the following general model:

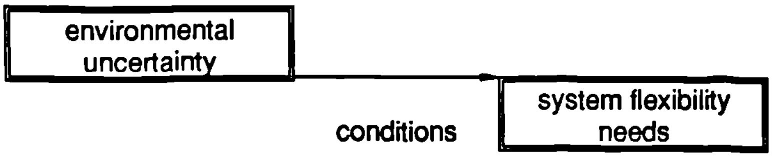


Whereas it is useful to establish a number of research questions from previous work, there are no formal hypotheses as such established *a priori*. Rather, the major aim of this research is to build theory by constructing a model which reflects, organizes and possibly expands the perception of managers themselves regarding the aforementioned variables and their relationships. However, establishing research questions will help to establish the basic starting point from which further analysis will follow.

As a first stage of describing the direction of this research it is necessary to return to the literature in this and related fields.

In general terms, the literature seems to recognize that there is a relationship between three of the categories involved in the manufacturing process: *variability of outputs*, *environmental uncertainty*, and *flexibility of the manufacturing systems*. Summarizing from Part I:

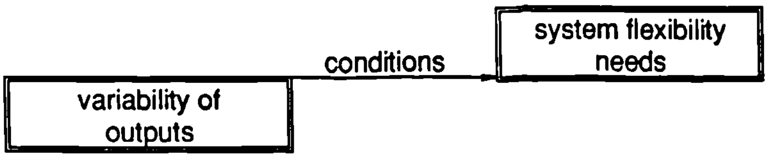
6.1.1. The Uncertainty - Flexibility Relationship



Swamidass (1986) develops a model incorporating the variables "environmental uncertainty" and "manufacturing flexibility", tests it empirically and, based on the results, states that "an organization may find at least some help in coping with the high uncertainties imposed by the environment by increasing its manufacturing flexibility". Gerwin (1986) argues that "social systems facing uncertainty utilize flexibility as an adaptive response"; going further, he suggests that since there are several kinds of uncertainty, there should be several kinds of corresponding flexibilities to cope with them. Gupta and Goyal (1989) suggest that manufacturing systems that are flexible can utilize flexibility as an adaptive response to unpredictable situations. Slack (1990a) also suggests that companies use flexibility to cope with short and long term uncertainties. Gerwin and Tarondeau (1989) take the analysis one step further by suggesting links between particular types of flexibility and different types of uncertainty, using Gerwin's (1986) classification.

Atkinson (1984) argues that companies seem to be trying to develop more flexible manpower structures to be able to cope more efficiently with uncertainties regarding the supply of Labour. Flexibility could also be developed as an "insurance" (Carter, 1986) against process short term uncertainty (Stecke and Raman, 1986). A more in depth discussion on the issues of *uncertainty* and *flexibility* can be found in chapters 4 and, 2 and 3 respectively.

6.1.2. The Variability-Flexibility Relationship.



Variability together with uncertainty has formed the rationale for the operation's interest in flexibility. Flexibility would allow, according to Gupta and Goyal (1989), the organization to change its competitive strategy from economies of scale to economies of scope (Goldhar and Jelinek, 1983): as set-up time decreases and small batch production can be as economical as large scale manufacturing. Flexible manufacturing systems are important, according to Muramatsu et. al. (1985), in order to be able to adapt to severe changes in the market. Gerwin (1986), Kumar (1987), Chambers (1990), Frazelle (1986) and Stecke and Raman (1986) also argue that the need for flexibility is increasing due to the changing nature of competition, which, nowadays, is based more than ever on the responsiveness of the companies to different customer requirements, shorter product life cycles and greater product proliferation. Slack (1990a) analyzes the links between types of variety and types of flexibility. For a further discussion on the concepts of *variability of outputs* and *manufacturing flexibility* see chapters 5 and, 2 and 3, respectively.

6.1.3. The Avoidance of the Need to Be Flexible

Although the point is not explored as much as one might have supposed given its implications, some authors suggest that flexibility is not necessarily desirable in all circumstances, given that flexibility would never come cheap (see for e.g. Slack, 1988). Slack (1991) also claims that organizations should not make their lives unnecessarily difficult by generating the need for flexibility internally, in order to cope with bad design, poor communication, lack of focus, excessive routing complexity and year-end spurs. Instead, they should try to eliminate the causes of such imperfections, by controlling the uncertainties and complexities involved in the process itself. This is in accordance with Slack's (1987) empirical findings according to which, "managers seek to limit the need to be flexible" by trying to compete on a non-flexible basis, adopting modular product design principles and by confining the need to be flexible to parts of the manufacturing system. With regard to the issue of controlling uncertainty, Thompson (1967) argues that organizations are open systems faced with uncertainty and ambiguity, yet require certainty and clarity to operate in a rational manner. Managers of the organization's technical core would therefore attempt to reduce uncertainty so as to maintain operational objectives.

6.2 General Comments on the Literature

Although the existence of some kind of relationship between the three concepts - *variability, uncertainty* and *flexibility* is recognized in the literature, further research is still required to provide both empirical support for these relationships and a greater understanding of the mechanisms driving them. If flexibility, for example, is the remedy to be used to deal with both variability and uncertainty, there may be an overall rationale behind this relationship, something that links both concepts uncertainty and variability. The same way, if it is true that managers tend to avoid having to be flexible, what are the ways they use to do so?

There seem to be a need for an overall theory, an overall rationale behind the aforementioned three concepts. This theory would help explain, analyze and make decisions with regard to flexibility, taking into account all the relevant variables involved rather than just one or some, treated in isolation. It is not clear in the literature, for instance, whether flexibilities of the same kind should be applied in dealing with variability and uncertainty or different flexibility types are prescribed, contingently.

There appears to be insufficient understanding not only of the relationships between factors, but also of the very way in which flexibility is understood and viewed in its contribution to manufacturing performance. This is evident from the number of papers which are still concerned with defining the concept and dimensions of manufacturing flexibility and trying to find physical analogies (such as the shock absorber model recently proposed by Slack, 1991) to explain it.

This research is an attempt to understand and investigate the above mentioned mechanisms further in an attempt to possibly build theory: a theory which accommodated the most relevant variables involved in the decision process with regard to flexibility and the different and segmented views found so far in the literature.

6.3 Overall Research Objectives

The objective of this research is primarily twofold:

Firstly, to try to answer the question: "How do managers regard the relationship between environmental uncertainty, variability of outputs and manufacturing flexibility?" by examining and, trying to falsify[1] some propositions which emerge from the literature (see chapters 2, 3, 4 and 5 for details) and are related to the research question. The propositions are listed below[2].

Proposition 1 - The variability of the manufacturing system outputs together with the uncertainties to which the manufacturing system is subject are factors which condition the companies to develop manufacturing flexibility (Slack, 1989) (Gerwin, 1986) (Gupta and Goyal, 1989).

Proposition 2 - Uncertainty and variability are dealt with by developing 4 types of flexibility at the system level: new product, mix, volume and delivery. (Slack, 1988).

Proposition 3 - Managers focus more on resource flexibility as opposed as system flexibility (Slack, 1987).

Proposition 4 - Different patterns of uncertainty and variability would call for different types of manufacturing flexibility (Gerwin and Tarondeau, 1989; Slack, 1987).

Proposition 5 - Managers would try to reduce the uncertainties to which their operations are subject (Thompson, 1967).

Proposition 6 - Managers seek to limit the need to be flexible (Slack, 1987) .

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1 In terms of testing hypothesis or propositions a very powerful concept comes from Karl Popper's work. Popper emphasizes the fact that no number of singular observation statements, however large, could logically entail an unrestricted general statement. If I observe that event A is attended by event on one occasion, it does not logically follow that it will be attended by it on any other occasion. Nor would it follow from two observations - nor from twenty nor from two thousand. If it happens often enough, said Hume, I may come to expect that the next A will be attended by B, but this fact is a fact of psychology, not of logic.... Even so, their degree of probability is raised by each confirming instance... This is known as the problem of induction: logically, according to Popper, scientific laws are unprovable. Popper's seminal achievement has been to offer an acceptable solution to the problem of induction. He begins by pointing to a logic asymetry between *verification* and *falsification*. To express it in terms of logical statements: although no number of observation statements reporting observations of white swans allows us logically to derive the universal statement "All swans are white", one single observation statement, reporting one single observation of a black swan, allows us logically to derive the statement "Not all the swans are white". In this important logical sense empirical generalizations, though not verifyable, are falsifyable. This means that scientific laws are testable in spite of being umprovable: they can be tested by systematic attempts to refute them. (Popper, 1990)

2The research propositions are not hypotheses which will be formally tested. Instead, they are an attempt to ensure that the research remains focused on the research problem and does not become overwhelmed by the data.

Secondly, to build theory, attempting to conceive a model which reflects, organizes and possibly expands the perception of the managers in order to help them analyze and understand issues concerning the relationships between *environmental uncertainty, variability of outputs* and *manufacturing flexibility*[3].

6.4 Criteria for the Choice of Research Method

The choice of method is particularly important in organizational research. It should ensure that it is possible to address the research problem in a valid way. The method selection should, at the very least, take the following criteria into account: the *adequacy for the concepts involved*, the *adequacy for the objectives of the research*, the *validity* and, the *reliability*.

6.4.1. Adequacy for the Concepts Involved

The categories, or tentative variables, with which the research is concerned, e.g. environmental uncertainty and manufacturing flexibility, are not concepts which have been sufficiently explored by the literature. For example, the terminology itself is not generally agreed upon (authors are still working on the definition of flexibility) - people use terms such as flexibility and uncertainty with several and some times different meanings. For that reason, the presence of the researcher during the data collection process is considered essential - therefore limiting the possible size of the sample - to clarify concepts and to ensure that the understanding of the concepts involved is consistent and precise across the samples' subjects.

Another characteristic of the categories involved is the difficulty researchers encounter, when trying to quantify them. For there are no commonly agreed upon objective measures of flexibility or uncertainty in the literature (see chapters 2 and 4 for a discussion on these matters). To cope with this difficulty, it is the manager's perception of such variables, rather than the objective measures of the variables, which should be

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[3] According to Eisenhardt (1988), contrary to popular thinking, one of the key features in theory building research is the initial definition of the research problem, at least in broad terms. Although no existing theories are in consideration in the present research and no formal hypothesis are being statistically tested, some *a priori* variables are considered, which are likely to be relevant in the theory building exercise. Miles (1979) also considers that research projects that pretend to come to the study with no assumptions, usually encounter much difficulty: the author believes that at least a rough working frame needs to be in place at or near the beginning of the fieldwork.

investigated. The method should therefore be able to accommodate a perceptual approach.

6.4.2. Adequacy for the Objectives of the Research

The precise confines of what could be found were not determined at the outset of this research. There was only a literature-based belief that correlations between the perception of uncertainty and the level of variability required and, the perception of the need for flexibility of the manufacturing system would be found to be positive. The identification of causal relationships between the categories is central to the present research work. The method chosen therefore, should also be able to allow for the building of theory regarding these causal relationships.

The main idea is not therefore to verify well established hypotheses but rather, to build theory. In this sense a deeper understanding of the functioning of the organization is needed, in order for the researcher to understand the subjects' perceptions and the decision making process regarding the variables involved.

6.4.3. Validity

There are three types of validity: *construct validity, internal validity* and, *external validity* (Bryman, 1989).

Construct validity - a method should establish correct operational measures for the concepts being studied to make sure that the information collected actually represent such concepts.

Internal validity - it is a concern only for causal and explanatory studies, where an investigator is trying to determine whether event x leads to event y. If the investigator incorrectly concludes that there is a causal relationship between x and y without knowing that some third factor - z - may actually have caused y, the research design has failed to deal with some threat to internal validity.

External validity - deals with the problem of knowing whether the findings of a study can be generalized beyond the immediate case study. This generalization can refer either to the theory involved (analytical generalization) or to the enumeration of the frequencies found (statistical generalization) (Yin, 1988).

6.4.4. Reliability

The objective here is to ensure that, if a later investigator followed the same procedures as described by an earlier investigator, *ceteris paribus,* the later investigator would arrive at the same findings and conclusions.

6.5 Macro Approaches for Research: Qualitative or Quantitative

The two general approaches of organizational research are, according to Bryman (1989): the quantitative approach and the qualitative approach.

6.5.1. Quantitative Approach to Organizational Research

This model of the research process closely resembles a "scientific" approach to the conduct of research. A term like "scientific" is inevitably vague and controversial, but in the minds of many researchers and writers on methodology it entails a commitment to a systematic approach to investigation, in which the collection of data and their detached analysis in relation to a previous formulated problem are the minimal ingredients. According to this model, the starting point for a study is a theory about some aspect of organizational functioning. A theory entails an attempt to formulate an explanation about some facet of reality. From this theory a specific hypothesis (or hypotheses) is (or are) formulated which will then be tested. This hypothesis should not only permit a test (albeit possibly a partial one) of the theory in question, but the results of the test irrespective of whether the findings sustain it or not, feed back into our stock of knowledge concerning the phenomenon being studied. It is the generation of the data used to test a hypothesis that in many respects constitutes the crux of the quantitative research process, reflecting a belief in the primacy of the systematically collected data (Bryman, 1989).

Hypotheses contain concepts which need to be measured in order for the hypotheses to be systematically tested. The process of translating concepts into measures is called operationalization.

These measures are treated as variables, that is, attributes on which people, organizations or whatever exhibit variability.

One of the preoccupations of quantitative research is the demonstration of causality, that is showing how things come to be the way they are. Experimental research more readily permits causal statements to be established, because of the considerable control that the researcher exerts over the settings being studied and because the researchers are able to directly manipulate the independent variables and observe their effects on the dependent variable. In survey research this facility is not present, thus causal relationships invariably have to be inferred. From the need for inference comes the general need for large samples in quantitative research.

Another preoccupation of quantitative research is generalization, that is the pursuit of findings which can be generalized beyond the confines of a specific investigation.

Finally, quantitative research exhibits a concern that investigation should be capable of replication. In other words, it should be possible for a researcher to employ the same procedures as those used on an earlier study to check the validity of the initial investigation's findings/conclusions. One of the reasons for the distrust of qualitative research among some proponents of quantitative research, is that the former does not readily permit replication.

An example of quantitative research in the context of this work would be to try to assess objectively the level of flexibility of a number of manufacturing systems using one of the objective measures for manufacturing flexibility (see chapter 2 for a discussion on the measurement of flexibility). One such measure would be that proposed by Chandra and Tombak (1990), a measure which is totally based on "hard" data, such as the "time required to process one unit of part i on machine k" or the "probability that machine k is operating at a given point in time" and so on. Questionnaires could be sent to a number of companies, or the researcher could go to the companies himself in order to obtain these data. Then, the level of "objective" flexibility could be calculated based on the ratios and calculations prescribed, and then correlated for instance with some other quantifiable factor, such as the number of different products the company produces. Although some methods have been proposed to objectively assess certain types of flexibility, very few empirical work or actual applications of the proposed methods are found in the Literature.

6.5.2. Qualitative Approach to Organizational Research

Since the early 1970s there has been considerable growth in interest in the approach to research that is referred to as "qualitative" and "interpretive".

"The label *qualitative methods* has no precise meaning in any of the social sciences. It is at best an umbrella term covering an array of interpretive techniques which 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". (Van Maanen, 1979)

It is tempting to distinguish between quantitative and qualitative research simply in terms of the presence or absence of quantification. This however would be misleading, since qualitative research is not averse to quantification as such and qualitative researchers can include some counting procedures in investigations. Similarly, quantitative researchers sometimes collect qualitative material for their investigations.

The most central characteristic of qualitative as opposed to quantitative research is its emphasis on the perspective of the individual being investigated. Quantitative research is propelled by a set of prior concerns, either deriving from theoretical issues or from a reading of the literature in a particular domain. Qualitative research, on the other hand, tends to eschew the notion that the investigator should be the source of what is relevant and important in relation to that domain. The qualitative researcher thus seeks to elicit what is important to individuals as well as their interpretations of the environment in which they work. The two most prominent methods of data collection associated with the qualitative approach to organizational research are participant observation and unstructured and semi structured interviewing, which can be part of, or a case study in itself. Whereas survey and experimental research is comprised of specific objectives derived from the investigator's preoccupations, qualitative research tends to be unstructured in order to capture people's perspectives and interpretations. As a consequence, theoretical reflections tend to occur during or towards the end of the data collection process rather than at the outset (Bryman, 1989).

"A striking feature of research to build theory from case studies is the frequent overlap of data analysis with data collection" (Eisenhardt, 1988).

6.5.3. Qualitative vs Quantitative Research: Strengths and Weaknesses

Quantitative studies tend to give less attention to context than qualitative research. One would not obtain the feel for the organizations under investigation. According to Mintzberg (1979), quantitative studies would not be the most appropriate method to conduct theory building, precisely because "creative insight seems to require the sense of things - how they feel, smell, seem."

Quantitative research also tends to deal less well with the processual aspects of the organizational reality. It often entails fairly static analyses in which relationships between variables are explored (Eisenhardt, 1988). In quantitative research, the confines of what can be found are determined at the outset, so that there is rarely an opportunity to change the direction of the research, since the structure largely determines the course of events. An advantage of qualitative research is that it allows for such changes in direction.

The proximity of the qualitative research to organizational phenomena contrasts sharply with the distance between the researcher and the subject that much quantitative research involves. In field experiments and interviewing the researcher may have a great deal of contact with the organization which enables him to develop a fairly strong sense of how it operates. On the other hand, qualitative researchers should also be aware that the proximity, if not well managed, can represent a higher risk of exercising undesired interference with the phenomenon studied.

Critics of the qualitative approach often point to the fact that a qualitative investigator fails to develop a sufficient operational set of measures and that "subjective" judgments are used to collect data, jeopardizing the construct validity of it. Such a criticism could however be overcome by developing multiple sources of evidence to compensate for these deficiencies.

A further criticism of the qualitative approach is the difficulty researchers face when trying to replicate it. The general way of approaching the problem of replication in qualitative research is to make as many steps as operational as possible, and to conduct the research as if someone were always looking over your shoulder. The development of semi-structured protocols is also a tactic to increase the reliability of qualitative research (Yin, 1988). Miles (1979) points out that the quantitative view of reliability is in many respects inapplicable in qualitative data collection: "Certain cases of reliability must be intentionally violated in order to gain a depth of understanding about the situation i.e. the observer's behaviour must change from subject to subject, unique questions must be asked of different subjects... there is an inherent conflict between validity and reliability - the former is what field work is specially qualified to gain, and increased emphasis on reliability will only undermine that function".

6.5.4. Macro-Approaches to this Research Work: Conclusion

In most of the cases, there is not a free choice of research design[4]. It is in general a matter of appropriateness to the research requirements and conditions. Given the criteria and a brief description of the two distinct approaches for research method - qualitative and quantitative, a matrix criteria/alternatives (see Figure 6.1) can be established in order to support the method choice:

Criteria	Research main needs	Approach Qualitative	Approach Quantitative
Adequacy for concepts	-presence of researcher in the data collection	usual	unusual
	-small sample size	possible	insufficient
	-variables difficult to quantify	possible	inadequate
	-perceptive measures	possible	difficult
Adequacy for objectives	-confines not pre-defined	possible	impossible
	-causality is central	preferable	possible
	-need to build theory	adequate	inadequate
	-in depth understanding of organizations decision making process	adequate	inadequate
Construct validity		possible	possible
Internal validity		possible	possible
External validity	-generalizable theory	possible	possible
Reliability		possible	possible

Fig 6.1 - Schematic choice of the research method - qualitative/quantitative

[4] According to Morgan and Smircich (1980), the appropriateness of qualitative research - like that of quantitative research - is contingent on the nature of the phenomena to be studied.

The Qualitative approach was considered the most appropriate one for this research. In terms of the criteria "adequacy for this research" (concepts and objectives), in other words, regarding the research requirements, the qualitative approach is clearly superior. With respect to the issues of "validity" and "reliability", one is unable to discriminate between the two approaches, if the research design and data collection process is properly conducted.

6.6 Choosing the Research Design

The principal organizational research designs are, according to Bryman (1989): Experimental research, Survey research, Case study/Qualitative research, and Active research.

Although some (mainly Survey research) are often regarded as having a predominantly quantitative approach, whilst others (such as the Case study) are regarded as having a predominantly qualitative approach, each of them can actually have more or less emphasis on either approach, depending on the specific research. Qualitative data can for instance be used in Case studies and a researcher conducting a survey could well supplement the quantitative data with qualitative information.

6.6.1. Research Designs: Description, Strengths and Weaknesses[5]

Experimental research - Experimental designs are of considerable importance in organizational research. Their particular strength as a research strategy is that they allow the investigator to make strong claims about causality - that one thing has a strong effect on something else.

What we want to be able to demonstrate is that our supposed independent variable, and that variable alone, is the cause of the variation of the dependent variable. The idea of "control" is therefore essential. Control implies the elimination of alternative explanations for the apparent connection between a putative cause and a particular effect. In experimental research, the researcher intervenes in the organization (by intervening in the independent variable) and observes the effects of this intervention (by observing the behaviour of the dependent variables).

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[5]This section is based on Bryman, 1989.

It should be noted that, when we deal with complex variables such as *environmental uncertainty*, for example as it is the case of this research, it is very difficult to exercise such control.

Survey Research - Survey research entails the collection of data (invariably in the field of organizational research by self administered questionnaires or by structured or semi-structured interviews) on a number of units and usually at a single point in time, with a view to systematically collecting a body of quantifiable data on a number of variables, which are then examined to discern patterns of association. As statistical generalization is generally pursued in survey research and, representative and large samples are required, this makes it especially problematic for one single, or a small group of researchers to be present in the data collection process. In such cases, questionnaires can be sent to the subjects by mail. However, another problem arises, in these cases, for there is the additional need to ensure that the understanding of the concepts involved in the research are uniform among the subjects. This can be very difficult to achiève, especially when concepts involved, such as *flexibility* or *uncertainty,* are controversial or not broadly accepted.

In survey research, the confines of what can be found have also to be defined at the outset of the research work. Survey research is almost always conducted in order to provide a quantitative picture of the organizations in question, hence the widespread tendency to associate survey research with quantitative research. An example of survey research in organizational study is the yearly survey on the manufacturing strategy of large manufacturers, the "Manufacturing Futures", carried out by research teams at INSEAD (Fontainebleau, France), Boston University (Boston, USA) and Waseda University (Tokyo, Japan). The objective of their research is to examine the state of manufacturing strategy at one particular moment in time and also to collect comparable data overtime, in different regions to identify tendencies and to draw statistical conclusions and generalizations (see De Meyer, 1986).

Qualitative research / Case study - It is often difficult to distinguish qualitative from case study research. Case studies entail detailed examination of one or a small number of "cases". The emphasis in these designs tends to be on the individuals' interpretations of their environments and of their own and others' behaviour. The emphasis tends to be on understanding what is going on in organizations from the participants' perspective rather than that of the researcher. Case study is a strategy with a distinctive advantage when a "how" or "why" question is being asked about a contemporary set of events, over which the investigator has little or no control.

A common concern with regard to case studies is that they provide very little basis for scientific generalization. "How can you generalize from a single or few cases?" is a frequent question. The short answer to this is that case studies, like experiments, can be generalized to theoretical propositions and not to populations or universes. In this sense, the case study does not represent a "sample" and the investigator's goal is to expand and generalize theories (analytic generalization) and not enumerate frequencies (statistical generalization) (Yin, 1988). Another clear distinction between case studies and survey research is the *choice* of samples made in both cases. Given that, in general, survey research tends to aim at enumerating frequencies and drawing statistical generalization, the sample in the survey research should be representative of the universe being analyzed. The elements of the sample should therefore be randomly selected. This is however, not the case with case studies. "Rather, they (the cases) are selected to fill theoretical categories and to provide examples of polar types. As Pettigrew (1988) notes, given the limited number of cases which can usually be studied, it makes pragmatic sense to choose extreme situations and polar types in which the process of interest is "transparently observable". Thus, the purpose of theoretical sampling is to allow systematic building of theory"(Eisenhardt, 1988).

A general criticism of case study research is the difficulty one encounters in "replicating" (or in ensuring the reliability of) it. The general way of approaching the reliability problem is to make as many steps as possible as operational as possible, by using protocols and documenting the procedures (Yin, 1988), for example.

Action Research - In action research, the researcher is involved, in conjunction with members of an organization, in dealing with a problem which is recognized as being one, by both parties. The researcher feeds information about advisable lines of action back to the organization and observes the impact of the implementation of the advised lines of action on the organizational problem. In a sense the researcher becomes part of the field of investigation. It is the nature of the relationship between the researcher and his or her subjects that constitutes the prime reason for conceptualizing action research as a distinct design. Conceptually, action research has similarities with Experimental Research, since the researcher also seeks to analyze the effect of an alteration of an "independent variable" on a "dependent variable".

6.6.2. The Choice of Research Design

Experimental research does not seem to be suitable for this research on the grounds that it is very difficult to design a representative experiment (or model) which includes variables, such as perceived environmental uncertainty or manufacturing flexibility, in the sense they are considered here. They are very complex and dependent on a number of other complex variables like the subjects cognitive process thus any attempts to control them appear to be very difficult.

Survey research and, more generally, designs based on self-administered questionnaires are not adequate for the present research because: a) they are methods in which data collection is generally made in the absence of the researcher; and b) their main concern is the quantification of variables and enumeration of frequencies.

The presence of the researcher is considered essential in this research, because of the risk of non-homogeneous interpretation of the concepts involved across the subjects. Whilst, the quantification of the variables and enumeration of frequencies were not considered to be of particular relevance for this present research because the main objective of this research is to build theory rather than to describe the reality in terms of statistical distributions.

Action research is unsuitable for this research because the researcher was not in the position of suggesting any lines of action to the case-companies.

Case study / qualitative research, on the other hand, seems to be a suitable research design for the present research. For they can, if well administered, provide the adequate level of contact between the researcher and the subjects involved. In addition, they can also provide the appropriate level of detail in the data collection. Case study is also particularly suitable to the lack of previous knowledge, about the confines of what could be found in the research and the possible need of redirecting it, should events require this. Moreover, case studies are suitable to allow for the building up of theory (Mintzberg, 1979; Eisenhardt, 1988), which is one of the main aims of the present research.

6.6.3. A Summary of the Research Design Alternatives and Choice

The following table summarizes the process of research method selection.

Research requirements/ characteristics	experimental research	survey research	case study/ qualitative research	action research
presence of the researcher in data collection	possible	unusual/ difficult	usual	usual
small sample size	possible	unusual	usual	usual
variables difficult to quantify	possible	possible	possible	possible
perceptive measures	possible	possible	possible	possible
confines not pre-defined	unusual	difficult	adequate	possible
causality is central	adequate	possible	adequate	possible
need to build theory; to answer a "how" question	possible	difficult	adequate	possible
in depth understanding of decision making process	difficult	difficult	adequate	possible
non-active role of researcher	possible	possible	possible	impossible
lack of control over variables	difficult	possible	possible	possible

Table 6.2 Summary of the process of research design choice.

6.7 Overall Conclusions on the Selection of the Research Method

Following from the above analysis, the general approach used in the present research work is predominantly qualitative, and the research design is case-studies.

To summarize what this means is:

1. A number of organizations will be chosen and analyzed in depth. The choice of the organizations will not be made at random. Rather, the criteria to choose them will be their potential contribution to the theory-building exercise.

2. The basic method of data collection will be interviews with a number of decision makers within the organizations in order to identify their perception with regard to a number of aspects related to the research question. A semi-structured questionnaire will be used in the interviews, to be performed by the researcher in person.

See chapter 7 for a detailed description of the research design development used in the research described here.

6.8 The Level of Analysis

As Gerwin (1986) points out, a basic aspect in addressing manufacturing flexibility issues, is the level of aggregation on which the research is to be based. Gerwin suggests the following classification of levels: the individual machine or manufacturing system; the manufacturing function, such as forming, cutting or assembling; the manufacturing process for a single product or group of related ones; the factory or the company's entire factory system. At each level, says Gerwin, the domain of the concept of flexibility may be different and alternative means of achieving flexibility will therefore be available. Slack (1990a) also addressed the issue of level of analysis. He argues that, from a strategic viewpoint, the most serious oversight in the literature concerns the level of analysis of most treatments of manufacturing flexibility. Slack defines 4 levels of analysis: the level of the firm, the level of the function (which not to be confused with Gerwin's definition of "function", concerns the manufacturing function as a whole) or total system, the level of the cell or small system and the level of the particular resource.

The underlying assumption of this research is that the primary reason for a company wishing to develop flexibility (or any other manufacturing objective) is to help the organization to compete. In other words, we are particularly interested in the strategic aspect of flexibility. Slack (1990a) points out that system flexibility (which can be understood as a production unit within a plant) would seem to be the most appropriate level of analysis for any examination of strategic flexibility, since it is the system's flexibility (as opposed as the individual resources') which contributes most directly to company's performance.

The level of analysis considered in this research is therefore the level of the manufacturing systems, or *set of manufacturing resources*. This level of analysis does not necessarily encompass the whole factory within companies (which, as in the case of car manufacturers, can sometimes mean huge plants), but can also apply to relatively independent production units within the plant. Nowadays, with the concept of manufacturing focus being adopted by many companies[6], it does not seem to be appropriate to deal with, or to study, the flexibility of large plants as a whole. Given that frequently, different cells (which may focus on different products or parts) or

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[6] Semi-autonomous production units within plants are frequent nowadays, with the companies adopting the focused manufacturing and "plant-within-a-plant" approaches (see chapter 1 for a discussion on the issue).

plants-within-the-plant have different requirements in terms of the performance regarding either flexibility or other competitive criteria.

The important point is that the level of analysis considered here is of relatively autonomous *sets of multiple resources* (machines, material, people, systems) under common management and not the level of the individual resources or groups of similar resources (such as a lathe or the cutting department in a highly bureaucratic organization).

6.9 Choosing the Companies

In case studies, cases are not chosen at random. Rather they are selected to fill theoretical categories and polar examples. (Eisenhardt, 1988; Pettigrew, 1988; Yin, 1988).

The cases in this research were chosen from companies, both in England and Brazil. The reason for this selection rests on the tentative variables analyzed and also on the possibility of access. The access to English companies was made possible through members of the staff of the Warwick Business School, who had previous contacts with the case-companies. The access to Brazilian companies was possible because of contacts previously established by the author when in Brazil. A split sample was chosen for the following reason: the industrial environment in Brazil is notoriously more uncertain than the industrial environment in England. Following Pettigrew's (1988) advice it was decided that it would make "pragmatic sense" to choose such an extreme situation which would allow the analysis of a very uncertain environment. However, because the Brazilian industry has, for a long time, been protected from foreign competition, it is not as developed as the English industry, in terms of product proliferation. Consequently, English companies were thought to be more apt at providing good data for valuable analyses in terms of *variability of outputs*. Thus, with companies from both countries in the sample, both variables - *uncertainty* and *variability* - could be analyzed based on "polar" cases.

6.10 The Brazil/UK factor

The non-uniformity of the sample, in terms of the countries the companies are located in, was not considered a methodological problem for two reasons. Firstly, because the sample is not intended to be representative of a specific population. From the outset of the research work, no statistical generalization was intended [7]. Secondly, from an operations viewpoint, the problems which a company belonging to the automotive industry face are of a similar nature, be it located in Brazil or in the UK. For the "hard" part of the processes are similar, e.g. the machines or the assembly operations, although the uncertainty regarding them is probably different. In terms of the "soft" part of the process, the organization, systems, and so on, the case-companies in both countries are still similar, since, of the two Brazilian companies in the sample, one is part of a large multinational group with headquarters in Europe and the other, because it is highly export-orientated, having to meet European and American standards rather than simply Brazilian ones, also follows European and American models of production organization and management. An alternative approach would have been to keep the whole sample either totally Brazilian or English, but in doing so, the richness of the "extreme" cases would be lost.

6.11 The Number of Cases

The number of cases was determined by research resource constraints: the number of researchers available[8] (in this case only one), the length of the research project, the available time of the researcher in Brazil, the number of people interviewed in each company (i.e. the depth of the investigation necessary) and the availability of host-companies. It was eventually decided that 4 companies, 2 in Brazil and 2 in England would be studied.

All of them can be broadly classified as being in the *batch* range (Hill, 1989), manufacturers of metal engineering products, belonging to the automotive industry. The uniformity of the sample aims at controlling extraneous variance, and defining the generalizability of the results (Eisenhardt, 1988). The selection of the uniform sample was therefore an attempt to control possible extraneous variances, which could appear as a result of having different industries in the sample.[9]

The case studies were done based on semi-structured interviews with a number of managers within the organizations.

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[7] Case studies rely on analytical generalization rather than statistical generalization as is the case with survey research (Yin, 1988).

[8] According to Miles (1979), collecting and analyzing data in qualitative research is a highly labour intensive operation, often generating much stress, even for top quality research staff.

[9] One of Slack's (1987) ten observations, drawn from an empirical study, is that "different types of manufacturing are concerned with flexibility of different resources".

The number of people interviewed varied from company to company, depending on the specific organizational structure, on their availability and willingness to cooperate.

The next chapter - chapter 7 - describes in detail the "micro"-aspects of the research design: the pilot field-work, the research instrument development, refinement and its use, the interviews design and execution, and the process of data treatment.

Chapter 7 - Research Micro - Design

The research method chosen for this research involves the use of "case-studies". The process of research method and case-companies selection was described in chapter 6. In chapter 7, the design and application of the data collection and data treating processes used is described, including the design and refinement of the research instrument or protocol, the pilot study, the use of the research instrument in the interviews and the data treatment process.

The overall objective of the research micro-design is to detail the operational aspects of the research, to ensure the appropriate levels of validity and reliability.

Chapter 7

Research Micro - Design

7.1. The Research Instrument

From the previous chapter, the "case studies" in the present research work were to be based on semi-structured interviews. The interviews were conducted personally, on site, by the researcher for the reasons discussed in chapter 6. An instrument (or protocol) was developed to be used in the interviews for the following reasons.

Firstly, it operates as an "aide-memoire", ensuring that, the same aspects are covéred with all the subjects, thus increasing the reliability of the research.

Secondly it helps focus the process of data collection on the relevant issues.

Thirdly, it makes it easier to register the information collected, given that some of the subjects might have preferred not to have the interviews tape-recorded.

7.1.1. The Design of the First Version of the Protocol

When first designing the protocol, one of the main concerns was, exactly what questions or topics to include. For the subjects should not be over influenced. Although in any classification structure or question sequence there is always some sort of presupposed viewpoint[1]. On the one hand, it was clear that the subjects could not be approached without any instrument or with very open questions, since the amount of time to spend with them was limited and therefore the need to focus on determined issues was very important. On the other hand, the subjects should be given the

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[1] "What is more, observation as such cannot be prior to theory as such, since some theory is presupposed by any observation... Twenty-five years ago I tried to bring home the same point to a group of physics students in Vienna by beginning a lecture with the following instructions: "Take a pencil and paper; carefully observe, and write down what you have observed!" They asked,. of course, what I wanted them to observe. Clearly the instruction: "Observe!" is absurd... Observation is always selective. It needs a chosen object, a definite task, an interest, a point of view, a problem. And its description pressuposes a descriptive language, with property words; it presupposes similarity and classification, which in turn presupposes interests, points of view and problems." (Popper, 1972, refered in Magee, 1990).

opportunity to go beyond the strict confines of closed questions. It was intended to identify their views on the issues, as opposed as to have them simply confirming or denying the researcher *a priori* views

Initially, it was decided to have the protocol divided into sections, each contemplating a different tentative variable: *environmental uncertainty*, *variability of outputs*, *flexibility of the resources* and *flexibility of the system* or set of resources. It was decided to address Flexibility through both levels - that of the individual resources and that of the system of resources because, on one hand, the level of analysis chosen is that of the system of resources (see chapter 6) and we expected many of the uncertainties (such as uncertainties related to the demand) to be related to the system as a whole, thus possibly calling for actions at the system's level. On the other hand, as Slack (1987) suggested, based on his empirical findings, managers feel more comfortable when talking about the flexibility of the individual resources. In light of this, it was considered that approaching the issue of the flexibility of the resources (as well as the flexibility of the system) would increase the construct validity of the research. At the same time, we expected that some of the uncertainties could be related to specific resources (such as machine breakdowns), possibly calling for actions at the individual resource level, although affecting (and therefore being of interest for the analysis of) the system as a whole.

The main concern of this field work was to attain an understanding of the managers' perceptions with regard to the relationships between the three tentative variables - environmental uncertainty, variability of outputs and manufacturing flexibility. The intention was to be able to analyze the relationships from the managers' perspective. In view of this, it was thought that, if the approach of asking the managers to confirm or refute the *a priori* relationships (such as the relationships between types of uncertainty and types of flexibility as proposed by Gerwin (1986), for instance) which were found in the literature, was adopted, the possibility would arise of inducing the managers to accept the *a priori* ideas. This would increase the risk of jeopardizing the internal reliability of the research. For this reason, it was decided to treat each different section as a "self-contained" part. In other words, we would, during the interviews, talk with the managers about each of the tentative variables involved in the research, namely *uncertainty*, *variability of outputs* and *manufacturing flexibility*, separately. For each of them, we would try to identify the manager's perceptions about a number of different aspects or *factors* taken from the literature, from the researcher's past experience, and from logical thinking. For each of the aspects covered, not only the level of the variable (such as the level of perceived uncertainty regarding the aspect "machine breakdowns", for instance) would be asked, but also how important they are regarded by the managers to be to their operation[2]. To allow the managers to scale their answers, and to facilitate comparisons, 5-point Likert scales[3] were used whenever the managers were asked to state their perception.

The "Uncertainty" part of the protocol - factors which are possible sources of uncertainties were listed and subjects were asked to comment on and grade their perceived levels of uncertainty, regarding each aspect, using a 5-point Likert scale varying from not predictable to completely predictable. They were also asked to comment on and grade, using a 5-point scale varying from "not important" (point 1) to Important (point 5), the aspects' importance with regard to the operation's functioning.[4]

The "Variability" part of the protocol - the variability part of the questionnaire was designed to be a more objective one. Questions were asked about the families of products and its components (how different the products within a family are), the contribution of each family to the sales turnover, the number of different prodúcts within each family and the importance (from "very important" to "irrelevant") of having that variety for the company's competitiveness were asked. The difference between products within a family was assessed using the following 5-point scale: 1. *Single product,* 2. *Minor differences between products (colours, accessories),* 3. *Fairly different products made-to-stock,* 4. *Assembly to order (but make to stock) according to customer's specifications,* 5. *Completely different products made to order according to customer's specifications.*

The (first) "Flexibility" part of the protocol (flexibility of the manufacturing resources) - Aspects regarding the individual resources drawn from the literature which were considered relevant to the system's flexibility were listed, and the subjects were then asked to comment on and assess: a) the performance of the company with respect to each of the aspects (the 5-point scale varying from "Very good" to "Very bad"); and b)

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2 We expected initially that by simply having their perceptions of the importance of the several aspects of each variable for their operation, we would be able to draw correlations between the variables. During the running of the pilot study this eventually proved to be a mistaken assumption

3 Likert scales are now widely used in assessing people's perceptions. It was first used by R. Likert (Likert, 1967), in order to study the informal structures within organizations. Likert scales are continuums representing certain aspects of the organization, upon which responses can be made. The continuums are divided into intervals. In completing the questionnaire, or answering questions in an interview, an individual is asked to place a mark on the continuum at the point which best describes his/her perception about the particular aspect of the organization under investigation.

4 Eventually we changed the way we treated the "importance" aspect and also the way we defined it. Such changes will be described in section 7.2. - "Refining the Research Instrument - The Pilot Study".

the importance the subjects regarded these aspects to have for the organization's competitiveness (on a scaling from "very important" to "irrelevant").

The (second) "Flexibility" part of the protocol (flexibility of the manufacturing system) - The assessment of the perception of the managers regarding the flexibility of the manufacturing system as a whole was made by using Slack's (1989) model. Slack's classification was selected, since his was considered the most consistent of all the classifications found in the literature, *given the level of analysis* (please see chapter 6) we intended to develop in this research. The other classifications available either mixed different levels of analysis (e.g. Browne et. al.'s, 1983) or approached flexibility at a different level than the one adopted here (a more in depth discussion on flexibility can be found in chapter 2).

The subjects were asked to comment on and assess the performance, compared to their main competitors, of the 4 types : *product, mix, volume* and *delivery* and two dimensions: *range* and *response* of the manufacturing system's flexibility (scaling varying from "much better" to "much worse" than the competition). They were also asked to assess the importance they assigned to each of the factors in terms of the competitiveness of the organization (the scale varying from very important to irrelevant).

7.1.2. Perception of Performance vs. Perception of Importance

The main reason why the assessment of the perceived performance of the aforementioned aspects was included in this research was to give the subjects the chance to clarify the concepts involved, by commenting on them, and going into the subject in more detail. Based on the comments received the researcher was also given the chance to ensure that the subjects did not interpret the terms in a way other than the intended meaning[5]. The information about the managers' perception of performance, which was collected, was not however analyzed further, since what mattered most for the present research was their perception of the *importance* of the factors, i.e. what the managers regarded as being the *best way of doing things* rather than the *way things are currently being done*. For, the way things are actually being done can be affected by several circumstantial problems, such as cash-flow restrictions. We were more interested in the longer term view of the subjects, which was seen to be more appropriate for the theory building exercise. Another reason not to consider the

[5] To ensure the construct validity of the instrument.

perceived *performance,* was that frequently the subjects did not have enough information on how the performance of some aspects actually was. This lack of information was due, mainly, to the level of decision and span of control of the managers interviewed (in a number of cases the plant managers did not have information about the performance of the competitors, for instance). In these circumstances, what the research aims at is to identify the manager's *preferred solutions* rather than the *actual performance* of the organizations, regarding the variables analyzed. Schematically:

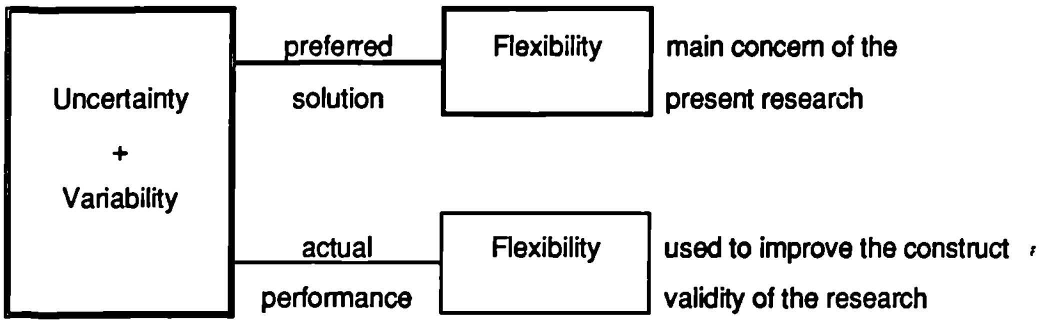

Fig. 7.1 Perception of importance vs. perception of performance.

7.1.3. The Ordering of the Sections

It was a deliberate choice to design the questionnaire with the sections in the following order: 1. Uncertainty; 2. Variability; 3. and 4., Flexibility.

The reason for this being that, we did not want to talk about possible "solutions" (the flexibility aspects), before talking about the "problems" (the uncertainty and variability aspects). In structuring the questionnaire in this manner, we avoided inducing the subjects to feel compelled to point to the solutions suggested by the literature.

7.1.4. The Size of the Protocol

On designing the size of the protocol it was necessary to bear in mind the time constraints of the interviews, which were negotiated with the companies to last 1.5 hours. It could not therefore be a very long protocol and during the pilot study it was in fact necessary to adjust its size. The first version of the protocol, when applied, made the interview take more than 2.5 hours, what proved to be both very tiring for the interviewee and excessively detailed.

7.1.5. The Way of Getting the Protocol to the Respondents

Initially, we planned that the questionnaire would be sent to the respondents in advance, together with a letter, explaining briefly what the objectives of the research were, as soon as the access to the company had been negotiated and gained. Factory tours and interviews would then be scheduled by phone and the interviews realized in person by the researcher.

The first version of the questionnaire is shown in Appendix 1.

7.2. Refining the Research Instrument - The Pilot Study

A pilot study was conducted with four companies, one being in England and three in Brazil, the aim being to refine the research instrument. One manager was interviewed in the English company and three managers in each of the Brazilian companies, all of them with a span of attributions which was consistent with the level of analysis of this research (see chapter 6). The four companies of the pilot study are suppliers of metal engineering parts for the automotive industry and leaders in their markets. They are briefly described below:

Company X/UK - An English company, part of a large corporation, which manufactures mechanical parts for the automotive industry and also parts for the process industry machinery. One person was interviewed - the Production Director.

Company X/Brazil - The Brazilian branch of the Company X/UK. Company X/Brazil has a narrower line of products than the one manufactured by the British branch and aims basically at the automotive industry. Three people were interviewed - the Managing Director, the Industrial Director and the Production Manager.

Company Y - Manufacturer of high quality parts for the automotive and aero space industry. Company Y has the largest milling shop in Brazil. Three people were interviewed - the Industrial Director, the Administrative Director (who was a former Industrial Director) and the Process Manager.

Company Z - Largest Brazilian manufacturer of off-road military heavy and light vehicles, major exporter of weaponry and off road military vehicles. Three people were interviewed in the pilot study - the Managing Director, the Quality Manager and the Materials Supply Director.

The instrument was then modified substantially, from the first version, based on the process and on the outcomes of the pilot study. The main problems encountered with the first version were:

Internal validity - it became clear, after interviewing the first three companies in the pilot sample, that it would be impossible to establish causal relationships between the variables from the data alone, if the managers continued to be asked only about their perception of level of performance and importance of the three variables - *uncertainty, variability* and *flexibility,* in isolation. The fact that a manager, for instance, considers the uncertainty factor UF-X to be highly uncertain and highly important and at the same time considers the resource flexibility factor RFF-X as highly important, does not necessarily imply that he considers RFF-X as important *in order to cope with* UF-X. Both, the uncertainty factor and the flexibility factor, could actually be "numerically" correlated, without any causal relationship at all. Probably a much larger sample would be necessary for the researcher to be able to conclude anything about causality with a reasonable level of confidence, using such procedure. In view of this problem it was decided to change some aspects of the data collecting process to be able to establish causality, and therefore increase the internal validity of the instrument:

Uncertainty part: Instead of simply enquiring about the levels of uncertainty (or predictability - see chapter 4) of the factors and their importance, it was decided: first, to continue asking about the levels of uncertainty of each factor. Second, instead of just asking for levels of importance, asking the managers to rank the uncertainty factors which they regarded as representing the higher levels of risk for their organization's competitiveness[6]. The managers were also permitted to mention as many uncertainty factors as they wanted. Once the factors were ranked by the managers, they would then be asked what was, according to their perception, the best way to cope with each of them. These could be ways which were *actually being used,* if the managers were satisfied with them, or ways which they considered *should be used* by their organizations to cope with the risky uncertainty factors. It was expected that answers would relate to flexibility factors, but by having the uncertainty part of the protocol first, it was made sure that the subjects were not induced to answer the factors listed in the flexibility list, given that they had yet to go through that section.

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6 Ranking the factors instead of assessing the importance of all of them, also substantially reduced the time of the interviews. This was an additional advantage, since they were found to be too long in the first interviews.

Variability part: It was decided to include a question at the end of the variability section: the managers were asked by the researcher what they considered would be the best way for their organization to cope with the variability of outputs which they have to deal with. Although answers related to flexibility-related factors were expected, once again it was made sure that the subjects had not been induced to answer according to the listed flexibility factors.

Flexibility part: The *resource flexibility* part was amended in a similar manner to the *uncertainty* part. Instead of simply asking the subjects to assess the levels of performance and importance of each of the factors, it was decided to: firstly, continue asking them to go through the whole list of factors, commenting and also ranking their performance (compared to the company's needs). Thus ensuring that they continue to have the opportunity to *go into the subject* in greater detail and also giving the researcher, the opportunity to make sure that the understanding of the concepts, by the subjects, was appropriate. Secondly, instead of asking the subjects to grade the performance of all the aspects, it was decided to ask them to rank the listed factors (although they were permitted to mention others), according to the ones they considered as being *critical success factors*[7] for the organizations' competitiveness. It was up to them to decide the number of factors they mentioned in the ranking. After ranking the factors, they would be asked to comment on *why* they considered the ranked factors to be important. At this stage, we expected to find answers relating to either uncertainty factors or variability factors.

The way of getting the questions to the respondents - It was noticed that the fact that the questionnaires were sent to the managers in advance could be inducing the managers to answer according to the *a priori* classification, since they were given the opportunity to go through the list of "solutions" (or the flexibility factors), before answering "*what is the best way of dealing with the problems*". This then might cause them to answer according to the list and not according to their own views. To avoid the possibility of a bias of this nature arising, it was decided not to send them the protocol in advance. The protocol would be presented to the interviewees at the beginning of the interviews.

The incompleteness of the lists - It was noticed that our list of factors for each of the variables could be restrictive. Thus, for example, at the end of the sections on *uncertainty* and *flexibility of resources*, a section where the subjects were asked whether

[7] Critical success factors were defined to the managers as the factors which they considered as the most important for the *competitive* success of their companies.

there were other factors which they considered important, which had not been included in the list was included. By doing so, it would be possible to take into account, from then on (in the current and in the following interviews) any other relevant aspects not mentioned before. As a result of this action, by the time the pilot study was finished, the protocol was found to be substantially different from its initial format. This inclusion, moreover, proved to be an instrument for the fine tuning of the protocol, which had little alterations made to it during the actual process of data collecting. For although, during the actual process of data collection itself, only minor changes were made to the list of questions, substantial changes in the data collection methods are also legitimate when one conducts case studies for theory building. According to Eisenhardt (1988):

"Indeed, a key feature of theory building, case research is the freedom to make adjustments during the data collection process. They can be changes to data collection instruments, such as the addition of questions to an interview protocol or questions to a questionnaire".

The inconsistency of the questions about "importance" - It became apparent that inconsistent and possibly dubious terms were being used, when asking the managers about their perception of the "importance" of the factors. The most appropriate way to obtain a greater degree of consistency was to link the question of importance, to the question of competitiveness of the organization. So, instead of talking about the "importance" of the uncertainty factors, we talked about the "risk for the organization's competitiveness". Instead of talking about the "importance" of the flexibility related resource factors, we talked about the "critical success factors to the organization's competitiveness". The system flexibility section remained as in its initial format, since the question asked to the managers in that section already mentioned the importance of the aspects for the organization's competitiveness.

The inclusion of other aspects of variability - Instead of asking only questions regarding the variety of the product line, we included some questions regarding the variation in quantity of the outputs, such as percent variation of overall volume, so that the managers did not feel constrained to talk simply about the variety of products.

The time length of the interviews - the first pilot interviews (in the United Kingdom) were found to be too long, i.e. 2.5 hours. Although it was known from the outset that there was a "learning curve" effect involved and that the researcher would have become a more "efficient interviewer" as the research developed, it was also clear that some parts (such as the ones mentioned above) would have to be included, which would add some time to the duration of the interviews. In order to substantially reduce the time span of the interviews, it was decided to substitute a *ranking* of the factors importance for the grading of all the factors using a Likert-type scale. Thus the final set of interviews lasted about one and a half hours even accounting for all the aforementioned inclusions.

The modified instrument, following the completion of the pilot study, is contained in the Appendix 2.

7.3. Who and How Many People to Talk to

The managers interviewed were chosen at the discretion of the researcher, among a list of possible interviewees, drawn from the initial contact with each company. In general, this first contact was the contact in which the researcher negotiated and gained access to the company. The decision, among the alternative managers, was made, mainly on the basis of who were the people considered to make decisions concerning a set of multiple manufacturing resources (at the level defined in chapter 6) and also considered to have relevant experience and information about the company to be able to give the researcher a "richer picture" in the interviews. Experienced production managers, process managers, quality/productivity managers, semi-autonomous manufacturing cell leaders are some examples of subjects considered appropriate for the purposes of this research. The same way, dedicated machine operators, cost accountants, design engineers, traditional marketing managers, finance managers and also some CEO's are examples of subjects which were considered inappropriate and therefore not selected to take part in the interviewing process. The number of people interviewed varied from company to company depending on the specific organizational structure and on their availability and willingness to cooperate.

7.4. Using the Research Instrument

On the day scheduled for the interviews, the researcher would go to the company. After being introduced to the manager, in the cases where the researcher had not already met the manager in one of the plant-tours, a briefing of the research objectives would be presented orally by the researcher. An overall explanation would then be made about the research instrument and one copy would be handed to the manager. The manager would then be asked if he agreed to the interview being tape-recorded. Problems of using the tape recorder were only encountered in one of the companies during the pilot study, a manufacturer of off-road military vehicles, where one manager preferred that the interview was not recorded. Recording the interviews actually proved to be extremely helpful, since by repeatedly listening to them, *a posteriori*, it was possible to pick up details which had escaped the researcher at the interview time.

One of the most difficult tasks for the interviewer was to maintain the focus of the interviews, without restricting the freedom of the managers to extend their comments on relevant points. Not all the managers were objective and concise in their answers and sometimes they would spend long periods discussing problems and aspects of their operations, which whilst interesting, were not always relevant to this research.

The researcher would take notes during the interviews. Given that it was being tape-recorded, an attempt was made to also take note of the non-verbal communication, such as gestures, expressions and so on, as well as impressions that we had at that very moment.

7.5. The Treatment of the Data

According to Eisenhardt (1988), analyzing data is the heart of building theory from case studies. It is both the most difficult and the least codified part of the process. Eisenhardt suggests the following key steps for case analysis:

Within case analysis - Generally, it involves detailed case study write-ups for each site. The need for within case analysis is driven by one of the realities of case study research: a staggering volume of data and therefore, the ever present danger of "death by data asphyxiation" (Pettigrew, 1988). Within case analysis typically involves detailed case study write-ups for each site (Eisenhardt, 1988) and helps the researcher to start the process of progressively making sense out of the large amount of collected data.

Cross case search for patterns - The idea is to force the investigator to go beyond initial impressions. The danger here is that investigators reach premature and even false conclusions. One tactic is to select categories or dimensions and look for similarities coupled with inter-group differences.

Shaping hypothesis - The central idea is that from within case analyses, plus various cross site analyses and overall impressions, tentative themes, concepts and possibly even relationships between variables begin to emerge.

Following the suggestions of the literature, efforts were put so that to ensure that the treatment of the data from the cases was as systematic as possible. The first step was to listen carefully to the tapes and transcribe literally every relevant bit of the interviews. The next step was then to highlight successively the pieces which represented the relevant relationships for the research, sifting information progressively by making successive passes, until the relationships between key words, representative of the factors were identified[8]. Elaborate charts were then constructed which summarized the results and consolidated the interviews from each company (an example of one of these charts can be found in Appendix 4). These charts would bring together a summary of the relevant information and the "addresses" of the detailed information, making references to the transcriptions, to the notes taken during the interviews and to the tapes. In using such a procedure, one could always clarify any doubts about the summary results by tracking it back to the primary data. In a number of situations, during the process of treatment of the data, some interviewees had to be contacted again, in order to supplement missing information.

7.6. The Within Case Analysis

From this stage, detailed within case analyses were completed and the results written up. The next step was to conduct the cross case analyses, searching for patterns, relationships, similarities and differences between cases. All the case write-ups are structured in a similar way. The following sections can generally be found in each case write-up, because they either refer to relevant general information on the case-companies or they are directly related to the research question and propositions:

Organizational issues - contains a brief description of some relevant organizational aspects of the companies. The objective is to place the case into context.

The interviews - the managers interviewed are mentioned and a brief description of each of their responsibilities and activities.

Line of products - variety, variation and innovation - aspects regarding the variability of outputs (part 2 of the protocol) of the company are discussed.

Manufacturing flexibility task and performance - aspects regarding the respondents' perceptions of the manufacturing system's flexibility are discussed (part 4 of the protocol).

Uncertainties involved - the respondents' perceptions of the uncertainties (associated with predictability) involved in their operations (part 3 of the protocol) are discussed.

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8 This is what Miles (1979) calls "formulating classes of phenomena", which is essentially a categorizing process, subsuming observations under "progressivelly more abstract concepts".

Coping with change, uncertainties and variability - the relationships between aspects of the three main research variables - *uncertainty, variability* and *flexibility*, according to the managers' perceptions are discussed.

The relationship between the flexibility-related order winning criteria and the critical success factors - aspects related to the relationship between the system's flexibility factors and the resource flexibility factors (parts 4 and 3 of the protocol) are discussed.

Conclusions of the within case study - conclusion of the within case studies are drawn (see Appendix 3).

7.7. The Cross Case Analysis

The next step was to conduct the cross-case analysis, trying to search for patterns. An analysis regarding the similarities and differences was conducted, conclusions drawn and comparisons with the research propositions were made. The result of the data treatment process can be found, summarized, in chapter 8 - "Field Work". More detailed information on the "within-case-analysis" can be found in Appendix 3 - "The 4 Case-Studies".

Based on the results of the case study, an attempt to build theory was then made, the results of which are presented in chapter 9 - "A Model to Help Understand and Analyze Unplanned Change From an Operations Viewpoint".

7.8. Brief Summary of the Method used in the Research

Qualitative research as the general approach;
Case study as the research design;
Semi-structured interviews as the basic data collecting method;
Emphasis on the perceptions of the decision-makers with regard to the research question and propositions;
Production units (factories or semi-autonomous parts of factories) as the level of analysis.

Four organizations - two in England and two in Brazil, belonging to the automotive industry, manufacturers of metal engineering products, as the case-companies, beside the four companies of the pilot study.

Part III - Field Work

Part III, which consists of chapter 8 - "Field Work", describes the principal aspects and conclusions of the field work performed, based on the guidelines defined in Part II. The 4 within-case analyses are briefly described and the cross-case comparative analysis is discussed. The research propositions defined in chapter 6 are analyzed and conclusions are drawn. The detailed description of the 4 case-studies can be found in the Appendix 3 - The 4 Cases-Studies.

Chapter 8 - Field Work

The objective of chapter 8 - Field Work is to describe the main analyses and results of the field study which was performed as part of the research described here.

The objective of the field work is to subsidize the analysis of the 6 research propositions described in chapter 6 and also subsidize the exercise of "theory building", to be described in chapter 9 - "A Model to Understand and Analyze Unplanned Change From an Operations Viewpoint".

As described in chapter 6 - "Methodology", the research method used in this research work is "case studies". The research problem is defined as "the relationship between manufacturing flexibility, variability of outputs and environmental and internal uncertainty". The research instrument used in the interviews with the managers, as well as the method used to collect and analyze the data presented in this chapter are described in chapters 6 and 7.

Initially, the within-case analyses performed for each of the 4 cases is briefly described (for details refer to the Appendix 3). Following the brief description of the within-case analysis, the cross-case analysis is presented. The aim of the cross-case analysis is to identify differences and similarities among the cases.

Finally, the analysis of the 6 research propositions is done, based on evidence drawn from the case studies. Some additional observations are also described and conclusions are drawn.

Chapter 8

Field Work

The within-case analyses, performed for each of the case-companies, is briefly described below (see Appendix 3 for further details).

8.1. Case A - The British Engine Manufacturer

Company A is an automobile manufacturer located in the Midlands, England, manufacturing parts to stock and assembling vehicles to order. This case relates to the engine manufacturing plant within Company A.

8.1.1. Case A - Organizational Aspects

The plant is organized in manufacturing cells. There are 8 main cells, each of them run by one manager, one "facilitator", one planner, one to four conformance engineers and the team of direct workers. The cell managers have considerable autonomy in deciding on scheduling and dispatching issues, employment, training and to a more limited extent, investment budget. There are statistical process control procedures implemented and the workers are responsible for the process quality. Maintenance is still performed by a separate team, although it is intended to be delegated to the operators in the future. This arrangement also applies for the setting up of the machines. The general approach regarding industrial relations has recently changed towards more stable relations. The payment system for the direct workers is based on 4 grades, according to the breadth of skills of the worker.

8.1.2. Case A - The Interviewees

Six people were interviewed in Company A: the Materials Manager, the Conformance Manager, the CNC Cell Manager, the Assembly lines Manager, the Transfer Line Manager and the Production Director.

8.1.3. Case A - Variability of Outputs

The variation in overall volume for the engine plant can be approximately 20% from month to month. The variation in the mix of products demanded can also be high. In each week 45 out of the 78 derivatives are produced, in average. Moreover every month at least 80% (or approximately 62) of the product range is produced; The introduction of new products or engineering changes is done on a batch basis, quarterly (or every 13 weeks). In general, around 15 changes are performed in each batch.

A number of important points can be underlined by the brief description of the process of launching a new product, done by one of the managers, in Company A: *the integration* between process development, product development and production via organizational links or via effective inter-function communication; *multi function team approach; early involvement of direct workers* in the design and prototyping phases; *early involvement of suppliers* and the delegation to "expert companies" of the task of designing and developing the parts; and, *reduction of the number of suppliers* and tendency to establish long term contracts with them.

8.1.4. Case A - Flexibility-related Competitive Priorities

Although belonging to quite different manufacturing cells, the managers' answers are clear and consistent, concerning the flexibility-related task of the engine plant. All the respondents, for instance, placed mix flexibility as their first priority.

8.1.5. Case A - Uncertainty

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company A's competitiveness show a distinct pattern. All the managers, for instance, placed the uncertainty with materials and parts supply as one of their two main concerns. Three of the managers placed demand product mix uncertainty among their two main concerns, and two managers placed labour behaviour - absenteeism and continuity - among their two main concerns.

8.1.6. Case A - Coping with Uncertainty and Variability

The most mentioned relationships between the types of uncertainty and variability and, the best ways, according to the managers, to deal with them, are shown below:

NUMBER OF MANAGERS (CASE A) WHO MENTIONED THE RELATIONSHIP	UNCERTAINTY RELATING TO -->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
4	parts and materials supply	rescheduling capability
4	labour behaviour (absenteeism, continuity)	multi skills of labour, transferability
4	product mix changes	rescheduling capability
2	parts and materials supply	materials control systems effectiveness
2	product mix changes	multi skills of labour, transferability
2	overall volume changes	excess capacity
2	general uncertainty	ability to work in groups
2	general uncertainty	multi skills of labour, transferability
2	product introduction	integration design/ manufacturing
2	variety	standardization of parts
2	variety	multi skills of labour, transferability

Figure 8.1. Case A - The most mentioned relationships between uncertainty types, variability and flexibility-related resource characteristics, during the field work.

8.1.7. Case A - General Observations

When asked how they coped with the different types of uncertainty and variability, the managers showed, in general, both different approaches and different levels of understanding of the variables involved with manufacturing flexibility. It is important to mention a certain "hierarchy" in the general approach adopted by a number of managers, in terms of the ways they find as the most appropriate to deal with uncertainties. They seem to prefer trying to reduce the level of uncertainty and variability which they are subject to, rather than having to deal with its effects. Managers also see flexibility as a way to deal with uncertain and variable changes, when the causes of such uncertainty and variability can not be eliminated.

An interesting point noticed was the emphasis given by the management in the achievement of manufacturing flexibility through the resource Labour. At least three of the managers mentioned it emphatically.

Another point made by some managers, mainly the ones who were most concerned about flexibility is that they see manufacturing flexibility as sort of a "reserve", something that the organization possesses although it is not using at every moment.

8.1.8. Case A - Relevant Findings

Managers in Company A see flexibility as a way to cope with uncertainties when the causes of such uncertainties can not be eliminated. (see chapter 9 for a complete discussion on this point)

Managers in Company A understand that variability and different types of uncertainty should be dealt with by developing different types of resource flexibilities. This point is further discussed in section 8.7. "How do Managers Cope with Uncertainties and Variability"

The most flexibility-conscious Managers in Company A see flexibility as a "reserve", something which has to be planned for, developed, maintained and seen as a valuable asset. This point is discussed in detail in chapter 9, section 9.4.3. - "The Flexibility of Structural Resources".

Managers in Company A have a high degree of consistency in their perception of the flexibility related competitive criteria they should pursue.

8.2. Case B - The Brazilian Carburettor Manufacturer

Company B is a carburettor manufacturer located in São Paulo, Brazil. It is the main supplier of carburettors for the Brazilian car assembly companies and for the spare parts market. Company B is part of a large transnational corporation with headquarters in Europe and interests in a broad range of industrial products.

8.2.1. Case B - Organizational Aspects

The Company B plant is organized on a functional (with the resources grouped by function) layout, although they are currently at early stages of the migration into cellular manufacturing. Some pilot cells had just been established, at the time of the interviews, with promising results, according to the managers.

Company B is, currently, in a very peculiar situation. The company has always been regarded as a carburettor manufacturer. However, with the new (for the Brazilian market) technological advent of the fuel injection systems, Company B has changed its mission into being a manufacturer of "engine feeding systems". The carburettor will "die" as an OEM (original equipment manufacturer) product in 1997, according to corporate plans. No large investments are being made in the conventional carburettor technology and therefore no major changes in the line of carburettors are expected to be introduced in the future. On the other hand, investment is being made to qualify the company in order to compete in the new market, that of fuel injection systems. In order to do that, managerial and technical staff are being sent abroad, in order to be trained in the company's headquarters. The new fuel injection technology represents a major change. Managers in Company B reckon that the change is bound to bring many problems to the company since the new technology is based on microelectronics, rather than mechanics principles. Therefore it demands completely different skills, machinery and systems in order to compete with other and more experienced competitors in the new market (the German Bosch, for instance). The change is supposed to happen gradually, resulting in the end of the carburettor (except for the remaining spare parts market) in 1997.

Company B's organizational structure is conventional and hierarchical although they are currently trying to include some aspects of the matrix organization, establishing several multi disciplinary "work-groups" with specific goals, such as product introduction, lead-time reduction, an so on, aiming at "breaking the barriers" between separate functions. There are statistical process control procedures implemented and the workers are responsible for the process quality. Equipment maintenance is still performed by a separate team, although the cleaning and the very basic maintenance procedures are performed by the operators themselves. This arrangement also applies to the setting up of the machines. The formal manufacturing planning and control system used by Company B is MRP for the planning of materials and master scheduling. The scheduling however is done on a "people-based" informal system by the logistics manager and staff.

The general approach regarding industrial relations has recently changed, favouring the company. This has partly been caused by the Brazilian recession, resulting in high levels of unemployment in the region where Company B is located. The payment system for direct workers is based on grades, according to an internal merit assessment system, which is not directly linked to the breadth of skills of the worker nor to any output rates.

8.2.2. Case B - The Interviewees

Six people were interviewed in Company B: the Industrial Director, the Logistics Manager, the Product Engineering Manager, the Production Manager, the Industrial Technology Manager and the Quality Control Manager.

8.2.3. Case B - Variability of Outputs

Currently, company B has a line of 7 basic product families, with minor to considerable differences between products within a family, depending on the specific family. The overall number of products or "derivatives" is 121. The variation in overall volume can be approximately 50% from month to month. The variation in the mix of products demanded can also be very high. E.g. in each week 30 out of the 121 derivatives are usually produced. Moreover, in every one month at least 60 % (or approximately 72) of the product range is produced.

The introduction of new products or the engineering changes of the existing ones are done on a continuous rather than on a batch basis. Six to eight engineering changes are usually made in every one month, being 50% minor changes concerning process improvement and 50%, changes in the "application" of the products, due to changes in the fuel composition, emission regulations and customer requests. Launching a completely new carburettor is not in the future plans of the company, since carburettors have a certain date to "die" as an OEM product in Company B. In the past, although the managers consider that Company B's performance in terms of introduction of new products and product changes have been clearly better than that of the competitors, this has been accomplished at very high costs, in terms of resources and organizational disruption. Historically, the time period to introduce a completely new product has been two years. Nevertheless, as a preparation for the new line of products, the fuel injection systems, the company has established a task force to develop a new system for the introduction of new products ("Sistema *Company B* de Novos Produtos" or, "System *Company B* for New Products"), trying to incorporate concepts of multi-functional work groups and simultaneous engineering (which are relatively new concepts in Brazil). The system now exists in the form of a written document but most of the managers recognize that there is still a long way to go in terms of breaking the barriers between functions and make it work fully. Managers consider that the ability to introduce new products quickly and reliably (in terms of quality) will play a major role in the future company B's competitive scenario.

8.2.4. Case B - Flexibility-related Competitive Priorities

The managers' answers concerning the flexibility-related task of the plant are consistent, at a certain extent. Four out of six managers specified product range as the particular flexibility type the company should primarily focus on. The other two managers mentioned delivery range and mix response as their first competitive priorities respectively.

8.2.5. Case B - Uncertainty

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company B's competitiveness are also relatively consistent. All the managers, for instance, placed "materials and parts supply" uncertainty as one of their two main concerns. Four of the managers placed "manager behaviour under changing circumstances" among their two main concerns. Other aspects mentioned as being among the two main concerns are: uncertainty regarding "machine breakdowns", uncertainties regarding the "specification of new products" and uncertainty related to the "availability of technological information".

8.2.6. Case B - Coping with Uncertainty and Variability

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below:

NUMBER OF MANAGERS (CASE B) WHO MENTIONED THE RELATIONSHIP	UNCERTAINTY RELATING TO -->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
4	parts and materials supply	rescheduling capability
4	parts and materials supply	supplier development, partnership
4	management behaviour	training, awareness
3	labour behaviour	multi-skills development
3	product mix changes	set-up times reduction
3	quality changes	interface prod design/ proc design/manufact
2	product mix changes	rescheduling capability
2	machine breakdown	re-routing capability
2	product introduction	integration design/ manufacturing
2	variety	standardization of parts
2	product mix changes	ability to get/ maintain lead times low
2	parts and materials supply	machine capability
2	labour behaviour (absenteeism)	extra capacity
2	machine breakdowns	ability to organize over time/subcontract
2	materials and parts supply	ability to organize over time/subcontract
2	quality	ability to work in groups

Figure 8.2. Case B - The most mentioned relationships between uncertainty types, variability and flexibility-related resource characteristics, during the field work.

8.2.7. Case B - General Observations

A point which is worth mentioning is the lack of emphasis given by the managers in the achievement of manufacturing flexibility through the resource Labour. Technological (fast set-ups, capability of machinery) and Infrastructural resources (integration design/production via a formal system, re-routing the production flow ability through a system) seem to play the major roles in the view of Company B's management as ways to achieve system flexibility.

Another point is the great emphasis placed on quality issues by the majority of the managers. Some unexpected associations of the resource aspects (meant to represent characteristics associated with flexibility) with quality appeared, such as the importance of having an agile product design function in order to give the process design function time to design a proper process which can guarantee the product quality. It was expected that fast design would be perceived to keep a relationship with fast product introduction, rather than with quality.

This may be caused by the present stage in which the company is, still struggling with basic quality problems. If that is the case, this comes to confirm De Meyer's (1986) hypothesis that there are stages which the companies progressively go through, first placing emphasis on costs, then on quality and then on flexibility.

Furthermore, it seems that some of the managers see flexibility as something they are "forced" to have in order to cope with uncertainties. Ideally they would prefer to reduce or eliminate the causes of the uncertainties, but since this is not always easily achieved in the short term and also because it is impossible to eliminate completely the stochastic components of the processes, they have to develop flexibility. Four of the managers, for instance, pointed the need to co-operate with the suppliers in the long term (or in other words, to increase the coordination between Company B and the suppliers), in order to reduce the uncertainties that Company B has to deal with. In this case they see the flexibility of the process as a means to deal with the effects of such uncertainties in the short term and with the amount of uncertainty they for some reason were not able to eliminate.

The same happened to the uncertainty regarding machine breakdowns. Three managers mentioned that in the long term, preventive maintenance should be used to reduce the uncertainty level of the process availability. Again, in the short term, they point out flexibility-related solutions such as alternative routes and multi-capable machines, as ways they consider as appropriate to deal with the effects of the aforementioned uncertain events.

8.2.8. Case B - Relevant Findings

Managers in Company B see flexibility as a way to cope with uncertainties when the causes of such uncertainties cannot be eliminated (see chapter 9).

Managers in Company B understand that different types of uncertainty and variability should be dealt with by developing different types of resource flexibilities. (see section 8.7. "How do Managers Cope with Uncertainty and Variability" for further discussions on this point)

Managers in Company B seem to have a greater concern towards quality issues than towards flexibility issues.

Managers' perceptions in Company B have a reasonable consistency in terms of the flexibility related competitive criteria they should pursue.

8.3. Case C - The Brazilian Shock Absorber Manufacturer

Company C manufactures and distributes, to the automotive market, parts having a high technological content. It is an entirely Brazilian-owned company whose capital is open to the general public and whose shares are traded on the Country's stock exchanges. As the largest domestic producer of automotive parts, it ranks 71st, based on sales, among private sector companies in Brazil.

Company C aims at the high technological content automotive parts market and with this objective invests approximately 3% of its operational revenue in product and process research and development.

8.3.1. Case C - Organizational Aspects

Company C is organized in 6 main industrial divisions: shock absorbers, engine components, castings, exhaustion systems (mufflers), sintered parts, and polyurethanes. This case focuses on the shock-absorbers division.

In 1987, Company C began operation of its first production cells in various divisions, as part of a comprehensive group program called "Programa de Qualidade Total *Company*

C", or "*Company C* Total Quality Program". This includes statistical process control implementation, cell manufacturing, set-up reduction programs, MRP II implementation and better industrial relations. To support the program an ambitious training program was designed in which more than 10 thousand men.days per year are dedicated to off-the-job training. The results so far have been considered satisfactory by the managers. Now, they have a number of cells in operation. They also claim reductions in the average production lead time for piston rings, for instance, from 25 to 14 days, 5% reduction in work in progress and "substantial" (not quantified) improvement in conformance quality levels. The operators are nowadays in charge of the cleaning of the work place, basic machine maintenance and statistical process control. The formal manufacturing planning and control system is MRP II for the planning and control of materials supply and inter-cells coordination. The dispatching and very short term shop floor control activities are made by special task forces, called "follow-up teams", responsible for keeping up with recent program changes.

The industrial relations and payment schemes are conventional, the payment of direct labour is linked to good output levels and the approach to benefits is considered by one of the managers as "patronizing". According to him, being patronizing with the employees is a "trade mark" of the group founder-president. Emphasis is given to training, but not to multiskills development, what is at a certain extent surprising, given that the company is trying to migrate into cell manufacturing. The relationship with the powerful "ABC"[1] Unions has not been very smooth with a number of disruptive strikes cropping up during the last few years.

The divisions are reasonably autonomous, with division directors leading teams of within-division managers. However, when the group decided to implement the reforms in the production processes, a new position was created in the organization chart, that of Director for Productivity and Quality (who is one of the interviewees in this case-study), who reports directly to the group's president. The recently appointed director established, then, a multi-functional, multi-division team who ought to be the "catalysts" within each division, aiming at implementing the planned manufacturing changes.

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1 The "ABC" is a very industrialized region in Sao Paulo, where most of the automotive industry plants are located. It is a place where the Unions are very powerful.

8.3.2. Case C - The Interviewees

Three people were interviewed in Company C: the Operations Manager, the Senior Sales Manager (who had been, for long years, the Production Manager) and the Director of Quality and Productivity.

8.3.3. Case C - Variability of Outputs

The shock absorber division has approximately 2000 active products, according to the operations manager, being in general similar products which are not very different from each other in terms of process.

A shock absorber has approximately 30 different parts and components. In Company C, more than 90% of them are made in. The company used to buy some components, mainly sintered and polyurethane parts. However, as part of the group's policy of vertically integrate (another "trade mark" of the group president, according to one of the managers) to reduce transaction costs, the group bought out two companies in the 80's which are today the sintered parts division and the polyurethane division.

Approximately 150 product changes are performed each year in the shock absorber division, being 20 to 30 new designs. The changes are not made in batches but on a continuous basis.

The process of launching a new product is done on a conventional fashion, with well defined sequential stages of product design, process design, prototyping and production. The use of CAD is in the company's plans but it has not been implemented yet.

The variation in volume is what seems to worry the operations manager most, since the group has an aggressive marketing policy aiming at new export markets. The overall demand can vary 30% very suddenly. This is a concern, especially because the factory is "bottlenecked", with very high occupation rates. This is due to another policy of the group which is a "capacity-chasing-the-demand" policy for investments. Investments in new equipment are made only when there is a guarantee that the equipment will be fully utilized. The group can afford to do that, mainly in terms of the domestic market niche where Company C operates, which is a "seller's market". The company is virtually a monopolist in one of the product lines (piston rings) and nearly a monopolist in others (Company C has 75% of the shock absorber domestic OEM market and 85% of the replacement market, for instance).

8.3.4. Case C - Flexibility-related Competitive Priorities

Regarding the flexibility-related competitive priorities, two out of three managers specified new product flexibility as the particular flexibility type the company should primarily focus on (response seconded by range). The other manager mentioned delivery response and mix response as his first and second competitive priorities respectively. This inconsistency may be caused by a lack of common understanding of the company's manufacturing strategic policy. Since all of them gave great importance to fast response to customer orders, the lack of agreement seems to be between serving better the orders regarding existing products or giving priority to winning new orders for new products.

8.3.5. Case C - Uncertainty

The uncertainties mentioned by the managers as the ones which represent the highest risk to Company C's competitiveness are basically related to two aspects: the supply chain and the government intervention. The lack of clear and stable rules and policies, set by the government - mainly with regard to exchange rates - under which the company has to operate, affects, according to the managers, several aspects of the company's operations, such as the export market demand. This gives export product prices an important uncertainty component and can cause sudden changes in demand, because the company can, for instance, suddenly become more (or less) cost-competitive in external markets due to an unexpected change in the exchange rates. Two of the managers ranked "government intervention" as the most risky uncertainty source for Company C's competitiveness. The third manager ranked "demand uncertainty" as one of his main concerns what, in a way, is also related to the government intervention aspect, as explained earlier. He also considers uncertainty with "parts and materials supply" in terms of delivery times as risky. The managers also mentioned several other uncertainty sources, but they were quite positive that their first and second ones were the most relevant.

8.3.6. Case C - Coping with Uncertainty and Variability

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below:

NUMBER OF MANAGERS (CASE C) WHO MENTIONED THE RELATIONSHIP	UNCERTAINTY RELATING TO -->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
2	parts and materials supply	improve coordination with suppliers
2	labour supply	training
2	machine downtime	preventive maintenance
2	government intervention	short lead times
2	volume changes	forecasting systems
2	unions behaviour	monitoring environment
2	new product introduction	ability to subcontract
A number of other relationships were mentioned by not more than one manager. Nevertheless they are worth mentioning:		
1	information flow	buffer stocks
1	demand mix	reduce set-up times

Figure 8.3. Case C - The most mentioned relationships between uncertainty types, variability and flexibility-related resource characteristics, during the field work.

8.3.7. Case C - General Observations

When asked what they considered as the best ways to be used in order to cope with the different types of uncertainty and variability, the managers showed, in general, a similar approach. Maybe because of the company's conservative "culture", mentioned by all the managers interviewed, a greater emphasis was put by them in developing ways in order to control the sources of uncertainty, than in developing ways to deal with the effects of such uncertainty (such as developing flexibility).

Among the ways used by the Company C's managers to control the environmental change, vertical integration seems to play an important role. They vertically integrated the supply of parts (sintered and polyurethane parts), equipment (a division was established to manufacture machines for the group in order to avoid the usual problems with machine supply), labour (they bought out a secondary school to educate people from the community at the levels they needed) and technology (Company C has established a large research and development centre to reduce the need to rely on other companies as their technology suppliers).

About the relationship with their suppliers, after vertically integrating up to the point in which almost 100% of the parts are made in, they still try to control further the uncertainties with suppliers by improving the coordination Company C-suppliers, by means of establishing long term contracts and co-operation. In terms of demand, improving forecast systems is considered another important way of managing the demand changes the company has to deal with.

It seems that, generally, the managers see flexibility as something they have to develop in order to cope with the uncertainties. Ideally however they would rather control the causes of the uncertainties, aiming at reducing them. Since this is not always easily achieved in the short term, they have to develop flexibility.

Managers in Company C seem to rely more on infrastructural resources (particularly systems) than in human or technological resources to achieve desired levels of system flexibility. The three interviewed managers mentioned the need to develop more responsive systems, whereas they consider that labour multiskills are not very important for Company C's operation.

8.3.8. Case C - Relevant Findings

Managers in Company C see flexibility as a way to cope with uncertain changes when the causes of such uncertainty cannot be eliminated (see chapter 9 for a complete discussion on this issue).

Managers in Company C understand that different types of changes should be dealt with by developing different ways of exercising control and/or by developing flexible resources and systems (see section 8.7. "How do Managers Cope with Uncertainty and Variability" for further analyses on this issue)

Managers' perceptions in Company C show discrepancies regarding which are the flexibility-related competitive priorities for the division.

Managers in Company C do not seem to have a clear view about the differences between controlling the uncertainties and variability and dealing with the effects of the uncertainties and variability (this aspect is discussed in detail in chapter 9)

8.4. Case D - The British Vehicle Manufacturer

Company D is a vehicle manufacturing plant located in the Midlands, England and it is part of a large transnational corporation with head-quarters in North America and interests focused on automotive products, industrial machinery and engines. It is one of the largest factories in the world dedicated to the production of that class of motor vehicle and it specializes in the design, manufacture and supply for worldwide markets. Ninety per cent of the 65000 vehicle sets produced at Company D's plant each year are exported to over 140 countries. The annual turnover of the plant is approximately 120 million pounds.

8.4.1. Case D - Organizational Aspects

The Company D plant is organized functionally, on a "job-shop" type of layout, although they are now at early stages of the implementation of cellular manufacturing. Two pilot cells have just been established with promising results, according to the managers.

Company D's organizational structure is hierarchical although they have recently gone through organizational changes. Such changes included the substitution of a number of directors, the re-design of the organizational chart, the inclusion of many aspects of the matrix-type of organization, with the establishment of several multi-functional groups with specific goals, aiming at "breaking the barriers" between separate functions. Presently, the team members are dedicated to the projects on a part time basis, keeping links with their functional departments. According to the managers, the dedication of the members to the projects is planned to become full time in five years time.

There are statistical process control procedures implemented and the workers are responsible for the process quality. Equipment maintenance is still performed by a separate team, although the very basic maintenance procedures are performed by the operators themselves. This arrangement also applies to the setting up of the machines.

The formal manufacturing planning and control system is MRP II, although the managers consider the use of MRP II as an intermediate stage towards the JIT production. The day-to-day changes in the schedules however are done by a "people-based" informal system, because, according to the managers, the MRP II software packages do not provide the company with the flexibility it needs to cope with its broad product range and highly variable demand (see chapter 3, section 3.4. "Flexibility of the Infrastructural Resources" for a discussion on the flexibility of manufacturing planning and control systems).

8.4.2. Case D - The Interviewees

Four people were interviewed in Company D: the Supply Director, the Product Design Manager, the Advanced Manufacturing Engineering Manager and the Production Manager.

8.4.3. Case D - Variability of Outputs

Company D builds vehicles to order and has currently a line of 2 basic product families, with considerable differences between products or configurations within a family. The overall number of products or "derivatives" is theoretically 3640, of which, approximately 2000 are made in any one year, which is considered exaggerated by two of the managers interviewed. A third manager, on the other hand, considers product variety as the main competitive advantage of Company D. The variation in overall volume can be approximately 20% from month to month. The demand is seasonal and the variation in the mix of products demanded is also considered high.

The introduction of new products or the engineering changes of the existing ones is done on a continuous rather than on a batch basis. In average, thirty minor engineering changes are made each month and one substantial change per quarter in functional aspects of the products. Historically, the time period to introduce a totally new product has been five years. However, according to the managers, the company has recently made efforts in creating the conditions for the simultaneous development of new products, with multi-functional teams participating in the process since early conceptual stages, to ensure "design for manufacturing". Although no results have yet been noticed in terms of time to develop a product, partially because the emphasis has been in designing out unnecessary variety, the managers believe that reductions in time will soon follow.

8.4.4. Case D - Flexibility-related Competitive Priorities

The managers' answers concerning the flexibility-related competitive priorities of the plant are somewhat consistent, despite the fact that the answers are not exactly the same. The answers, regarding the priority flexibility-related tasks which the company should focus on, varied mainly between product and mix flexibility. This is understandable in a build-to-order environment, in which the distinction between mix and new product flexibility is not clear cut. The managers also seem to prioritize the range dimension of the flexibility types rather than the response dimension (see chapter 2 for a discussion on manufacturing flexibility types and dimensions).

8.4.5. Case D - Uncertainty

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company D's competitiveness show a consistent pattern. All the managers, for instance, placed "demand mix" uncertainty as their main concern. As a second main concern, two managers pointed "overall demand volume" uncertainty and two pointed uncertainty with "parts and material supply". It seems that the uncertainty sources which concern the managers most are those related with the demand.

Three of the managers qualified Company D's suppliers as very good and reliable. The ones which pointed "parts and materials supply" as an uncertainty source recognize that the uncertainty with the supply was a consequence of the uncertainty with the demand rather than caused by the suppliers themselves. The two factors which most concern the managers at Company D, in terms of uncertainty and variability are the demand uncertainty, mainly in terms of mix and, the large variety of products. Although two of the managers considered the variety of products offered by Company D as exaggerated[1], another one considers the variety of products as the most important competitive advantage of Company D.

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[1] Chapter 5 contains an analysis of the disadvantages of an excessive variety of produts and parts in manufacturing organizations.

8.4.6. Case D - Coping with Uncertainty and Variability

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below:

NUMBER OF MANAGERS (CASE D) WHO MENTIONED THE RELATIONSHIP	UNCERTAINTY RELATING TO	-->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
3	demand mix		rescheduling capability
2	parts and materials supply		supplier development, partnership
2	demand mix partnership		suppliers development,
2	demand mix		buffer stocks
2	product introduction		integration prod design/ proc.design/production
2	demand mix		fast set-ups
2	demand mix		forecast sensitivity

Figure 8.4. Case D - The most mentioned relationships between uncertainty types and flexibility-related resource characteristics, during the field work.

Managers in Company D also showed great concern about the large variety of the company product-line. They commented on some ways which they consider as appropriate to deal with it:

NUMBER OF MANAGERS (CASE D) WHO MENTIONED THE RELATIONSHIP	VARIABILITY RELATING TO	-->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
3	product variety		standardization
2	product variety		supplier development/ partnership
2	product variety		buffer stocks
2	product variety		fast set-ups

Figure 8.5. Case D - The most mentioned relationships between variability and flexibility-related resource characteristics, during the field work.

8.4.7. Case D - General Observations

A point which is worth mentioning is the emphasis given by the management in the achievement of manufacturing flexibility through the resources people and infrastructure.

Technological resources do not seem to play a major roles in the view of Company D's managers as ways to achieve system flexibility. This is possibly due to the inherited inflexibilities of the machinery they have. If that is the case, the managers would be conscious that they could not do much in terms of improving the flexibility of the system by using the technological resources apart from attempting to reduce set-up times as much as possible.

Another important point is the great concern placed on product variety by the majority of the managers. All of them mentioned variety as a source of complexity and argued that parts variety should be reduced although they seem to recognize that product variety is a competitive advantage for Company D.

It seems that some of the managers see flexibility as something they have to develop in order to achieve product variety - seen as a competitive advantage - but they generally prefer to control and eliminate unnecessary variety and uncertainty as much as possible via parts standardization, focus, improved forecasting systems and so on, in order to reduce the need to be flexible. Generally, when asked how they dealt with variability and uncertainties, they first mentioned measures (e.g. standardization) aiming at reducing the uncertainty and variability levels which Company D has to deal with. Then, when asked how they dealt with the changes *ex-post*, given that the changes have already occurred, they would mention flexibility-related measures (e.g. re-scheduling).

In terms of the uncertainty regarding demand mix, for instance, managers firstly mentioned the development of a cooperative relationship with suppliers and the development of better forecast systems aiming at reducing the uncertainty the system would have to deal with. On the other hand, they pointed out that fast set-ups, buffer stocks and rescheduling capability should be used to cope with the effects of the mix demand uncertainty, when the uncertainty and the variability are taken as given.

The number of managers mentioning the ways they are used to coping with demand mix uncertainty shows the importance they give to this factor. Additionally, they also emphasized the product variability, with 9 mentions by the managers. They suggest standardization and co-operation with suppliers and, buffer stocks and fast set-up as ways to deal with variability. This is a similar list (except for the item "standardization" which is exclusive for the variability list and "forecasting" and "rescheduling" - exclusive for the uncertainty list) to the one the managers suggested as appropriate ways to deal with mix uncertainty. That suggests that in an environment like Company D's, with a broad product line and where products are built to order, the uncertainty of the mix and the variability of products are regarded by managers as calling for similar resource characteristics.

8.4.8. Case D - Relevant Findings

Managers in Company D see manufacturing flexibility as an appropriate way to be used in order to cope with uncertainties and the variability affecting the manufacturing operations when the causes of such uncertainties and variability can not be eliminated or reduced (see chapter 9 for a complete analysis and further development of this point)

Managers in Company D consider that variability and different types of uncertainty call for different types of flexibility-related resource characteristics.

Managers' perceptions in Company D have a reasonable consistency in terms of the flexibility related manufacturing task they should pursue.

Managers in Company D consider that manufacturing flexibility is generally necessary to deal with broad product lines even when the demand is predictable. They also prefer controlling the variety of parts and products as much as possible than developing the flexibility necessary to deal with it.

8.5. The Cross-Case Analysis

In the cross case analysis, the aim is to identify and analyze the differences and similarities among the cases.

The first result found in the comparison of the case studies is that there was not a clear cut difference between the ways managers regard the management of uncertainty and variability between the Brazilian cases and the British cases. There was, for example, a major concern regarding the supply network as a source of uncertainty which can be risky to the company's competitiveness in all the cases. Other similarities are discussed below.

8.5.1. The Similarities

The preference for uncertainty and variability control - Although approaching the problem of dealing with change from a multitude of viewpoints, the interviewed managers generally showed a preference for trying to control the sources of the uncertain and variable changes (trying to reduce their impact) which the company has to deal with, rather than developing ways to respond to such changes, or in other words, developing flexibility. Not all the managers are able to conceptually discriminate clearly between *restraining the occurrence* and *dealing with the effects of* the changes but the fact is that intuitively they seem to prefer change restriction. This point is extensively discussed in chapter 9.

Supply chain uncertainties - in general terms, managers in all case companies showed great concern about the uncertainties related to the supply chain as being risky to the company's competitiveness. The exception was Company C, which is the most vertically integrated of all, with more than 90% of their components made in. Even in this situation, although two of Company C's managers considered the uncertainties with the "Government policies" as the most risky, Company C's operation's manager considered "parts and material supply" as the most risky uncertainty factor for the company's competitiveness.

The approach used to deal with the uncertainties with supplies was also somewhat similar among the managers in all companies. Preferably, they try to increase the control over the suppliers. The ways they use to do so vary, though. Whereas Company

C tended predominantly to vertically integrate, Company A, Company B and Company D tended to try to develop long term contract and co-operation with suppliers. In the very short term and because it is impossible to get rid of the stochastic component of the supply function process, managers in all companies emphasized the need to develop skills in re-scheduling the production quickly to allow the company to remain functioning by using the material which is available at the moment (when a faulty supply is identified).

8.5.2. The Differences

The government intervention component - certainly one of the great differences between companies is the concern with the unpredictability of the government policies. Such factor has not even been mentioned by any of the managers of the British case companies and have been mentioned by two out of three managers in Brazilian Company C as their greatest concern regarding uncertainty factors. The other Brazilian company, Company B had all the managers mentioning the unpredictability of the government policies but they actually do not feel so vulnerable to this unpredictability since none of the managers mentioned the government actions as risky for the company's competitiveness. Maybe these differences between manager's perceptions in two companies subject to the same government actions is due to the fact that Company C has a considerable amount of its turnover originating from exports, which can be directly affected by government actions regarding, for instance, exchange rate mechanisms. Even Company D, one of the British ones, which has 90% of its production exported to around 140 countries, did not mention government intervention as its concerns, although the exchange rates were mentioned as a source of uncertainty mainly relating to American currency, which is the reference currency to most of the countries with which Company D deals.

The emphasis given to different types of resource to achieve flexibility - Company A's managers consistently consider that system flexibility is primarily achieved through the human resource whereas Company C's managers in general give less emphasis to the human aspect of system flexibility. Instead, they rely much more on managerial and information systems to achieve the levels of flexibility they need. Company D's managers, in turn, regard systems and people as the key resource types for the achievement of manufacturing flexibility. This is possibly due to the inherited inflexibility of the machinery which the Company D's plant has (the company was initially set-up to produce high volumes of a low variety of products). Chapter 9 discusses the roles of the different resource types in the achievement of manufacturing system's flexibility.

The "arsenal" of solutions to cope with "uncertainty" changes - managers in Brazilian Company B produced the largest "arsenal" with which to deal with uncertainties of all the case companies. That is not surprising for the Brazilian industrial environment is notoriously less predictable than the British one and the other Brazilian case company is vertically integrated at the level of 90% and virtually a monopolist in its domestic market.

The concern about manager's behaviour under changing circumstances - It was remarkable, in Company B, the consistency of the managers' views, in terms of their concern about the uncertainties with the middle managers' behaviour under changing circumstance. Four out of 6 managers interviewed in Company B mentioned that point as risky to the company's competitiveness as opposed as no mention of that aspect by managers in any other case companies. This could be explained by the peculiar situation in which Company B currently is. All the present line of products will die out as OEM products by the end of 1997. In the meantime, a completely new technology will be introduced: that of the electronic fuel injection. The middle management probably are feeling very insecure about their jobs and demonstrating this anxiety in their attitudes since now. They will need to learn a new technology from scratch and this effort is being set off by now. The new technology is based primarily on electronics principles whereas the present one is based on mechanics principles.

8.6. Types of Uncertainty and Types of Flexibility-Related Critical Success Factors

The most mentioned relationships between uncertainty types and resource characteristics considered as the most appropriate to deal with them are shown below:

UNCERTAINTY RELATING TO	-->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
parts and materials supply		rescheduling ability
parts and materials supply		coordination with suppliers
parts and materials supply		buffer stocks
parts and materials supply		internal machine capability
product mix		rescheduling ability
product mix		fast set-ups
product mix		semi finished stocks
product mix		ability to get short lead-times
product mix		forecasting systems
machine breakdowns		preventive maintenance
machine breakdowns		fast corrective action
machine breakdowns		re-routing ability
labour absenteeism		labour multiskills
labour absenteeism		some excess capacity of labour
product introduction		integration prod.development
product introduction		ability to subcontract supply
management behaviour under change		training/awareness
demand		forecasting systems
labour supply		internal training
government intervention		short lead-times
technology information		ability to subcontract supply
unions behaviour		close monitoring

Figure 8.6. Summary of the cases: the most mentioned relationships between uncertainty types and flexibility-related resource characteristics, during the field work.

With regard to variability:

VARIABILITY	-->	BEST WAY TO COPE WITH IT IS BY DEVELOPING
product variety		standardization
product variety		buffer stocks
product variety		fast set-ups
product variety		coordination with suppliers

Figure 8.7. Summary of the cases - The most mentioned relationships between variability and flexibility-related resource characteristics, during the field work.

8.7. How do Managers Cope with Uncertainties and Variability

The way the questions were formulated made it clear that what was being asked was what were the *ways which the managers considered as appropriate in order to deal with* their current level of uncertainties relating to the various factors (since the primary aim of this research related to the flexibility aspect). The answers therefore were not expected to include primarily the ways the managers consider as appropriate to reduce the levels of uncertainty they have to deal with. However, so strong was the preference for adopting preventive measures against the uncertainties, among some managers, that they frequently insisted in mentioning ways to exercise control over the "uncertainty-related" and "variability-related" changes, before mentioning ways to respond or adapt to the uncertainties and variability. This can be noticed by the number of managers who mentioned, for example, preventive maintenance and coordination with suppliers to reduce the uncertainties with machine breakdowns and parts and materials supply respectively. The way the question was formulated can also explain why the number of answers regarding flexibility aspects is still higher than the number of answers regarding control, whereas it has been said in this report that in general managers have a preference for controlling the changes they would otherwise have to deal with. The relationships between different types of uncertainty and variability and the best way to deal with them, according to the managers will be explored further below:

Parts and materials supply - By far the uncertainty factor which appears more frequently in the mentioned relationships. The managers deal with it:

-by developing system's rescheduling ability - Eight of the managers mentioned the system's rescheduling ability as a way to deal with it. Once a faulty supply is identified, the schedule has to be re-done to allow the system to continue functioning, processing the next order which already has available the necessary material. Interestingly, all the interviewed companies except for one (company D) had rescheduling systems which were based on some key people's ability. They say that the formal systems help check availability of materials, but other factors also have to be considered such as orders priorities, subsequent bottlenecks, among others, which the formal systems can not keep up with. They also mentioned the slow responsiveness of the computerized systems (MRP II was being run once a week in the three companies which had it installed) for very short notice changes (see chapter 3, section 3.4.2. "Flexible Supply Network Management" for a discussion on the flexibility of the most usual production planning and control systems).

- by developing coordination with suppliers - six managers mentioned the need to develop closer links with suppliers in order to reduce the level of uncertainty in the interface between the customer-company and the supplier-company. They mentioned, among others, longer term contracts with reduction of the supplier base, cooperation, technical collaboration and intense information interchange as ways which can be used in order to reduce the uncertainties of the interface customer-supplier. The full "partnership relationship" is generally considered by the managers as a goal, but they consistently recognized that they still had a long way to go in developing such relationship. Meanwhile, other sort of solutions should therefore be used to cope with the effects of the current confrontation-type of relationship, which most of them still have with their present suppliers (see chapter 3, section 3.4.2. "Flexible Supply Network Management" for a discussion on the relationship customer-supplier)

-by building up buffer stocks - the managers tended to make it clear that they considered stocks as being undesirable, in principle. Nevertheless, three of them mentioned the use of what two of them called "strategic stocks" (the timely build up of stocks of raw materials or components when they notice that a problem with supply might be imminent). One example was Company C who starts building up buffer stocks of iron powder for sintered parts every year in October because they know it is likely that the North American winter causes delays in the transportation of the powder, imported from the United States (see chapter 9, section 9.4.3. "The Flexibility of the Structural Resources" for a discussion on the role of buffer stocks in the development of manufacturing flexibility).

-by developing internal capability - some managers consider that having a broad internal capability is a good way of dealing with uncertain supplies. In Company B, for instance, it is not rare that parts which are received below the quality specification levels are reworked in. That also happens when the suppliers are too busy to complete the part. Sometimes Company B accepts the parts semi-finished and finishes them by using its internal capability. (see chapter 9, section 9.4.3. "The Flexibility of the Structural Resources" for a discussion on the role of the resources capability in the development of manufacturing flexibility)

Product mix - uncertainty regarding the product mix also appeared a number of times among the relationships mentioned by the managers. Fourteen managers explicitly mentioned ways they considered as appropriate alternatives to deal with product mix uncertainty and these ways can be grouped in four:

-by developing rescheduling ability - to be able to respond quickly to the changing demand mix. Interesting enough, the two companies whose managers considered their companies' ability to reschedule to be good (Company A and Company B) had the rescheduling made by a skilful scheduler, rather than by a system. On the other hand, the company who had the rescheduling system almost completely automated by an MRP II system was considered by its own managers to have a poor performance in terms of rescheduling.

-by developing *fast set-ups - with fast set-ups, some managers argue, the cost and times* for changeover are reduced, allowing for quicker response to the changes. All the case companies had programs running on set-up reduction. Set-up reduction was consistently one of the first aspects to be mentioned by managers when talking about developing flexibility in general. In a first approach, before analyzing types and dimension of flexibility, managers seem to associate flexibility very closely with fast set-ups (see chapter 3, section 3.2. "Flexibility of the Technological Resources" for a discussion on the role of the set-up times in the achievement of manufacturing flexibility).

-by having stocks of semi-finished goods - stocking components and parts and assembling them or configuring them to order was also mentioned as a way to respond quickly to demand mix changes. Another interesting approach for reducing the response time to mix changes is used by Company A: as the engines they make have a number of common parts and features they have rearranged the assembly operations sequence along the track to assemble all the common features first and the special features, those which actually differentiate the engines later. In doing so, they managed to reduce the time elapsed to changeover products in the assembly line from 7 hours to two hours in average.

-by developing the ability to get short supply lead-times - according to the managers, that can be achieved either by efficient procurement or by coordination with suppliers.

Having short supply lead-times, companies would be able to respond better to unexpected changes in their product mix.

Machine breakdowns - mentioned 10 times by various managers. The two approaches in dealing with unexpected changes are quite clear cut in this aspect of the case studies.

-by developing preventive maintenance - that is another clear example of the insistence of the managers in the preference for controlling or restraining the occurrence of the changes. Five of them mentioned that the best way to deal with breakdowns is by not allowing them to happen.

-by developing the ability to take fast corrective actions - once the breakdown occurred, acknowledging the occurrence and mobilizing the right resources to have the machine up and running again is what fast corrective action is about, according to the managers who mentioned it. Company B, for instance, keeps a separate budget, controlled by the production manager (for the urgent replacement parts purchase not to have to pass through the purchasing department) and even a car specially dedicated to fetch the replacement parts in case of critical breakdowns. This scheme is kept in parallel with a preventive maintenance program also been worked on (see chapter 9, section 9.3.3. "Flexibility: Dealing with the Effects of the Stimuli" for further discussion on this issue).

-by developing re-routing ability - that aims at by-passing the broken machine. To be able to do that quickly, Company B has recently done a study on "what machine can perform what part" and displayed the result on a big board on each manufacturing unit so that the foreman can quickly redirect all the critical parts in the broken machine queue to other machines which can perform the operation the part was queuing for.

Labour absenteeism - mentioned 9 times. A consistent level of absenteeism was found in all companies - all of them varying from 3 to 6 %. the Managers mentioned two basic ways of dealing with it:

-by having some excess of labour capacity. All the companies keep some excess workers for absenteeism cover, ranging from 3 to 6%. However, excess capacity is not enough for companies to be totally covered against absenteeism. Company C's assembly line, for instance, needs 50 people to be run, but they need the right 50 people. One can even be sure that the next morning 50 people will be ready to work in the line and still one cannot tell whether he is going to have the right set of skills to run the line. The solution, mentioned by several managers is to develop multiskilled workers.

-by developing multi skills - if some of the workers at a production unit are trained to perform a number of the unit's tasks, it is more likely that within the 50 people of the example above, there will be the right skills to run the line.

New product introduction - uncertainties with new product introduction and product changes (regarding launch dates, specifications and so on) were mentioned by 6 managers. The way they consider appropriate to deal with them is:

-by developing inter-function integration between product design and development, process development and production - to make sure that the products are designed to manufacture right first time. A number of aspect of this integration were mentioned by one of Company A's managers, describing a recent and very successful introduction of a new engine to equip a new car (the elapsed time between the initial conceptual ideas about the car and the first car to be assembled regularly was reduced to 3 years, a record for the company): multi function team approach, early involvement of direct workers in the design and prototyping phases, early involvement of suppliers and delegation to expert firms of the task of designing and developing the parts, reduction of the number of suppliers and tendency to establish long term contracts with them.

-by development of the ability to subcontract supply - Company A and Company C's managers mentioned the ability to subcontract supply as a way of dealing better with the uncertainties regarding new product introduction. However, they mentioned subcontract supply for two different reasons. Company C is a company with a very high occupation rate, "bottlenecked", in the words of one of its managers, not only in terms of production but also in the product development function. One of the Company C's managers mentioned that there was a queue of 6 months to get a new die made, because of the company's machining shop overutilization. The manager thinks that if the company subcontracted external companies to make the dies, they would be able to respond much better to the demand for new products. The Company A's manager who mentioned supply subcontract, on the other hand, was referring to a different type of supply. According to him, Company A is following a trend in the automotive industry: the car assemblers would be delegating the task of designing and developing the parts to expert firms. Company A, for instance, had always designed its own diesel engines. With the new laws and regulations regarding emissions, the technology involved has evolved quite quickly in recent years and hence Company A preferred to buy in the design of its new diesel engine from an expert firm in Italy. (chapter 9, section 9.3.2. "Control - Managing the Influx of the Stimuli" discusses the role of subcontracting and a number of other actions in managing unplanned change).

Management behaviour relating to change - all four managers who mentioned management behaviour were Company B's managers. Probably what made them mention this aspect was the peculiar situation in which the company was by the time of the interviews. In 6 years time they expected the whole of the current line of products to die as OEM products. A new technology (electronic fuel injection) and the introduction of a totally new product line was being planned, what had caused, according to the managers, mixed feelings among the middle managers - on one hand, they were motivated by the challenge, but at the same time somewhat anxious and insecure because of the "unknown" to come. According to the managers interviewed, the way they were using to deal with this uncertainty is

-by emphasizing manager training and improving their awareness about the changes to come.

Demand - uncertainties about demand were mentioned by three managers who associated it with the need for the development of better forecasting systems, to reduce such uncertainty.

Labour supply - mentioned by two Company C's managers who were at the time of the interviews, facing a problem with finding the right skills to man a new factory which Company C had opened in a remote country side region. The way to deal with this uncertainty, according to the managers is to intensify the training done within the company. This way, they can recruit people who are not qualified and provide them with the right skills.

Government intervention - mentioned by two out of three Company C's managers as the most risky factor for their competitiveness. This concern is probably due to the dependence of Company C on export markets to support its strategy, which in turn is dependent on government policies, regarding exchange rates. Unexpected changes in the exchange rates can make what seemed a good deal at the sale, a bad one at the time the payment is done. According to the managers, the only way out is to reduce all the cycle times involved in the production to reduce the company's products' lead-times. With shorter lead-times, according to the managers, the company is less vulnerable to such uncertainties.

Unions behaviour - mentioned by 2 managers in Company C, probably because they are located in a region where the Unions are very powerful. They see close monitoring of the Union behaviour as the only way to avoid an unexpected strike, for instance.

Product variety - mentioned 9 times by the managers. They approach the variety issue in several ways:

-by developing standardization - managers mentioned standardization of parts as well as standardization of products. They emphasized that the best way of doing it is by designing out excess variety and actually to have different parts among products, exclusively for the parts which represent the difference between products which the customer actually values.

-by developing coordination with the suppliers, in order to help them shorten lead-times, set-up times and therefore reducing their lot sizes, in order to make them more able to respond to a higher variety of parts.

-by having strategic buffer stocks of some parts with low level of value added, aiming at reducing their perceived lead-times.

-by having fast set-ups - the more quickly switchable the resources are, the greater the variety of products the system can provide within a certain period.

8.8. Analysis of the 6 Research Propositions

The six research propositions formulated from an analysis of the literature in chapter 6 are now discussed based on the elements drawn from the case study.

Proposition 1 *- The variability of the manufacturing system outputs together with the uncertainties to which the manufacturing system is subject are factors which condition the companies to develop manufacturing flexibility (Slack, 1989) (Gerwin, 1986) (Gupta and Goyal, 1989).*

Confirmed - Invariably all the managers pointed flexibility as a necessary characteristic of their systems in order to cope with their current levels of uncertainty and variability. This can be noticed either explicitly or implicitly in their answers. Some managers would mention specific system's flexibility types when asked what they considered as the best way to deal with uncertainty and variability types. Others (in fact the majority of the managers) would mention resource characteristics which are linked to the concept of flexibility, such as fast set-ups to deal with uncertainties with the demand mix, Labour multi-skills to deal with demand variability, among others.

Proposition 2 *- Uncertainty and variability are sufficiently coped with by developing 4 types of flexibility at the system level: new product, mix, volume and delivery (Slack, 1988).*

Refuted - The case studies showed evidence that the managers interviewed, in general, consider the four types of system flexibility proposed by Slack as appropriate to model the flexibility which is necessary to cope with the variability of outputs and uncertainty at least with regard to the company's demand side. With regard to coping with uncertainties within the process (machine breakdowns and Labour absenteeism, for instance) and with the input side, however, another type of flexibility appears to be necessary to be developed at the system's level. It refers to the ability of the system to remain working despite unplanned changes in the process and in the company's inputs. This was clear with company B, for instance. Their managers were very aware of the need for this additional type of system's flexibility, because their aged machinery was not considered by them as reliable. They had to establish infrastructural (systems) and structural (equipment and people) resources with the specific aim of reacting quickly to machine breakdowns. These resources included, for instance, a chart showing, for one machine shop, which machine is able to perform which part, spare capacity of some machines (both in order to allow for the shop manager to quickly reroute the jobs in case of a breakdown) and a car which was exclusively dedicated to fetch the necessary spare parts in the market in case of breakdowns.

Proposition 3 *- Managers focus more on resource flexibility as opposed as system flexibility (Slack, 1987).*

Inconclusive - Some managers, when asked about the way they considered as the best way to cope with uncertainty and variability of outputs, mentioned flexibility-related characteristics of individual resources (e.g. flexible machinery). Other managers, on the other hand, mentioned characteristics of the set of resources, such as the ability of the manufacturing system to reschedule the production (which is highly dependent on the manufacturing planning and control system, but also on the ability of the structural resources to switch between activities). However, when dealing with flexibility at the system level, they seem to have more difficulty than when dealing with flexibility at the resource level. The managers seem to lack terminology and possibly a consistent model to refer to, when discussing the different types of system's flexibility. When introduced to Slack's model (according to which the manufacturing system flexibility would have 4 types - new product, mix, volume and delivery and two dimensions - range and response), in the last part of the interviews, they were generally satisfied with it, with regard to the analysis of the flexibility, at least of the system's outputs. They were also able to understand the model quickly and to use it in order to rank their flexibility-related priorities in the last part of the protocol.

***Proposition 4** - Different patterns of uncertainty and variability call for different types of manufacturing flexibility (Gerwin and Tarondeau, 1989; Slack, 1987).*

Confirmed - The use of flexibility in order to cope with uncertainty and variability of outputs appeared to be highly contingential in the manager's views. This can be seen in the extensive lists which can be found in the "within case analysis" report, in early sections of this chapter and in details, in the Appendix 3. These lists show different flexibility-related ways which the managers considered as the most appropriate to deal with different types of uncertainty and variability. The relationships are not one-to-one. Some of the flexibility-related ways the managers mentioned can serve a number of purposes, or, in other words, can be used to deal with a number of uncertainty and variability types. The same way, one type of uncertainty or variability can also be dealt with by a number of alternative or complementary ways. The contingentiality of the relationship however was confirmed by the field work.

***Proposition 5** - Managers would try to reduce the uncertainties to which their operations are subject (Thompson, 1967).*

Confirmed - As a rule, managers seem to prefer to reduce the uncertainties which they are subject to than to have to react to the "uncertainty-type" changes when they crop up. This was one of the most remarkable and consistent aspects of the case study. Invariably the managers would show a preference for reducing the levels of uncertainty they operate under (unless they are competing strategically based on their ability to react to uncertainties to which the whole market is subject). However, as it is impossible or sometimes not viable to eliminate completely the stochastic component of the changes they have to deal with by controlling (or restraining) them, they then use flexibility to deal with the changes which were left uncontrolled. In some cases, the preference for reducing the uncertain changes was very clear, e.g. virtually all the managers pointed the preference for developing effective preventive maintenance procedures as opposed as to carry on buffer stocks or to invest in quick corrective maintenance. Another situation in which the preference for control was clear refers to the uncertainty with the supplies. All the companies' managers showed preference in terms of developing coordination and a better relationship with their suppliers as opposed as carrying buffer stocks in order to cope with supplier uncertainties. In the cases where the company uses the ability to react as a competitive advantage, however, the preference for reducing the levels of uncertainty was not so clear. In case A for instance where Company A assemblies cars to the specific customer order, the managers see their ability to change quickly the production program as something that represents a competitive advantage to them and in this case the preference for controlling, for instance the number of final products in order to improve the predictability of the demand mix was not clear as opposed as to invest in achieving and maintaining superior levels of manufacturing flexibility.

Proposition 6 - Managers seek to limit the need to be flexible (Slack, 1987).

Confirmed - That seems to be a "richer" way of stating proposition 5, because uncertainty was not the only variable managers try to control. They actually seem to try to control the changes to which their operations are subject to, be them either certain or uncertain.

There are some instances, on the other hand, in which managers compete based on their ability to react to changes in the environment. When all the competitors are subject to the same changes, effective reaction to change can be a competitive advantage. In such situation a reduction in the environmental pattern of change in itself could result in a reduction of such advantage. One could think that in this situation, managers would behave in an opposite way, trying to encourage the market to demand more changes. That can be true and it seems to happen when companies offer customized products for instance (e.g. companies A and D). However, the managers still try to reduce the need to be flexible by reducing the need to be flexible which appears as a result of uncertainties, excessive or unnecessary variety of parts, or any other imperfection regarding the inputs and process which are under the organization's control.

8.9. Conclusion

The case studies also evidenced some relevant points with regard to the research question formulated in chapter 6. Most of such points however are further analyzed in chapter 9.

The managers consider flexibility as one of the ways to deal with change in organizations, mainly when the change perceived by the organization cannot be eliminated by restraining its occurrence.

The managers not always explicitly discriminate between control and flexibility and not always have a clear view of what should be the most appropriate way to deal with the different types and dimension of change. However, they were able to mention a number of ways they actually use in order to reduce the levels of uncertainty and variability they have to manage and also a number of ways they see as alternatives to be used in order to react to the changes they did not control for some reason.

The managers understand that different types of change should be dealt with by developing different types of resources. However, they in general do not seem to have a consistent model to help them make decisions in that regard, what causes anxiety and sometimes frustration to a number of them.

The managers who are more aware about manufacturing flexibility see flexibility as a "reserve", something which should be planned for, developed, maintained and considered as a valuable asset of the organization. However, this view is intuitive and the managers were not able to explain it or analyze it in more depth.

The managers who face the most uncertain situation with regard to supply (erratic or uncertain supplies, for example) and process (unreliable machines, for example), develop specific characteristics of the set of their structural and infra-structural resources in order to increase the reliability of the manufacturing system. This does not include only procedures which aim at increasing the reliability of the individual resources, such as preventive maintenance, but also procedures which involve the set of inter-acting resources.

The managers generally found Slack's (1988) classification of flexibility in types and dimensions understandable and useful, at least to describe the flexibility aspects which are related to the output of the manufacturing systems.

The next chapter, "A Model to Understand and Analyze Unplanned Change From an Operation's Viewpoint" is an attempt, drawing evidence from the field work and from the literature, to build theory regarding the relationships between the variables uncertainty, variability of outputs and flexibility of the manufacturing systems.

Part IV - Results and Conclusions

Part IV describes the principal results of this research work. An original model for the analysis of flexibility of manufacturing systems is proposed and described in chapter 9, "A Model to Understand and Analyze Change from an Operations Viewpoint". The development of the model is based on the literature - reviewed in Part I - and on the field work, described in Part III.

In chapter 10, "Conclusions", the overall conclusions of the research are drawn. Some unanswered questions and avenues for further research are proposed and discussed and a critical review of this research work is done.

Chapter 9 - A Model to Understand and Analyze Unplanned Change from an Operations Viewpoint

The objective of chapter 9 is to develop a conceptual framework aiming at helping to understand, analyze and manage what will be termed the "unplanned changes" which affect the manufacturing system's operations within organizations.

In order to attain this objective, both the relevant literature from Part I and the field study from Part II are used to support and guide the analysis and the resulting proposition of a classification of unplanned change types.

A new approach to the management of unplanned change is also proposed, which involves two complementary concepts: flexibility and unplanned change control. "Unplanned change control" is related to actions which aim at avoiding to have to deal with the changes whereas Flexibility is related with the decisions and actions aiming at dealing with the effects of the unplanned changes which are left "uncontrolled".

The role of the different types of manufacturing resources (structural and infra-structural) which determine both flexibility and unplanned change control is also analyzed. A new way of approaching the flexibility of the structural manufacturing resources is proposed. The new approach is based on the observation that the flexible structural resources always possess some level of redundancy in terms of its capability, capacity and/or in the way the resources are utilized.

Chapter 9

A Model to Understand and Analyze Unplanned Change from an Operations Viewpoint

Some authors (Slack, 1989; Gerwin, 1986, among others) have suggested that flexibility is needed in order to deal with the intrinsic uncertainties and the variability of outputs which are always present to some degree in manufacturing systems (see chapter 2 for a discussion on flexibility of manufacturing systems).

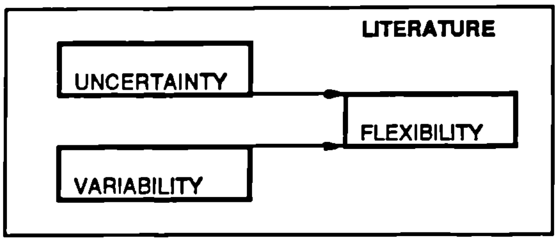

Fig 9.1 - The reasons to be flexible, according to the literature.

From the case studies (described in chapter 8), however, it was noticed that, at the level of analysis[1] adopted in this research, the managers generally, during the interviews, attempted to "translate" the abstract terms "uncertainty" and "variability" into terms which were more meaningful and closer to their activities. For example, variability with regard to demand mix was translated into, or thought of, as frequent process *changeovers* between products; uncertainty regarding machine breakdowns was translated into unexpected *changes* in the availability of the machinery which could be used to perform the necessary tasks; variability with the product line was translated into *changes* in the tasks to be performed, from old ones to possibly novel ones; variability with demand volume was translated into *changes* in the occupation rates of the plant and the work volume to be done. It was also observed that, according to the manager's viewpoint, both the *variability* and the *uncertainty* affecting their operation are linked to the concept of *change*. *Uncertainty and variability,* then, are regarded as attributes of

[1] The level of analysis is the level of production units (see chapter 6 for details).

change. By analyzing the manager's answers it is possible to attain a better understanding of their views with regard to the concept of *change,* which is relevant to the present research. The next section discusses the concept of change, drawing contributions from the literature and from the field research.

9.1. Change - Definition and Segmentation of the Universe

When dealing with change in organizations, the literature makes an important distinction between two major types of change: the unplanned changes and the planned changes (Cummings and Huse, 1989; Lawrence et. al., 1976).

The first type, unplanned changes, are changes which happen independently of the organization will but to which the organization has to adapt, e.g. an unexpected change in demand, a machine breakdown or a faulty supply. In this research, they will be called the ***stimuli*** acting on the system. Stimuli are thus defined here as the changes - either internal or external to the organization - which are perceived by the system's managers as relevant to the system's working and which happen independently of any conscious organization's managerial decision.

The second type, planned changes, happen as a result of the organization's conscious managerial decisions which are taken, in order to alter some aspect of the organization or its relationship with the environment. The implementation of a new technology aiming at quality improvements and, programs to improve the level of commitment of people to the organization's goals are examples of the second type of changes.

Change types	Planned change
	Unplanned change or Stimuli

Fig 9.2 - Change types.

Most of the definitions found in the literature on organizational change refer to planned change. Wieland and Ullrich (1976) consider change as an organizational response made in anticipation of substantial environmental changes which, in turn, are associated with environmental discontinuities. The authors do not go further in defining "environmental discontinuities". Benne (1961) adopts Kurt Lewin's definition: change would occur when an imbalance occurs between the sum of the restraining forces (those forces striving to maintain the status quo in the organization) and the driving forces (those pushing for change) which constantly affect the organization. Lawrence et. al.

(1976) also emphasize planned change in their definition: change would be an alteration in the organization design or strategy or some other attempt to influence the organization's members to behave differently.

In the present context, because the interest of the research do not especially emphasize planned change, a broader definition of change will be adopted, which is a modified version of Cummings and Huse's (1989) which in turn was based on Lewin's:

Change in the present context is defined as, "any modification, originated internally or externally to the organization, of those forces keeping a system's behaviour stable and running, without the need for any special decision or action by any of its elements". Whenever a modification happens to one of these forces which calls for any decision or action, we consider that a change happened.

The two types of change, unplanned change (which will be alternatively called *stimuli* in this research) and planned change represent concepts which are not mutually exclusive. Dealing with some types of *stimuli* may call for planned change. Organizations can use planned change to more readily solve problems, to learn from experience, *to adapt to other changes* or to influence future change (Cummings and Huse, 1989). Changes in the available technology, such as the development of MRP II systems[2] in the 70's, for instance, lead the companies which decided to use it, to take a number of decisions and actions in order to consciously change (planned change) aspects of the organization in order to prepare and adapt to the new technology (Corrêa, 1988; Wight, 1982). In the present research, we will be interested in discussing the *stimuli*-type of change and how the organizations manage it. This is because *stimuli* is the type of change which, according to the literature (see chapter 2 for a discussion on the objectives of flexibility), calls for the flexibility of the manufacturing systems, at the level of analysis we are interested.

9.2. Stimuli - Nature and a Proposition of Taxonomy

As open systems (Thompson, 1967), manufacturing organizations are continuously subject to the influence of stimuli originated from a series of internal and external sources, namely the process itself, the Labour, the suppliers, the customers, the corporate management, the other functions and the competitors.

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[2] See chapter 3 for a brief description of MRP II (Manufacturing Resources Planning) systems.

Stimuli sources	Process Labour Suppliers Customers Society Corporate & Other Functions Competitors

Fig 9.3 - Main stimuli sources affecting manufacturing systems.

9.2.1. The stimuli dimensions or attributes.

Variability and uncertainty can be seen as attributes of the unplanned change or the *stimuli*-type changes. A particular *stimulus* can be more or less certain (or predictable) and, more or less variable. However, it was noticed in the discussion with the managers, during the field study, that variability appears to be too broad a concept to allow for an adequate analysis at the level adopted in the present research. Generally, variability had to be specified in more detail to be analyzed by the managers. The managers also mentioned, in a number of opportunities, examples of unplanned change types which they usually have to manage. Such examples can help in the search for a taxonomy of *stimuli*. The following section cites some examples from the field study.

Types of stimuli found in the field work

The marketing function of a Brazilian heavy weaponry manufacturer (one of the case companies of the pilot field study), facing a military off-road and light vehicles sales drop in the late 80's decided to launch a new line of products - jeep-type light vehicles - to the consumer market. This decision was made as an attempt to utilize the plant's idle capacity. Such change in the marketing strategy represented a completely novel set of stimuli to the manufacturing system e.g. new quality requirements, new competitive criteria and new production volumes to which they had to respond. *Novelty,* therefore, seems to be a relevant aspect or dimension of stimuli for the study of manufacturing flexibility. It relates to how novel is the situation brought up by the change.

A division of a British car manufacturer (field work's Company A) which manufactures engines, faces changes in its demand mix for engine derivatives on every shift. Some of such changes are due to frequent and unexpected changes in the schedule of its internal customer, the vehicle assembly line. Others are an intrinsic part of Company A's business, which assembles vehicles to order. This requires the engine plant to produce approximately 60% of the total number (78) of engine derivatives on every one week, resulting in frequent machine and assembly line changeovers. Some Japanese motorcycle manufacturers are another, and perhaps less trivial, example of frequency of change. They have a broad variety of products. Therefore, even with a very stable "frozen" production plan period (what could give the impression of a situation of few changes), their operation functions face and have to respond to frequent changes because they have to produce a multitude of products within a limited period using a limited amount of resources (Stalk and Hout, 1990). ***Frequency*** thus, which relates to how frequent is the occurrence of the change seems to be another relevant dimension of the stimuli, for the purposes of the present research. Figure 9.4. illustrates the point by showing an example of two hypothetical volume demand-related changes, represented by 2 different demand curves - "A" and "B". They represent changes in demand which happen with different frequencies.

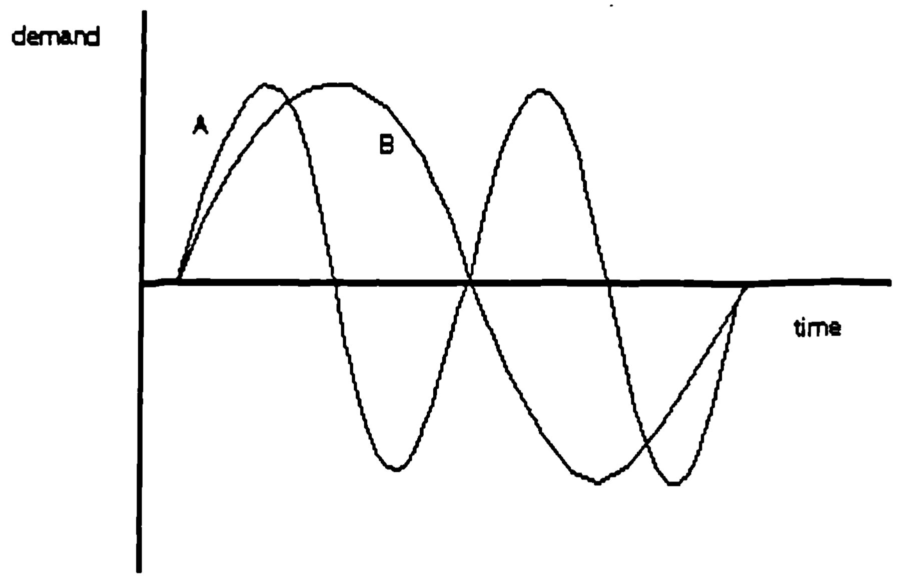

Fig. 9.4. A hypothetical example of demand volume changes: different frequencies.

A third dimension, as expected from the suggestion of the literature, is the ***Certainty*** of the change. The Company A's engine shop had a high degree of uncertainty regarding its demand changes. The engine shop and the paint shop worked based on the same master schedule. However, because of unexpected changes in the paint shop's schedule due to technical problems, the engine shop had its demand frequently changed so as to match the actual outcomes of the paint shop. Probably because of lack of coordination between both units, the engine shop assembly line schedulers did not know timely what car body was coming out from the paint shop and therefore what engine types should be produced. They had to schedule the engine's assembly line under conditions of severe uncertainty and therefore, according to one of its managers, to master the art of "fire-fighting", or reacting quickly. ***Certainty***, therefore is another relevant dimension of *stimuli* for the analysis of flexibility. It relates to how complete and accurate is the information which the system has about the changes - either present changes (something that has changed but the system has not acknowledged for some reason) or future changes (the predictability of the change).

A fourth dimension, which is complementary to the first three, can be logically identified: similarly to the dimension Novelty, it relates to how different the new situation brought up by the change is, compared to the situation before the change. However, a change may be large, but not novel, predictable (not uncertain) and not frequent. Company D has a highly seasonal demand, what causes large changes in its demand volume from summer to winter. Although the aforementioned demand Company D curve shape is very predictable and not novel, the demand in both seasons are substantially different, and probably call for a different managerial response than the response demanded by the three first stimuli types. The fourth dimension thus relates to the ***Size*** of the change. Figure 9.5. illustrates the difference in size of a change by showing the hypothetical demand curves "A" and "B", which represent changes of same frequency but different sizes. Another way of looking into the size of the change is analyzing it along the time axis. In this sense, both demand levels represented by curves "A" and "B" change substantially, along the time.

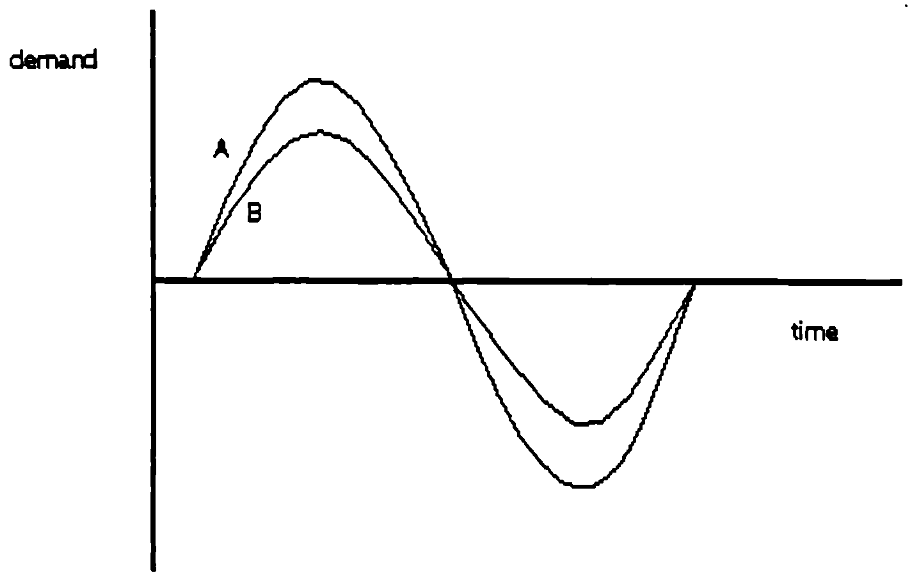

Fig. 9.5. A hypothetical example of demand volume changes: different sizes.

There is a fifth dimension of change which is relevant for this research. Change in demand volume is one of the main concern for Company C's managers (see Appendix 3 for details). Their concern is not only because the changes are uncertain and large but mainly because the demand volume changes considerably in a very short period. Sometimes, one single large order can represent a considerable percentage of the annual production of the company. In order to fulfil the order, they would have to change their output rate considerably in a very short period. In the words of one of Company C's managers:

> "Last week, for instance, an American buyer came to us and ordered 128000 shock absorbers. This represents 10% of our annual production... We will have to struggle to deliver them in the four months period we promised."

Responding to this sort of "steep slope" in the demand curve probably requires that the organization develop different abilities than those which would be required to respond to changes of the same magnitude (size) but which happen at smaller rates. The ***Rates*** of the change seems therefore to be a fifth relevant dimension of change for the purposes of this research. Figure 9.6. illustrates this point by representing two hypothetical demand curves which do not differ in frequency and size, but differ in rate.

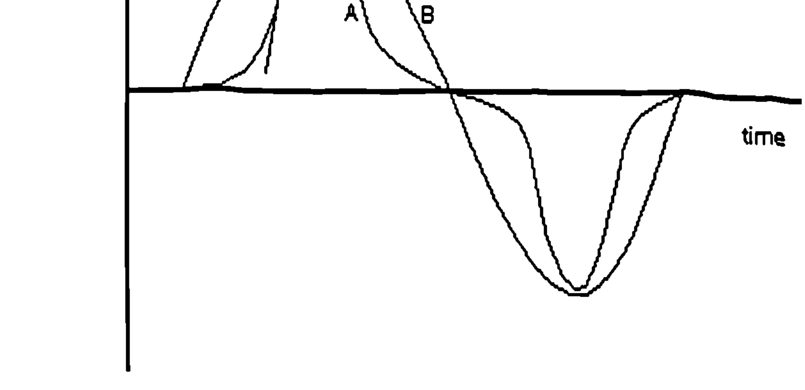

Fig. 9.6. A hypothetical example of demand volume changes: different rates.

The demand curve "B" in Figure 9.6. changes at a larger rate than demand curve "A", for a certain period of time, as can be seen by the difference in angles "a" and "b", which represent the rate of demand change for curves "A" and "B" respectively, at a certain point in time.

	company A	company B	company C	company D
size	n/a	n/a	n/a	demand: seasonal with reasonably known general pattern
novelty	technology: changes due to new emission control laws	technology: for the new line of products - fuel injection systems	technologies: concerning the high technological content products	n/a
frequency	demand mix: products made to order what makes each and every vehicle different	machinery: frequent machine breakdowns due to unreliable and dated machinery	suppliers: frequently missing due dates (25% of the deliveries)	demand mix: a broad range of possible products to be made with scarce resources
certainty	cell demand mix: changes in the engine assembly line program	supply: erratic supplies in terms of dates and quality	government policies: changes in the exchange rate policies of the government	demand mix: changes due to the diversified set of customers (from 140 countries)
rate	technology: technology involved with diesel engines evolving too quickly	n/a	demand: large orders change the demand curve dramatically in a short time period	n/a

Fig. 9.7 - Some examples from the field study with regard to change types.

Summarizing, based on the field work and on logical analysis, a taxonomy is proposed in order to analyze *stimuli* and its links with flexibility: there are five dimensions of stimuli, which are relevant to the analysis of the manufacturing systems' flexibility, at the level we are interested in this research: the *size*, the *novelty*, the *frequency*, the *certainty* and the *rate* of the *stimuli*. Putting it in other words, the pattern of *stimuli* to which the manufacturing systems are exposed can vary in terms of its magnitude and dynamics. In terms of the magnitude of the stimuli, *how large* and *how novel* it is, are two relevant dimensions. In terms of the dynamics, *how frequent, how uncertain* the changes are and, *at what rate* they happen, are two other relevant dimensions.

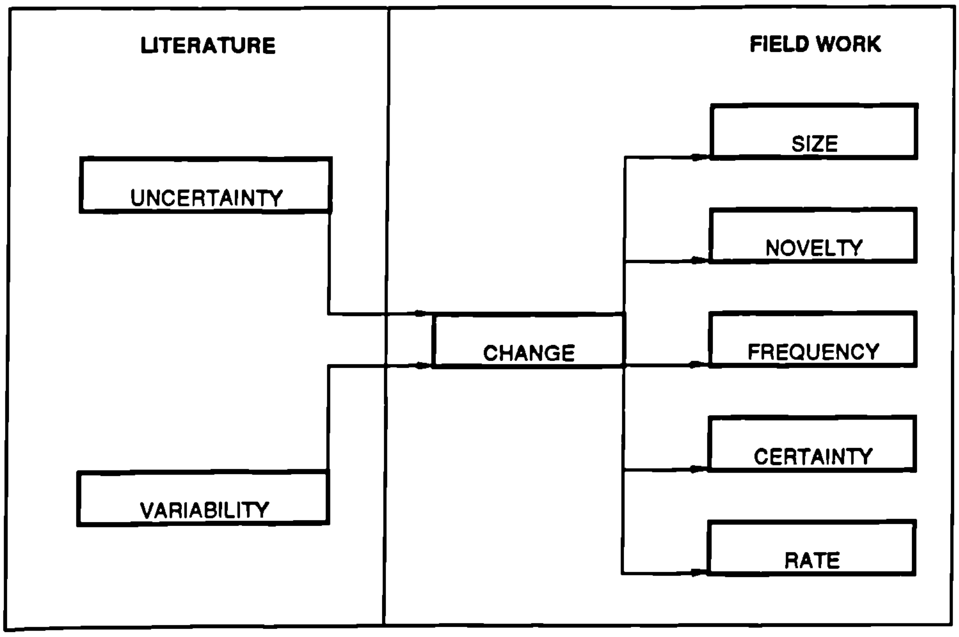

Fig. 9.8 - Stimuli-type change dimensions.

Each stimulus triggers, within the organization, a perception of the effects it will cause. The stimuli are perceived by managers as meaning either threats or opportunities to the organization's competitive position (see chapter 8 for examples). The management of the stimuli is an important part of the manager's job (Wieland and Ullrich, 1976), in the sense that it helps the potential threats to be minimized and the opportunities to be explored.

9.3. Managers Dealing With Change

The suggestion from the literature, according to which, flexibility is needed in order to deal with uncertainties and variability of outputs in manufacturing systems at a certain extent is confirmed by the field work developed in this research and described in chapter 8 and, in more detail in Appendix 3. However, it was noticed that the managers consistently approached the subject in a somewhat unexpected way.

In the case-studies, one of the most remarkable aspects noticed among the managers was their similar general approach to the management of *stimuli.* Invariably two concepts came into the scene when the managers described the ways they usually deal with the stimuli-type of change. When the managers were enquired, for instance, about the ways which they considered as appropriate to be used in dealing with uncertainty and variability, they frequently emphasized ways to try to eliminate or reduce the levels of uncertainty and variability of the changes which they would have to deal with. They would thus be trying to avoid or reduce the need to be flexible. In other words, they would, not only try to act *ex-post facto*, *responding* to the changes (by being flexible), but they would frequently prefer to act *ex-ante facto*, trying to *control* (meaning restraining or regulating) the uncertainty and variability of the unplanned changes which they would otherwise have to deal with. It is important at this point to clarify what is meant by control in this context. Although generally including some sort of feedbacking, the term control when used in operations management literature frequently includes a broad array of different elements such as despatching, planning and scheduling. Control is a term which is in general loosely defined in the operations management literature. Different authors seem to consider control with different meanings. According to Schmenner (1990), there are 4 main functions that are reasonably identified with production control: a) the specific, sequential assignment of jobs to each work centre, b) monitoring the performance of actual production versus the schedule and informing management of the status of orders, c) taking action to remedy the unacceptable status of some jobs, and d) an architect of information flow in the process (*sic*). Voss et. al. (1985), treating service operations management, argue that the term operations control relates to a series of aspects which include a broad range of different activities such as customer contact, diagnosis of customer problem, filtering customers, despatching and sequencing of jobs, selling, controlling information and invoicing. More specific, Wild (1989) adopts more strictly the system's approach for control: "control derives from the process of monitoring activities and the comparison of actual and intended states".

In this context, the term control, when associated with change or one of its dimensions, means simply "a means of restraining or regulating"[3]. Although there is not a commonly accepted meaning for the term control in the context of operations management, in order to avoid confusion with other definitions, when meaning "restraining or regulating change and its dimensions", the text will be explicit e.g. using terms such as "change control", "unplanned change control", "stimuli control", uncertainty control" and so on or making the meaning clear by the context itself.

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[3] According to The Oxford Paperback Dictionary, Third Edition. Oxford University Press. Oxford, 1988.

Examples of the use of unplanned change control and flexibility from the field work

When argued about the ways they consider as appropriate to deal with unexpected machine breakdowns, for instance, a number of managers answered that the ideal way is to improve preventive maintenance (to avoid the uncertain changes in machine availability, caused by the possible breakdown). With regard to those breakdowns which preventive maintenance could not avoid for some reason, the managers mentioned that the system should be able to take fast corrective actions (e.g. by sourcing the necessary spare parts quickly and/or by re-routing the production flow) - *ex-post* the breakdown. In a similar way, a number of managers would suggest the reduction of the variability of parts via standardization, for instance, as a preferred way of dealing with the variability of parts and products, and in doing so, avoiding the need to cope with such variability. For the cases in which the market really demanded variability and, standardization was impossible or inconvenient for some reason, they would then suggest, for instance, that being able to perform fast set-ups or developing Labour multi-skills is important in order to cope with the variability of the product mix (see chapter 8 and Appendix 3 for more examples).

	case A	case B	case C	case D
control	**changes** caused by variability. **solution:** standardization	**changes** in the supply chain. **solution:** supplier development	**changes** in the supply chain. **solution:** coordination with suppliers	**changes** in the demand mix. **solution:** forecast sensitivity
flexibility	**changes** caused by variability. **solution:** Labour multi-skills	**changes** in the supply chain. **solution:** rescheduling capability	**changes** in the supply chain. **solution:** buffer stocks	**changes** in the demand mix. **solution:** fast setups.

Fig. 9.9 - - Some examples from the field work with regard to the use of control and flexibility.

The fact that the managers mentioned ways to reduce the need to be flexible was not completely unexpected, since it had already been suggested by Slack's (1987) empirical findings. What was unexpected was the emphasis placed by the managers in trying to keep the uncertainty and variability of the changes under control. In view of the findings of the field work, it is surprising that the literature has neglected this aspect which proved to be a major concern for the managers and which is actually complementary to flexibility in the management of unplanned change: the *control* of the changes. Control, as considered here, relates to the set of decisions and actions taken, in order to restrain or regulate the level of uncertainty and variability, *ex-ante* the changes which the system would otherwise have to deal with.

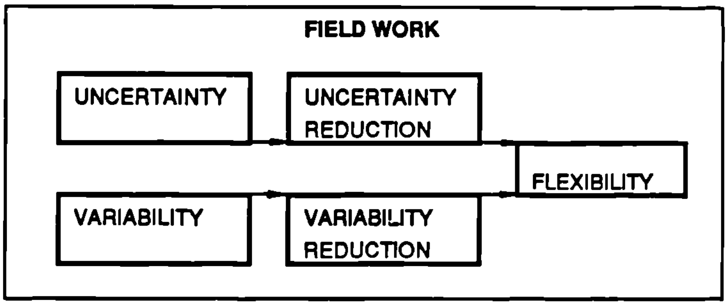

Fig. 9.10 - Managers emphasize uncertainty and variability reduction.

It is important to notice that *stimuli control,* in the sense it is being considered here, does not mean exclusively interfering *directly with the source* of the stimuli. Doing so is only one of the ways of exercising unplanned change control. Substituting a machine which frequently breaks down, and thus causing frequent unexpected changes, for instance, is an illustrative example of exercising control by acting directly upon the source of the *stimuli.* However, acting on the source is not the only form of control identified in the field study. A decision can be consciously made in order to make a work unit or a manufacturing operation less exposed to the *stimuli.* Sometimes, this is done by altering aspects of the operation itself, without interfering directly with the source of the *stimuli* involved. An example is focusing a production unit on a specific range of products or on a specific task[4]. Company A, for instance, has its engine plant organized in manufacturing cells[5]. One of them is dedicated to machine only two basic types of engine blocks. The operators therefore do not have to perform frequent machine changeovers in this cell. By focusing the cell on a specific task the plant manager restrains the amount of change which the cell "perceives", although not interfering directly with the source of the changes which is possibly the demand mix.

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[4] See chapter 1 for a discussion on manufacturing focus.

[5] Groups of machines, generally in charge of completing one or some families of parts. See Burbidge (1989) for details.

9.3.1. The Management of Change - How the Literature Treats it.

There is an extensive literature under the heading "management of change", generally by researchers on Organizational Behaviour. Their approach strongly emphasizes the management of planned change rather than *stimuli.* The question they try to answer is basically "how to change the organization effectively?". The management of stimuli is, in a way, neglected. The literature on Production Operations Management usually deals with the issue of managing stimuli under a number of different headings. One of them, which is evidently related to stimuli-type changes is "manufacturing flexibility" ("the ability to respond to changing circumstances", according to Mandelbaum, 1978). Although very valuable contributions are found in the manufacturing flexibility literature (Browne et. al., 1984; Mandelbaum, 1978; Buzzacott, 1982; Zelenovic, 1982, among others), few (Slack, 1990a; Gerwin, 1986; Swamidass, 1987) tried to actually understand, identify, classify and relate reasons to be flexible (the "changing circumstances", or, according to the terminology used here, the "stimuli") with different types of flexibility. They argue that flexibility is necessary in order to deal with uncertainty and variability, but since their emphasis is on flexibility, they do not explore[6] the fact that uncertainty and variability can also be dealt with by ***controlling*** them.

Thompson (1967), on the other hand, worked on the idea of the manager's needs to control uncertainties but at least for this context, did not explore sufficiently the need to deal with the uncertain stimuli which were left uncontrolled. Gerwin and Tarondeau (1982) propose the adoption of flexible technology as an addition to Thompson's strategies for controlling uncertainty but they concentrate their analysis on the technological resources and on the long term uncertainties. They have not gone too far in actually discussing how the complementarity control/flexibility would work either.

The control of *stimuli* is also treated, although not always explicitly, under a number of research headings. Manufacturing focusing, vertical integration and make-or-buy decisions (which , as will be explored in chapter 10, can be seen as particular cases of stimuli control), for example, also have a rich research literature, but each of them, unfortunately, is invariably treated in isolation.

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[6] Slack (1987) identified that managers would try to avoid being flexible, in his empirical work. He however does not explore this idea further.

Based on the previous evidence from the field study, an alternative approach to the ones found in the literature is proposed here. According to the proposed approach, there are two distinct ways used by managers in order to manage unplanned change in manufacturing systems:

a. *by controlling the unplanned change* and therefore by interfering either directly with, or with the way the manufacturing system perceives, the size, novelty, frequency and/or certainty of the changes, before the changes.

b. by dealing with the effects of the stimuli *by being flexible* which is the ability to respond to the changing circumstances, after the changes.

The scheme shown in the Figure 9.11 represents the reasoning (based on the field work and literature) of this proposed approach. Summarizing:

According to the literature, variety and uncertainty are the main reasons for companies to develop manufacturing flexibility (top box in Figure 9.11). From the field work, there was evidence that uncertainty and variety always referred to change and that a more appropriate way of classifying change for the purposes of this research was in five dimensions: size, novelty, frequency, certainty and rate (bottom box in Figure 9.11). Also from the field work, there was evidence that the managers were concerned not only with the need to respond to change but they frequently emphasized their concern about the possibility of reducing the levels of uncertainty and variety with which they have to deal with (second box from the bottom in Figure 9.11).

The concurrence of these aspects results in the proposed alternative approach, represented by the second box from the top (in Figure 9.11): unplanned change has five main dimensions - size, novelty, frequency, certainty and rate. To manage these unplanned change dimensions, managers adopt a mixed approach, contingently - preferably they try to control the occurrence of change *ex-ante* at a viable or convenient extent. Then, they develop flexibility in order to be able to deal with the effects of the unplanned change which were left uncontrolled.

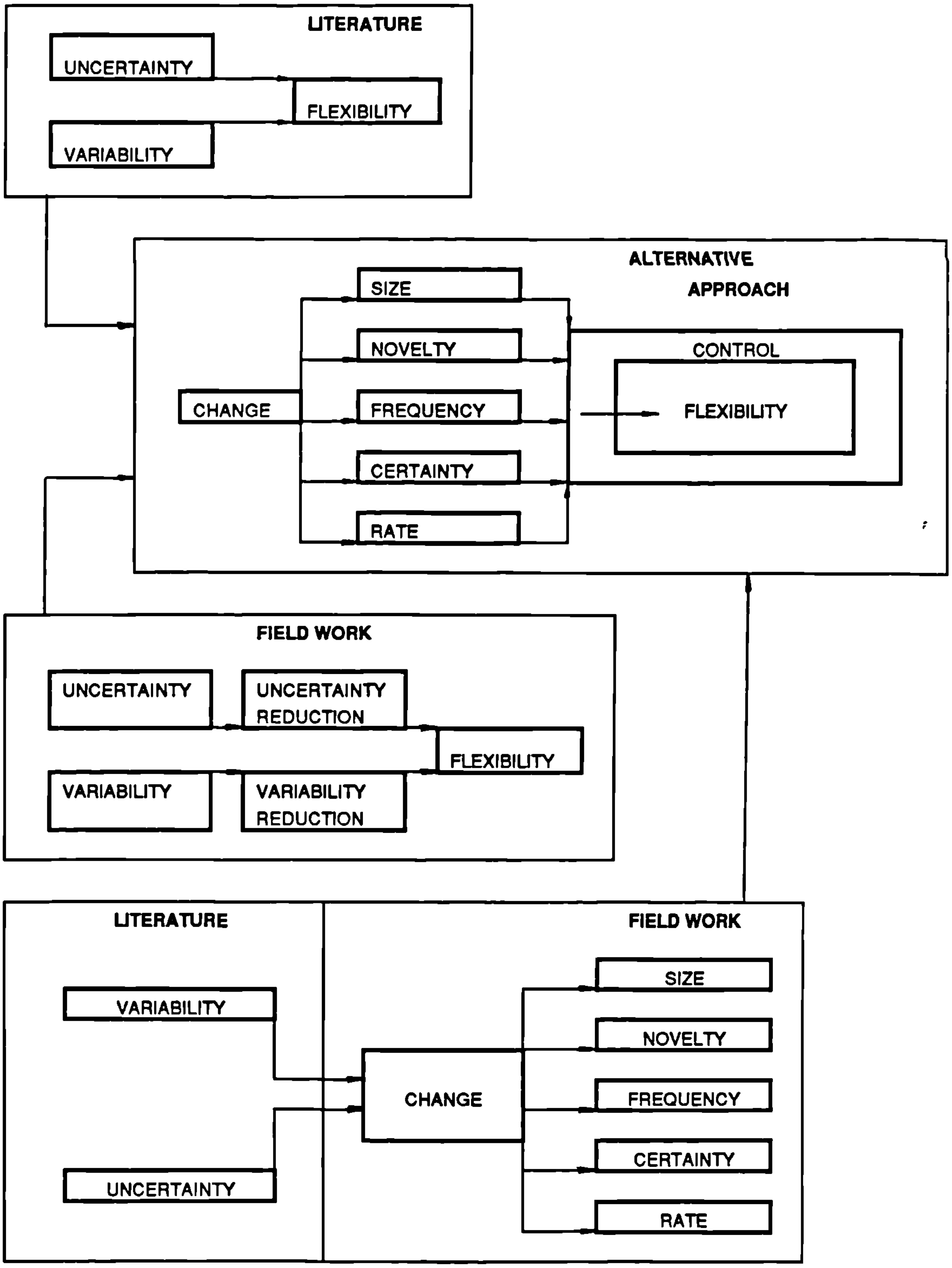

Figure 9.11 - Schematic development of the proposed alternative approach for stimuli management.

9.3.2. Control - Managing the Influx of the Stimuli

There are several ways which the managers of the case studies use to control their perceived "influx" of *stimuli* (the level at which the organization perceives and is influenced by the *stimuli*). Some of them relate to interfering directly with the sources of the stimuli whilst others relate to interfering with the way the system is affected or chooses to be affected by the stimuli. Some of the ways which can be used in order to control the stimuli are described by the examples below. The examples are drawn from the field study.

Examples of unplanned changes control types from the field work

Company C, facing a turbulent environment in terms of industrial relations, monitors closely the trends of the behaviour of the Labour Unions in Brazil, in order to avoid being taken by surprise, for instance, by a Labour strike. In doing so, Company C is trying to increase the *predictability* or reduce the *uncertainty* of some of its stimuli. They also adopt monitoring as a way to keep up with the new process and product-related technological developments. Two offices were established with this aim by Company C, one in the United States and one in Germany. This way, they are trying to reduce the *novelty* of the stimuli which they would have to deal with if they only noticed a new technology when it had already been completely developed. Thus Company C uses ***Monitoring and forecasting*** as ways to control some of the dimensions of their stimuli.

Company A's engine manufacturing shop reduced its short-term demand *uncertainty* by establishing on-line computer links in order to coordinate the engine shop with the paint shop. With on-line information, the engine shop has now accurate and timely information about the car bodies which are coming out from the paint shop and therefore they have better information about the next few hours' demand for engine derivatives. This achievement allowed them to schedule the assembly line more effectively, under less uncertainty. Another example of reduction of uncertainty by coordination is the notorious change that has happened in recent years in the relationship customer-supplier (of which the relationship between Toyota and its suppliers is a representative example), from confrontation to cooperation and integration (Womack et. al., 1990). The reduction of the supplier base, the tendency to establish long term stable contracts, with strong emphasis in personal contacts are some mechanisms used by some organizations in order to increase the *integration* and control over the changes with their supply. About internal suppliers (sectors of the manufacturing systems which supply other sectors), another example of coordination is the use of pull systems[7] in order to coordinate downstream demand with upstream operations, using visual techniques such as Kanban cards[8]. Upstream vertical integration by acquisition of suppliers is another possible way of integrating and therefore increasing control over the changes regarding supply. This approach has been largely utilized by Company C, which, along the years, has bought out a number of either uncertain or unreliable supplier companies[9]. ***Coordinating and integrating*** therefore are actions used by companies in order to control the stimuli to which they are exposed. They can primarily influence the *certainty* of the change.

Company A's engine shop adopts the "focused manufacturing" approach[10], organizing its machine shop in work units or cells. Company A's cells are generally set up to perform a limited range of parts. The cell which machines the engine blocks, for instance, uses automated transfer lines in order to perform only a few slightly different engine block types. On the other hand, another cell is manned with multi skilled workers and equipped with computer numerically controlled - CNC - machines to perform a multitude of aluminium and steel engine components with considerably different characteristics. This way the need to be flexible is confined to one production unit or cell whilst the rest of the machining cells work only on a limited range of parts each. With the focused approach, depending on what sort of task the system decides to focus on, the *size, novelty, frequency* and/or *certainty* of the stimuli which is perceived by the system or part of the system, can be altered. If the chosen task is to produce a limited product range, when a hypothetical customer's demand pattern changes and he orders a completely different product, the company then may opt not to attend to it. This way, by focusing, the *novelty* of the change the system has to deal with is restricted. Another way of focusing would be, for instance, on serving only large orders, influencing the *frequency* of the system's machine changeovers. The focus can be, on the other hand, on flexibility, where organizations choose to focus the operation

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7 Production control systems in which downstream operations' consumption of materials triggers upstream operations' production, "pulling" material throughout the production process.

8 See Schonberger, 1982 for a detailed description of the Kanban technique.

9 See chapter 8, case C for details.

10 Focused manufacturing relates to focusing the operation on a limited task by selecting a limited, concise, manageable set of products, technology, volumes and markets to be served while structuring basic manufacturing policies and supporting services so that they focus on one explicit manufacturing task instead of many inconsistent, conflicting, implicit tasks (Skinner, 1974) - please see chapter 1 for a discussion on manufacturing focus.

on producing products of large variety; and as a consequence investing on employee skills, process equipment and systems, which should then support the needs for flexibility. In this case, one way to exercise control over the stimuli, which the system as a whole perceives, is confining the need to cope with substantial changes into a few flexible work units (see Appendix 3, case A for a detailed example). This way, the amount of change which the rest of the operation has to deal with is controlled. In this sense, ***Focusing*** and ***confining*** are other means used by some organizations with the aim of controlling their stimuli.

According to one Company A's manager, gradually, some car manufacturers, including Company A itself, seem to be increasingly delegating, to suppliers or expert companies, the task of designing parts and components of their products. They are giving some of the suppliers only the design requirements and broad functional specifications about interfacing components instead of giving them detailed drawings and specification, as they used to do. This is one way which these companies are using in order to limit the amount of change, mainly in terms of the *novelty and rate* which they have to deal with, regarding product technology and design. Company A, for instance, had always designed its own diesel engines. However, in recent years they made the decision of subcontracting an European expert firm to design them, mainly because the technology involved with Diesel engines' design was changing substantially (*novelty*) and at a very fast *rate* (due, among other reasons, to new regulations with regard to emissions control). They considered that it would be more convenient for the organization not to try to keep up with the technology changes by using only internal design expertise. By ***Delegating*** and ***subcontracting***, which relate to delegating to a contractor the need to cope with some of the changes, companies can control the stimuli they are exposed to.

Company B, dealing with erratic supplies, decided to run programs on supplier base reduction and supplier development. However, while the suppliers are still below the desired levels of reliability, the company decided to keep some of the standard components supplied by a number of sources rather than one or a few. This decision aims at hedging against the short term *uncertain* delivery the suppliers were still providing. By having a number of suppliers, Company B hedge against the *uncertainty* of one or some unreliable suppliers. If a company is relying on just one erratic supplier, it is probably more vulnerable to the undesired changes which the supplier can possibly cause. Although hedging is in a way contradictory with the general tendency of reducing the number of suppliers and developing a closer relationship with them, there may well be short-term situations (such as the one involving Company B, described above) in which the organizations consider that ***hedging*** is a convenient way to control its uncertainties with regard to supply.

One of the most evident ways to limit the stimuli levels which an organization has to deal with is by substituting the source of the change, replacing it with a less "changeable" one. If a supplier is consistently unreliable, for instance, frequently causing changes in the system's schedule by faulty deliveries, a company can reduce the occurrence of these changes by substituting the supplier, replacing it for a more reliable, *certain* one. The same applies to an unreliable piece of equipment which frequently breaks down (influencing the change *frequency*) and to a worker who is not dependable. ***Hedging*** and ***substituting*** are therefore also among the ways which organizations can use in order to control stimuli.

Company D's manufacturing plant is running a program of parts standardization aiming at reducing the variety of parts which they have to manufacture. Such an effort involves negotiation with the plant's internal customer: the marketing function. By negotiating, the plant is trying to reduce the amount of change it has to cope with. ***Negotiating*** consists of an attempt to interfere directly with the customer (either internal or external) in order to reduce the changes she/he can possibly demand. Another illustrative example of negotiation is what happens with the firms which use Kanban systems (such as Toyota). Such firms, given that they need a stable environment in order to operate effectively, generally "freeze" their master plan for a considerable period of time ahead (Stalk and Hout, 1990). This aims at controlling the *uncertainty* and *frequency* of the short-term demand changes. The management of this sort of change control also requires negotiation with the customers, be them either internal or external. By negotiation, the demand curve shape is altered in order that the system has to deal with less uncertain, smaller, less novel, less frequent or less drastic changes. Another way to interfere with the demand curve shape is by advertising, trying to influence customers in order that they consume determined types of products or to induce determined patterns of custom which can also interfere with the *frequency, rate* and *size* of the future demand changes. Promotions and advertising campaigns are usual ways to stimulate off-peak demand in order to level, or in other words, reduce demand change *size* and *rate* over time. ***Negotiating, advertising*** and ***promoting*** are therefore another way which companies can use in order to control their stimuli.

Most of the managers interviewed during the field study mentioned preventive maintenance as a desirable way to deal with machine breakdowns. A well maintained machine would be less subject to changes in its availability, caused by possible breakdowns. Maintaining the resources would thus be one way to reduce possible undesirable changes with regard to its *frequency* and *size,* caused by equipment breakdowns. The idea of maintenance, however, is not only suitable for structural resources, such as machines. The maintenance of payment schemes and systems, in order to make sure that they are updated and appropriate and, the maintenance of computer systems records to ensure data integrity, are other ways to exercise control, in order to reduce the possible future occurrence of severe changes (by reducing the possible change *size, rate, frequency* and *uncertainty*), such as a possible unexpected disrupting industrial dispute, or a late acknowledgement about some relevant inaccurate information in the computer records such as inventory quantities. With regard to human resources, one of the ways used by managers in order to reduce the uncertainty of people's behaviour is by *training* them in order to standardize procedures and increase the awareness of people about the importance of their activity and its impact on the overall performance of the operation. Four out of 6 Company B's managers, all of them concerned with the uncertainties regarding the middle management's behaviour under a major change which the company is to face, said that training was the most appropriate way of reducing the uncertainty and increasing the predictability in that respect. Therefore, ***Maintaining, updating and training*** are also ways which companies can use in order to control their stimuli.

Summarizing, 7 general types of control of stimuli-type changes were identified during the interviews. Figure 9.12 below lists them and also shows where the identified control types fit in the proposed approach, developed in previous sections:

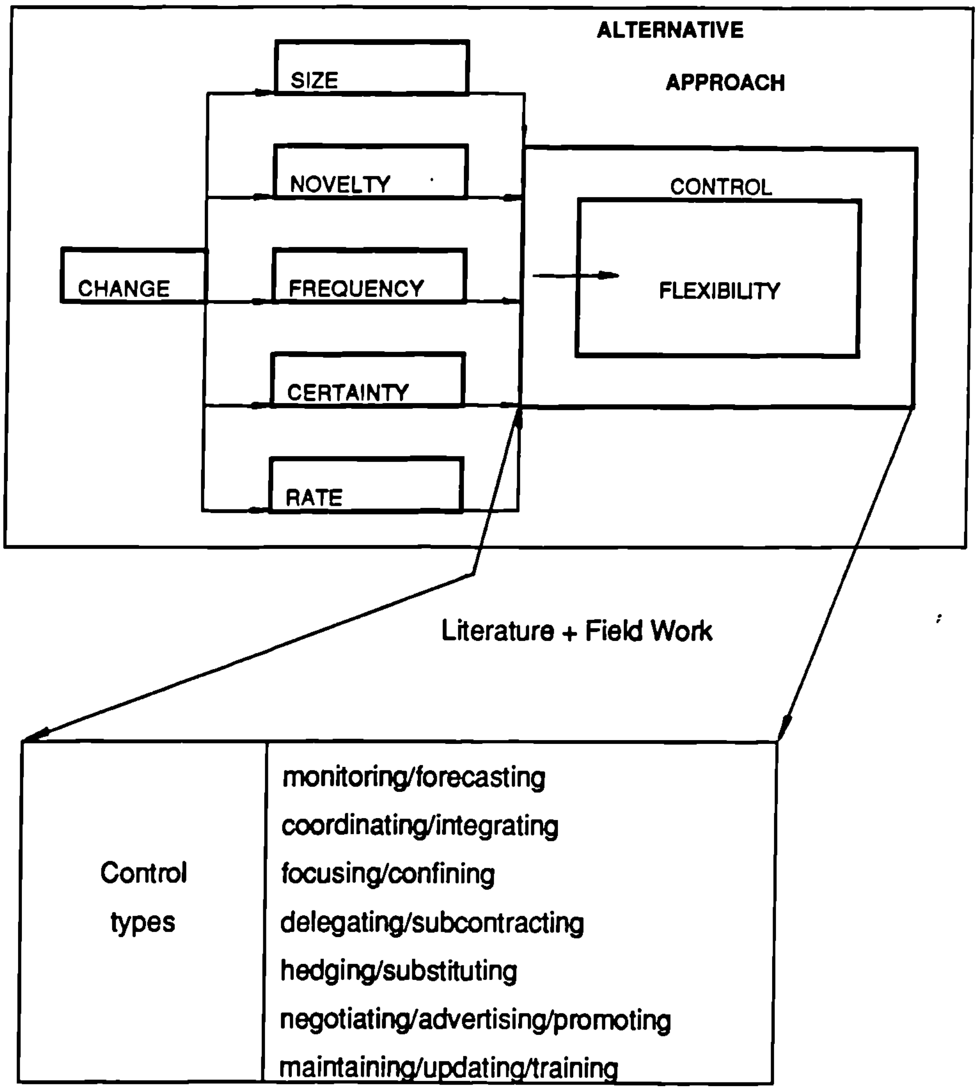

Fig. 9.12 - Detailing the alternative approach: unplanned change control types identified in the field work.

9.3.3. Flexibility - Dealing with the Effects of the Stimuli

When studying the flexibility of manufacturing operations at the level of analysis defined in chapter 6, we are primarily interested in the flexibility of the manufacturing system, or, in other words, of *the set of manufacturing resources*, the ability of the *manufacturing system as a whole* to respond to its stimuli. At this level of analysis, the flexibility of particular resources are only means to help the achievement of the system's flexibility. This is also the most appropriate level of analysis if we intend to be able to understand the ways the manufacturing system can actually help the organization compete, bearing in mind the strategic role of the manufacturing function. In this sense, we assume that the performance of the whole system is more relevant for the organization than the performance of the particular resources, and therefore the particular resources will not be analyzed in isolation or in detail, but always as parts of a greater system.

The same way, the decisions which are made beyond or at a higher level than the manufacturing operations management's level will not be emphasized here. Some authors, for instance, define "expansion flexibility" (Browne, 1983), as one of the manufacturing flexibility types. Although decisions regarding the manufacturing unit expansion, through investments, acquisitions or other means concern the manufacturing function, they are generally made beyond the level of decision of the manufacturing system. They are decisions generally made at the corporate or business level. Here, for the sake of keeping the focus of this research, Browne et. al.'s (1983) "expansion flexibility", for instance, and other flexibility types alike will not be considered as manufacturing system's flexibility.

The consideration of flexibility here assumes a given core technology which encompasses the bulk of machinery, equipment and facilities which the manufacturing system already possesses and which, in general, cannot be substantially altered by decisions made at the operational level.

There are several classifications of manufacturing flexibility in the literature (see chapter 2 for details). Some of them mix different levels of analysis (such as the aforementioned Browne et. al.'s (1983)). Others (such as Mandelbaum's "action" and "state" flexibilities), are too broad and, although valuable in the effort of conceptualizing flexibility, are of little practical use for the analysis of the manufacturing operations. At the manufacturing system's level, Slack's (1989) classification seems to be one of the most consistent. The author suggests that 4 types and two dimensions of manufacturing flexibility can be identified at the manufacturing system operation's level: *new product flexibility* (related to the system's ability of introducing different products or modifying existing ones), *mix flexibility* (related to the system's ability of manufacturing a broad range of products within a given period of time), *volume flexibility* (related to the system's ability to change its aggregated level of output), and *delivery flexibility* (related to the ability of the system to change delivery dates). The two manufacturing flexibility dimensions defined by Slack are: *range flexibility* - the total envelope of capability or range of states which the operations system is capable of achieving and *response flexibility* - the ease, in terms of cost or time, with which changes can be made within the capability envelope. Slack's classification was used in the interviews performed at the field work stage of this research (see chapter 8 and Appendix 3for details).

Slack's 4 types and two dimensions were generally considered by the managers as valuable and consistent with their needs, at least with regard to changes with the system's demand. The managers usually understood the four types and two dimensions with ease and they were able to assess the performance of their operations in terms of each of them and identify the ones which they regarded as competitive priorities, recognizing the importance of such classification in terms of allowing the managers to establish priority actions and focus. In fact, logically, the system's demand can change in terms of its 4 main attributes: specification, mix, volume and delivery dates, which would be dealt with, respectively, by new product, mix, volume and delivery flexibilities. However, this taxonomy was not seen as sufficiently comprehensive. The field study results suggest that, when analyzing change in a more comprehensive way, there is a need to define a complementary type of system's flexibility, which is possibly similar to Mandelbaum's (1978) "state flexibility"[11]. A 5th type of system flexibility is proposed in order to complement the four types proposed by Slack (1989). The fifth system's flexibility type is related to the robustness of the manufacturing system, considered here as the ability of the system to overcome unplanned changes either in the process (such as Labour absenteeism or machine breakdowns) or in its input side (such as faulty deliveries). Here, it will be called "system robustness" flexibility.

The need for a 5th system's flexibility type comes from the field study's observation that even a system with high levels of performance in the 4 Slack's flexibility types can lack flexibility to deal with some of the changes which may happen to the process or to the input supply. A production unit could, hypothetically, have excess capacity (allowing for volume changes), short set-up times (allowing for fast mix changes), could be very capable (being able to manufacture a large range of parts) and still, it could have, among its machines, one which is the only one of its kind in the unit, a machine which is the only one able to perform certain tasks. If this machine breaks down, for instance, the system's performance can be severely affected if some sort of system's robustness flexibility is not present (such as a buffer stock after the machine, a responsive corrective maintenance system or an efficient outsourcing system, able to outsource the parts which otherwise would have been made by the broken machine). This was evident in Company B, which emphasized this sort of flexibility because their dated equipment was not very reliable (See chapter 8 and Appendix 3, case B, for details).

In an attempt to explore further the concept of system's robustness flexibility, we can also think of this type of flexibility in terms of the two dimensions: range and response. The range dimension refers to how big can the change or the disruption suffered by the system be, before its performance is relevantly affected. The response dimension refers

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[11] "The capacity to continue functioning effectively despite the change" (Mandelbaum, 1978).

to how quickly, easily and cheaply the regular operation can be restablished, once a disruptive change has happened.

System's robustness flexibility is a way to achieve system's reliability by other means than by increasing the reliability of the individual resources. In other words, if a system works on the reliability of its individual resources, it would be exercising control rather than flexibility, because the intention is to avoid the occurrence, *ex-ante* the change. On the other hand, when a system develops system robustness flexibility, it is getting prepared to be able to deal with the changes, *ex-post* the occurrence of the change. Both approaches aim at increasing the overall reliability of the system.

Summarizing, from the evidence of the field work, it is proposed here that five types of system flexibility are relevant to the analysis of the manufacturing systems at the level analyzed in this research: new product flexibility, mix flexibility, volume flexibility, delivery flexibility - the first four from Slack's (1989) model - and system's robustness flexibility. The five of them can be seen as having two relevant dimensions: range and response.

A correlation can be logically established between the types of change - system input-related changes, process-related changes or output-related changes - and the types of system flexibility - new product, mix, volume, delivery and system robustness.

Changes relating to the output side of the system or with the system demand - new products (or product changes), product mix, overall demand level and delivery dates are mainly (although not exclusively) associated respectively to the aforementioned first four types of system flexibility - new product, mix, volume and delivery.

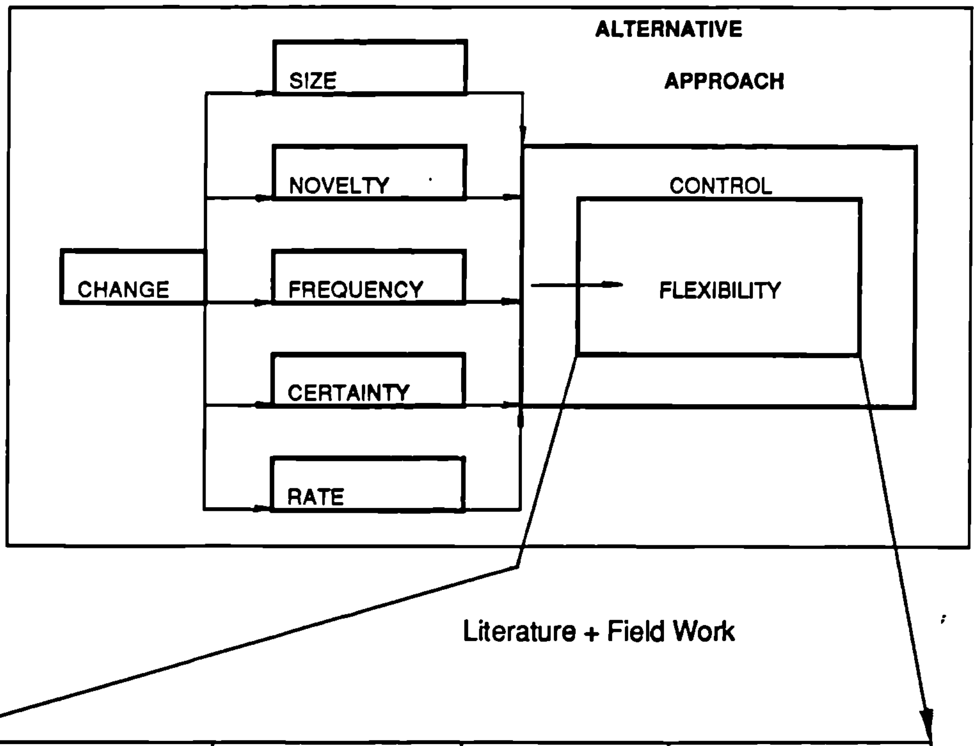
Changes related to the input side and to the process elements (which can also be seen as inputs, as long as the system is analyzed with a long term perspective), which generally represent risk of disruption for the transformation process, are in turn primarily related to the fifth type of system flexibility - the system robustness flexibility.

Also, there seem to be a correlation between the five stimuli dimensions - size, novelty, frequency, certainty and rate - and the two flexibility dimensions - range and response.

Size and novelty relate to the breadth of the change, to how different is the new situation after the change. Therefore, it is necessary that the resource or the set of resources involved with dealing with the change have the ability to assume a very different state (to deal with the size of the change) or to assume a large number of states (to increase the probability that one of them match the novelty represented by the post-change or during-change situation). This suggests that change size and novelty are related to range flexibility rather than to response flexibility.

Frequency, certainty and rate, on the other hand, relate to the dynamics of the change process. The more frequent, uncertain (unpredictable or unknown) and fast the changes are, the more dynamic is the environment and the shorter is the response time required from the resource or set of resources, because these changes happen either unexpectedly, frequently.or quickly. In other words, the more uncertain, frequent and fast the changes, the more response flexibility would be required.

Figure 9.13 below represents the 5 types and two dimensions of flexibility proposed and also shows how they fit in the general proposed approach developed in previous sections.



System flexibility types	New product Product mix Volume Delivery	primarily related to changes	in the output side
	System robustness		in the input side and in the process
System flexibility dimensions	range	related to the change dimensions	size novelty
	response		frequency certainty rate

Fig 9.13 - Detailing the alternative approach: system flexibility types and dimensions.

Drawing from the different types of control and flexibility proposed, let us try to analyze and explore further the concepts of control and flexibility.

9.4. Unplanned Change Control and Flexibility: Exploring the Concepts

The manufacturing system is a configuration of interacting individual resources which can be classified in (see chapter 3 for details):

-*Technological resources* - the facilities and technology or the hardware side of the manufacturing system.

-*Human resources* - people in the manufacturing system.

-*Infrastructural resources* - the systems, relationships and information couplings which bind the operation together.

Manufacturing resource types	Structural	Human Technological
	Infrastructural	

Fig. 9.14 - Manufacturing resource types.

The next section is an attempt to determine which, among the three basic types of manufacturing resources, are the ones which play the dominant roles in the achievement of the 7 types of control.

9.4.1. Control and the Manufacturing Resources

-*monitoring/forecasting* - related primarily to forecasting and information systems, although a company can have some people with expertise or experience in forecasting (see chapter 8, case C for an example):

-*coordinating/integrating* - in terms of the external suppliers, it is related to the supply management or to the information systems, depending on the type of coordination / integration the organization chooses to adopt. In terms of internal suppliers, it depends basically of the manufacturing planning and control systems of the organization, which includes inter-functional communication, forms of work organization and so on (see chapter 8, case A for an example).

-*focusing/confining* - depends on the organizational and work structuring which determines the work units and their tasks (see chapter 8, case A for an example).

-delegating/subcontracting - depends primarily on the make-or-buy policies and on the sourcing systems (see chapter 8, case A for an example).

-hedging/substituting - in terms of supply and suppliers, it depends on the sourcing system and on policies regarding the relationship with the suppliers. In terms of substituting machines or people for less "changeable" ones, it depends on technological and human resources and on the system and policies which are responsible for deciding for the substitution (see chapter 8, case B for an example).

-negotiating/advertising/promoting - depends basically on the systems and policies which determine the relationship with the customer (see chapter 8, case D for an example for an example).

-maintaining/updating/training - here the idea is that reliability is built on the resources, making people, machines and systems less "changeable". It depends therefore on the three types of resources and on the systems which actually build up the resource reliability, by training people, maintaining machines and updating systems (see chapter 8, case B for an example).

Except for substituting resources for less changeable ones (hedging/substituting) and for "building reliability" (maintaining/training/updating) on them which involve primarily structural resources, the other types of control relate primarily to infrastructural resources. Infrastructural resources therefore seem to play a major role in developing ways to control stimuli in manufacturing systems.

Figure 9.15 below summarizes the main contribution that infrastructural resources can give to the 7 control types.

Infrastructural resource key players in the achievement of the different types of stimuli control		
Monitoring / forecasting		information and forecasting systems environmental and internal monitoring
Coordinating / integrating		vertical integration, MPC systems, supply chain management, organizational systems, inter-functional communication
Focusing / confining	Achieved	organization structure, MPC systems, strategic planning
Delegating / subcontracting	through	make or buy policies, outsourcing, vertical disintegration policies
Hedging / substituting		supply chain policies, procurement systems investment policies
Negotiating / advertising / promoting		marketing/manufacturing interface marketing policies
Maintaining / updating / training		maintenance systems, training policies, information systems, industrial relations policies

Fig. 9.15 - Infrastructural resources: key players in the achievement of stimuli control.

The structural resources, to be controlled, have to be reliable. More reliable resources will originate less unexpected stimuli for the system to deal with. .

Structural resources contribution to the achievement of the different types of stimuli control		
Substituting	increase resource RELIABILITY through	new more reliable machines and people
Maintaining/updating/ training		"building up" reliability on machines and people

Fig. 9.16 - Structural resources contribution in the achievement of stimuli control.

A similar exercise can be done with the relationships between the three types of manufacturing resources and the 5 types of manufacturing flexibility, drawing examples from the field study.

9.4.2. Flexibility and the Manufacturing Resources

Robustness flexibility - To deal with a faulty supply, for instance, Company A's engine plant developed a good ability to reschedule its production giving priority to orders of which the components are already available. In this particular case the rescheduling is mostly done by people. Another way of dealing with faulty supplies is to keep safety buffer stocks of raw material and components, such as the "strategic" stocks of components built up by Company B, to prevent against possible problems with delivery.

In order to deal with the changes which affect the availability of process elements such as machine breakdowns and Labour, the trivial way is to have excess capacity of the same resource (Company B, for instance, has excess process capacity in the Zamac injection shop, where the machines are not considered to be reliable and, all the case companies kept excess people to cover absentees). In this regard, a non bottleneck machine, is, by definition, a machine which has capacity in excess. Even if it breaks down, provided that the time to make it up running again does not exceed its idle time in the period, the system's working probably will not be substantially disrupted. If the time to make the machine up running again exceeds its normal idle time and there is a risk that a subsequent bottleneck starves (stops running because of lack of input material), one way to increase the system robustness flexibility is to build up some safety buffer stock - in general a time rather than a stock buffer[12] in front of the bottleneck resource (the "bottlenecked" Company C builds up stocks of iron powder every year in October in order to make sure that it continues running even if problems crop up with a North American supplier which is vulnerable to problems with transport during the winter season).

An alternative way for a manufacturing system to be robust against breakdowns is, for example, to have a number of non-bottleneck machines which are able to perform each other's jobs (some extra equipment capability and capacity - this is the strategy used by Company B in its Zamac injection shop). In case of bottleneck machines, which have no excess capacity by definition, another way to increase system robustness flexibility

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[12] See Goldratt, 1990 for a detailed discussions on bottleneck buffering

is to have the capability to subcontract internal or external suppliers in order to do the broken down bottleneck machine's job (Company A uses this policy, keeping records of possible substitutes for its bottleneck-machines in and outside the corporation to which Company A belongs).

In terms of Labour absenteeism, two aspects have to be considered, according to the observations from the field study. The availability of *quantity* of people and the availability of the *right skills*. When a worker is absent, someone else has to do his job. If the skills of the absentee are standard or non-specialized, some excess capacity can make it up. Company A's engine assembly line keeps a certain amount of people in excess (some extra Labour capacity) to cover for the "normal" absenteeism rate which is assumed to be 3%. They still have another problem, though. Not all the workers in the assembly line can do all the assembly tasks. Therefore, although they know the average daily number of absentees, who or what kind of skills will be absent in the next shift is a variable which is much more difficult to predict. In order to increase the system robustness flexibility with regard to absenteeism, Company A has improvement programs running which aim at training people in order to develop multi-skills (providing some excess Labour capability) to allow for the Labour transferability between tasks. This way, the line management increase the probability that, not only have they the right number of people to run the line every day but also, that they have the right set of skills.

Summarizing, companies pursue the achievement of *system's robustness flexibility* in a number of ways by using technological, human and infrastructural resources and, in this sense, apparently, there is not one type of resource which plays a major role.

Product flexibility - product flexibility seems to be dependent on a number of aspects: the human and technological resources have to possess a "reserve" of capability (see chapter 8, case A) in order to be able to deal with a large range of activities which are required by the introduction of new products. Some excess capacity is also needed for testing and prototyping-related activities. To achieve fast introductions (product response flexibility) the important feature seems to be the integration/coordination between functions involved with the product introduction/change to ensure design for manufacture (see cases A and B in chapter 8). This seems to depend on effective systems and other infrastructural resources - communication channels, organization structure, inter-functions interaction and so on.

Mix flexibility - mix flexibility depends on technological resources which should allow for quick set-ups and should also have a broad capability range. Human resources should also have multi-skills and infrastructural resources should be effective in order to allow for quick and frequent rescheduling and outsourcing (see case A in chapter 8).

Semi-finished goods stocks can also be used in order to shorten lead-times (assembly to order instead of make to order - see chapter 8, case D) and allow for quicker mix changes.

Volume flexibility - volume flexibility seems to be related to having excess capacity of human and technological resources or having the ability to get them - through systems - at the amount needed and quickly (see chapter 8, case D).

Delivery flexibility - in order to allow for delivery flexibility it seems that a system should have the same ability of a company with mix flexibility and additionally, some excess capacity. Otherwise, the anticipation of one order would simply delay others (that is exactly what happens to Company C, which is "bottlenecked"). Delivery flexibility can also be achieved by keeping finished and semi-finished goods inventory (see chapter 8, case D).

Concluding, no specific type of manufacturing resource thus seems to play a major role in developing any of the flexibility types or dimensions. It seems that what sort of resource should be used in order to achieve what sort of system flexibility is contingent to the particular situation.

9.4.3. The Flexibility of the Structural Resources

An interesting aspect of the flexibility of manufacturing structural resources was observed in the manager's views. In terms of structural resources, there always seem to be some sort of resource "reserve" (or "redundancy") involved in the achievement of manufacturing system's flexibility. Three managers at Company A, for instance, described flexibility explicitly as a reserve, an asset, something which is possessed by the system but it is not being used at each time. In fact, if a system is able to respond effectively to a changing circumstance, it means, implicitly, that the system is able to assume different states and therefore to perform more activities than the activities it is performing at each time. It has therefore redundant or excess capabilities. A totally dedicated machine, for instance, is not flexible exactly because it is only able to perform one single task: there is therefore no redundancy in its capability.

Not only redundancy is necessary, though, for the structural resources to contribute with the system's flexibility. They also need to be "switchable" (the term borrowed from Dooner and De Silva, 1990), in order to respond quickly and easily to the changes. In other words, they have to be able to change quickly, easily and cheaply between the activities they are "redundantly" able to perform.

The switchability of the resources seems to be linked to the system's response flexibility whereas the redundancy seems to be linked to the system's range flexibility.

Structural resources main contribution to the system's flexibility	Redundancy Switchability

Fig. 9.17 - Structural resources general contribution to flexibility.

An analysis aiming at developing further the concept of resource redundancy and its links with flexibility follows.

From the field study, it was noticed that some managers consider that structural resources have to possess some level of redundancy or "reserve" in order to be flexible. To be able to respond to changes in the number of available assembly line workers, caused by absenteeism, Company A, for instance, provide the assembly line with some extra Labour capacity, with the aim of covering for the absentees. This means that Company A's assembly line has redundant *capacity* of the resource Labour. However, they also have to make sure that the assembly line team has the right skills to perform all tasks, despite the absentees. The way they overcome this problem is by training a number of members of the team in order to enable them to perform a multitude of tasks. In doing so, it becomes possible to transfer people between tasks and therefore to accommodate the necessary skills. In providing people with multiple as opposed to dedicated and specialized skills, Company A is creating a "reserve", or redundancy of the *capability* of the resource Labour. Both types of redundancy can also be created in the resource Technology. A multi-capable machine (such as the ones used by Company A in the "CNC" cell) has redundant capability and a production unit with extra machine capacity (such as the one used by Company B in the Zamac injection shop) has redundant capacity. Beside redundancies with capability and capacity, a third kind of resource redundancy was identified in the field study. Company D, for instance, builds up stocks of semi-finished goods in order to be able to be flexible in responding quickly to its variable demand. To build up these stocks, the structural resources machine and Labour involved are activated before the time in which it would be strictly necessary. The build up of stocks allows the system to be more flexible allowing therefore the company to respond in a quicker way to the changes in demand. It would not be enough for the company to attain this objective only by keeping its current level of extra capacity or extra capability. Aiming at responding quicker, the system had to activate its resources earlier than what would be strictly necessary to respond to firm orders. A stock of parts or products is typically a "reserve", built up in order to help the system respond better to a changing circumstance. This reserve is built up by a redundant (or excessive, compared to the needs) utilization of the structural resources.

Therefore, there would be three kinds of resource redundancy, which can translate into resource flexibility, provided that they are managed properly: capability, capacity and utilization. Each of them is further analyzed in turn:

*Redundancy in the structural resources **capability*** - is a function of the range of abilities which the resource possesses but which are not being used at each and every time. If a machine, for example, has the capability of performing 10 different product or part types, it is more redundant in terms of capability than another one which is able to perform only three different product types (given that both are currently performing one product type at a time). The ability of a machine, expressed as the range of different product types it can perform[13], is in general a design characteristic. Considering the resource Labour, the redundancy of capability of a worker can be increased by training and/or experience. If a worker is trained to perform a number of different tasks, for example, his capability reserve or redundancy is increased.

*Redundancy in the structural resources **capacity*** - is the difference between the level of output the resource is normally producing and the maximum level of output it is able to produce. If a machine has the capacity of manufacturing 1000 parts per hour and is normally assigned to produce 700 parts per hour, it has a larger redundancy in terms of capacity than a similar machine assigned 900 parts per hour. The same concept applies to a worker or to a group of workers.

*Redundancy in the resources **utilization*** - occurs when a resource is activated more than it was strictly required (such as the build up of stock-buffers) or before it was strictly required (such as the build up of time-buffers), generating a physical amount of stock. It is basically a redundancy due to the production planning and control system which determined that the excess amount of stock should be produced or purchased at that specific time. Here a "stock" (generated by a redundancy in the utilization of resources) is defined as the amount of raw material, semi-finished or finished goods, within the system, which has been produced or purchased either in a larger amount or before it was strictly needed to respond to a specific firm customer order.

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13 This is just a simple example. Other considerations are also important in assessing the capability of a machine, such as how different are the products it is able to produce.

<table>
<tr><td rowspan="3">Manufacturing structural resources redundancy types</td><td>Capacity</td></tr>
<tr><td>Capability</td></tr>
<tr><td>Utilization</td></tr>
</table>

Figure 9.18 - Structural resource redundancy types.

There is another characteristic of the structural resources which is not related to any sort of redundancy, but it is also important in the achievement of higher levels of flexibility, mainly response flexibility: the *switchability* of the infrastructural resources.

Resource switchability - relates to how quickly, cheaply and easily a resource switches the activity it is currently performing into another one (Companies A, B, C and D are running programs of set-up time reduction, in order to increase response flexibility, or in other words, technological resources switchability). In terms of technological resources, it relates to changeover times which in turn is linked to set-up times. In terms of human resources it relates to the ease and to the time it takes for the person to switch between tasks up to the point when he or she is performing the subsequent task at the same levels of performance he or she was performing the previous one.

Summarizing, a structural resource is flexible as long as it has the appropriate amount and types of redundancy and levels of switchability which are required in order to respond effectively to the system's needs.

<table>
<tr><td rowspan="4">Structural resources main contribution to</td><td rowspan="4">System Flexibility</td><td rowspan="3">Redundancy</td><td>Capability</td></tr>
<tr><td>Capacity</td></tr>
<tr><td>Utilization</td></tr>
<tr><td colspan="2">Switchability</td></tr>
</table>

Fig 9.19 - Structural resources contribution to system flexibility.

9.4.4. The Flexibility of the Infrastructural Resources

The system's flexibility is not a function exclusively of the redundancy and switchability of its structural resources. They are necessary but not sufficient for a system to achieve flexibility.

In terms of infrastructural resources it does not seem necessary for the system to have any redundancy, in order to achieve higher levels of flexibility. Infrastructural resources have to play their role precisely to contribute to flexibility: establishing effective inter-function communication and, participative and agile decision-making process and ensuring that the appropriate information, at the right level of detail get to all the decision points which need it accurately and as quickly and as soon as possible. An example is the simultaneous engineering which helps in achieving new product response flexibility (see chapter 8, case A). Two systems with the same level of redundant resources (designer's skills, spare capacity for prototyping and so on) will produce different performance in terms of reacting quickly to a customer's request of a new product if they have different level of ability to make the right information to get to the right decision points the earliest possible. If one coordinates well the product design function with the process design function, for example, and the process engineers get to know about the relevant information they need at early stages, they will be able to start their work in parallel with the product engineer's work and the whole system as well as the customer are likely to benefit from the parallel - as opposed as sequential - activity development, in terms of response time[14].

Infrastructural resources do not seem to influence range flexibility as dramatically as it influences response flexibility. Infrastructural resources only have a supportive and facilitating role in the manufacturing process. The structural resources are the ones which actually "do the job" and therefore they are the determinant resources in terms of the range of possible jobs or activities the system can perform.

9.5. The Control-Flexibility Relationship - a Systems Approach

The set of resources: technology, Labour and infrastructure, in a manufacturing plant, work as a system - the *manufacturing system.* The manufacturing system performance is a function of its specific configuration of resources although it seems plausible that

[14] See Womack et. al. (1990) for a discussion on the simultaneous development process.

different configurations can achieve similar performance levels. Determined levels of flexibility of the manufacturing system, for instance, could be achieved by different configurations of particular redundant and switchable structural resources and different types of infrastructural resources.

When an organization decides what type and amount of control it is going to exercise over its "influx" of stimuli (or unplanned change), it is also and automatically defining what are the stimuli which will "pass the control filter". In other words, the organization is also defining what sort of changes it is going to deal with or respond to, either because the ability to deal with some changes is strategically important (flexibility may be important as one of the system's competitive criteria) or because it is economically inconvenient or even impossible to control them. The way to deal with the effects of the "non-controlled" stimuli is by being flexible. A typical example is the occurrence of unplanned changes with the machine availability caused by breakdowns. All the case companies' managers emphasized that such changes should be avoided (controlled) by developing preventive maintenance procedures. However, since it is impossible or sometimes non viable to eliminate completely the occurrence of machine breakdowns via prevention, it is necessary that the system is flexible, or in other words, it is able to respond quickly once a breakdown occurred - or once a stimuli "passed through the control filter".

Control here is defined as every activity which aims at interfering with the amount and/or nature of the stimuli with which the system has to deal. Control activities are developed *ex-ante* the occurrence of the stimuli. Once the stimuli happened, there is nothing that control activities can do to deal with it. This is the point where flexibility comes into the scene in order to respond to the change, utilizing the redundant/switchable resources it has, as quickly as the infrastructural resources are able to make the relevant information about the stimuli to get to all the appropriate decision points.

Sometimes, the same action, say coordination, can serve both purposes - to increase the unplanned change control and to increase the flexibility. Consider coordination with suppliers. On the one hand, coordination can have a character of control, reducing the uncertainty the organization works under, with regard to the suppliers. On the other hand, coordination with suppliers can also have the purpose of increasing the organization's flexibility, making sure that the relevant information about the changes in its demand pattern, for instance, are acknowledged quickly by its suppliers and therefore the response of the *system formed by the organization and its supplier* can be quicker. This is an interesting aspect of the relationship between control and flexibility, related to where one defines the system's borders. What is control (such as coordination between two departments) at one level (internal) is or can represent flexibility from the viewpoint of the external environment or of the next external level (for instance of the system's customer). When the company's product demand changes, for example, the response to that change will probably be quicker and better (or more flexible) if there is a good level of coordination between the company and its suppliers. This is "intra-system" coordination which does not interfere with the change in demand itself. It aims at increasing the overall system's ***flexibility***. If the company, on the other hand, develops coordination or negotiation with its customer aiming at working with more stable schedules, that is *inter-system coordination* aiming at increasing the company's ***control*** over the demand changes in terms of reducing its frequency (by freezing schedules, for example) or its predictability (by having a longer planning horizon, for example).

The double character shown in the example above does not seem to happen exclusively with coordination. By improving forecasting systems, for instance, a company can reduce the level of uncertainty it works under but at the same time, it can prepare itself better to respond quicker to future customers orders (such as Company B's build up of "strategic finished goods inventories") and possibly increasing the flexibility which the customer perceives. This finding seems to be in accordance with the idea of the need to ensure some baseline stability (or "rigidity") in order to allow for flexibility, advocated by Adler (1987) who argues that the point about flexibility is not to increase flexibility indefinitely, but to find the right mix of rigidities and flexibilities.

The examples above suggest that in order to analyze flexibility and control we should adopt a systems approach. Intra-system control, for instance, can make inter-system flexibility. Intra-system control aims at reducing the intra-system turbulence caused by the stimuli. The same managerial action can have a character of control or a character of flexibility depending on where one defines the system's borders. These considerations are only possible if a system's approach is adopted.

9.6. Summary of the main aspects of the proposed model

There are two main types of change affecting the manufacturing systems: planned change and unplanned change. This model is primarily concerned with the management of unplanned change, which is called stimuli here.

Stimuli or unplanned change has five main dimensions: size, novelty, frequency, certainty and rate.

Managers use two main approaches in order to deal with unplanned change: either they try to *control* the amount of unplanned changes which affect the manufacturing system's operation by acting *ex-ante* the occurrence of the change or they try to be *flexible* by developing the system's ability to respond effectively to the unplanned change *ex-post* or, after its occurrence.

Seven general types of managerial actions which represent ways of exercising unplanned change control were identified: monitoring / forecasting, coordinating / integrating, focusing / confining, delegating / subcontracting, hedging / substituting, negotiating / advertising / promoting and maintaining / updating / training.

Five general types of manufacturing system's flexibility are important in order to respond to the unplanned changes which were left uncontrolled because either it was impossible or inconvenient to control them: new product, mix, volume, delivery and system robustness flexibility.

Infrastructural resources seem to play a major role in terms of exercising unplanned change control whereas no resource type was considered to be particularly important in terms of developing flexibility. It seems that the answer to the question "what type of resource should be developed in order to achieve what type of system's flexibility" depends on each particular contingency.

The development of manufacturing system's flexibility is done through the development of a configuration of flexible resources. In order to be flexible, structural resources have to possess some level of redundancy in terms of its capacity, capability and/or utilization and some sort of switchability which is the ability to switch easily, cheaply and quickly between tasks. Infrastructural resources do not have to be redundant in order to contribute to the system's flexibility, they only have to perform their function properly.

It is essential to adopt a system's approach in order to understand properly the concepts in isolation and the complementarity between *change control* and *flexibility*. Intra-system change control can contribute to the flexibility of the overall system.

Some of the main points of the proposed model are represented in Figures 9.20 and 9.21 below.

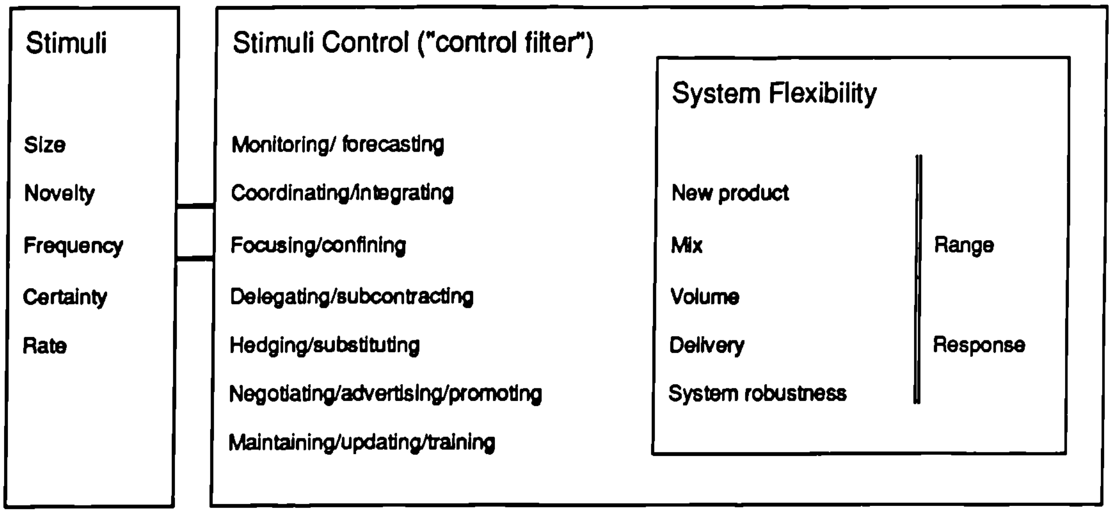

Fig. 9.20. Summary of the main points of the proposed: system's level.

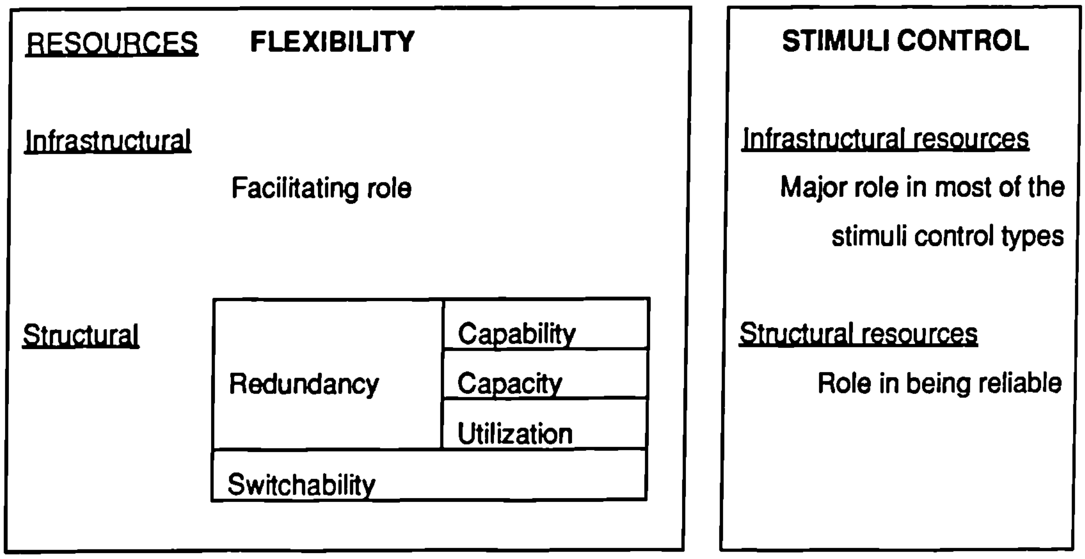

Fig. 9.21 - Summary of the main points of the proposed model - the role of the resources.

Chapter 10 - Conclusions

The objective of chapter 10 is to summarize the main findings of this research work, compare them with the current literature and suggest research avenues and opportunities which still lack further exploration.

The first part of the chapter concentrates on the empirical findings, drawn from the field study which was realized as part of this research and which is described in chapter 8 - "Field Work" and in Appendix 3.

The second part concentrates on the principal aspects of the conceptual model proposed. The model development process is described in details in chapter 9 - "A Model to Understand and Analyze Unplanned Change from an Operations Viewpoint".

The third part of chapter 10 suggests some research opportunities which were open or which have not been explored sufficiently by this research.

Chapter 10

Conclusions

10.1. The Main Empirical Findings and the Current Theory

In this section, the main empirical findings of this research (please see chapter 8 and Appendix 3 for details) are presented, briefly discussed and some comments and comparisons between them and the current literature are also presented:

1. Managers consider flexibility as one of the ways to deal with change in organizations, mainly when the change perceived by the organization cannot be controlled (eliminated or reduced).

Some authors (e.g. Mandelbaum, 1978) have proposed that flexibility can be used in order to deal with changing circumstances. However, little empirical evidence has been found in the literature to back this proposal. Slack's (1987) work represents an exception and resulted in his hierarchical model of manufacturing flexibility. However, the main focus of Slack's research was on flexibility and therefore the control of the uncertain and variable changes which the manufacturing systems are subject to, or in other words, the managerial alternative of trying to reduce or eliminate them, was not contemplated. The present research findings can be regarded as an extension of Slack's model. It is an attempt to include not only the managerial actions which aim at dealing with the unplanned changes' effects *ex-post* the change, but also to consider interfering with the amount of unplanned change which the organization has to deal with *ex-ante* the occurrence of the change. No similar approach has been found in the literature, although the proposed approach is not contradictory with most of the existing research work on the fields of flexibility and/or control. Rather it is an attempt to organize and define more precisely both concepts and the aim is to help managers understand and analyze the manufacturing system's functioning from an alternative viewpoint.

2. Managers not always discriminate explicitly between control and flexibility and not always have a clear view of what should be the most appropriate way in order to deal with the different types and dimension of unplanned change.

The approach generally adopted by the literature has not helped much the managers in making the formal distinction between control and flexibility. Invariably, both concepts are treated in isolation and under a variety of different labels. The literature on "management of change" contemplates primarily the management of planned change, neglecting the type of change on which we focus in this research work: the management of the unplanned changes (called here *stimuli*). No relevant research work has been found on the classification of unplanned change as such. The literature on "uncertainty", by some theorists on "organizational behaviour" attempted to classify uncertain changes in the seventies but the research on the field seemed to have come to a halt after some public disagreements between some researchers via less than complimentary replicas and treplicas to each other's articles (see chapter 4). Apart from that, the "non-uncertain" changes are not contemplated in their analyses either. The mention made by some interviewed managers regarding the need to deal with change as such, sometimes regardless to its certainty, lead us to rethink the tentative "motif" which we had initially considered, based on the literature, for a system to be flexible: from *uncertainty and/or variability* to *change* with its dimensions.

3. Managers understand that different types of change should be dealt with by developing different types and characteristics of resources. However, they in general do not appear to have a consistent model to help them make decisions in that regard.

That is consistent with the approaches found in the literature, which are generally contingential. Several authors attempted to suggest types of flexibility which would be appropriate in order to deal with different uncertain changes or with the variety of the system's outputs. However, possibly because of the use of an inappropriate flexibility taxonomy or because of lack of empirical research to back them, the models in the literature which attempted to relate types of, say, uncertainty and types of flexibility (for example, Gerwin's, 1986) are too general and of little practical use. They associate, for example, "uncertainty with overall volume" with "volume flexibility" (see chapter 2 for more examples), failing to analyze which are the managerial alternative actions involved in developing, for instance, volume flexibility. In this regard, several ways which can be used, according to the managers, in order to deal with the uncertainties and with the variability of outputs they have to face in their day-to-day activities, were identified during the interviews. A more detailed discussion about them and on the related literature follows:

The literature suggests links between uncertainties and flexibility (Gerwin, 1986)(Slack, 1990a), but lacks empirical evidence on the issue. The present research work provides some empirical evidence that flexibility is actually one of the ways which managers use in order to deal with uncertainties.

Gerwin and Tarondeau (1989) propose the following relationship between uncertainty types and flexibility types:

Uncertainty with regard to:		
Disagreggated product demand	needs	mix flexibility
Product life cycle	needs	changeover flexibility
Product specification	needs	modification flexibility
Aggregate production	needs	volume flexibility
Machine downtime	needs	routing flexibility
Process characteristics	needs	specification flexibility

On top of the fact that some relatioships are merely trivial, such as "volume flexibility is needed to deal with demand volume uncertainties", the author's prescription seems to be of limited use for managers. The authors do not analyze the relationships further, in terms of how the managers should go about reaching, for instance, "modification flexibility" (or "the ability of a process to make functional changes in the product" - Gerwin, 1986) or "mix flexibility" ("the ability of a manufacturing process to produce a number of different products at a certain point in time" - Gerwin, 1986) which are not trivial.

Consider the last case, for instance. Suppose a manufacturing system with a very large number of small and totally dedicated machines, with very long set-up times. This hypothetical system is surely able to produce "a number of different products at a certain point in time". But is it flexible in mix? Can it really deal with uncertainty with "disagreggated product demand"? It is doubtful that it can. The authors failed to recognize and prescribe that in dealing with uncertainty in mix, the most important characteristic is exactly the switchability of the resources, provided that there is sufficient capability in the process. That is an example of the reasoning that lead us, in the present research's field work, to try to link types of uncertainty to resource characteristics (see Table 10.1) rather than to system's flexibility types. The managers with whom we talked also seemed to be more used to thinking in terms of managerial actions or features referring to resources, as opposed as to categories or classifications related to the whole system's functioning which, most of the time, they were not aware of (such as "mix flexibility").

Apart from that, some of these actions or features can, according to the managers, have an effect on a number of system flexibility types (for example a multi-capable machine can help in Gerwin's "mix flexibility" and also in "routing flexibility"). The same way, in order to achieve one of the types of system flexibility, it is frequently necessary that more than one feature concur (for instance, in order to achieve routing flexibility, not only multi-capable machines are sufficient, but it is also necessary that the system "knows" or has information regarding, for instance, the alternative routes of the products or parts involved). This inter-relationship between resource features, managerial actions and system's flexibility types makes it dubious to talk about what system flexibility types should be used in order to deal with which different types of uncertainties. The reason for that follows in the form of a hypothetical situation. Consider that a specific resource feature RF is necessary in order to deal with a certain type of uncertainty U. Suppose that this resource feature RF helps (but does not determine) some system flexibility type FT. To assume that being flexible in that system flexibility type FT is what is required in order to deal with the uncertainty U is, to say the least, risky, because being flexible in that system flexibility type FT does not necessarily mean that the specific needed resource feature RF is possessed by the system, since RF is not the only determinant of the system flexibility type FT and it could even not be present in the system if other alternative determinants are.[1]

Knowing the specific resource features which are desirable in order to deal with the different uncertainty types seems therefore to be a more appropriate approach. One can always relate the resource features to the system flexibility types *a posteriori* if necessary or convenient. The following are the ways that managers of the case companies mentioned as appropriate in order to deal with the various types of uncertainty they had previously mentioned as important:

[1]That is the reasoning that motivated, for instance the development and proposal of a new specific system flexibility type which we call system robustness flexibility (see Chapter 9 for details).

Uncertainties regarding	can be dealt with by developing
parts and materials supply	rescheduling ability
	coordination with the suppliers
	buffer stocks
	internal machine capability
product mix demand	ability to re-schedule production
	fast set-ups
	stocks of finished and semi-finished goods
	ability to get short lead times with suppliers
machine breakdown	preventive maintenance
	fast corrective action
	re-routing capability
Labour absenteeism	Labour multi-skills
	some excess capacity of Labour
new product introduction	integration design/development/production
	ability to subcontract supply
management behaviour under change	training / awareness improvement
global demand	forecasting systems
Labour supply	internal training
government intervention	shorter cycle times
technology information	ability to subcontract supply
Unions behaviour	close environment monitoring

Table 10.1 - How the case companies' managers deal with uncertainties.

Although the managers were asked about how they dealt with the uncertainties *ex-post* the uncertain changes had already occurred, many of them emphasized measures which should be used in order to avoid the changes to happen. In the Table 10.1 above, many relationships actually refer to control (e.g. preventive maintenance, and developing forecasting systems) rather than flexibility. This behaviour of the managers is possibly related to the new ideas brought about by concepts such as the "lean production", which advocates proaction rather than reaction for the manufacturing function's attitude. Womack et. al. (1990) illustrate this point when describing aspects of the organization of the "lean-factory":

> "So, in the end, it is the dynamic work team that emerges as the heart of the lean factory (...).Workers then need to acquire many additional skills: simple machine repair, quality checking, housekeeping and materials-ordering. Then they need encouragement to think actively, indeed proactively, so they can devise solutions before the problems become serious."

4. The managers who are more aware about manufacturing flexibility see flexibility as a "reserve", something which should be planned for, developed, maintained and considered as a valuable asset.

The approach to flexibility put this way has not been found in the Literature. Slack (1989) was one author who actually suggested the existence of some sort of redundancy in flexible resources but the author did not attempt to analyze it further, in terms of establishing for instance types of redundancy. One of the advantages of modelling flexibility as a reserve is that the idea, when presented *a posteriori* to some production managers in courses on manufacturing flexibility, given at the University of Warwick and other institutions, appeared to be very appealing to them. The proposed model was informally presented to manufacturing managers from a number of companies (belonging predominantly to the automotive and aerospace industry) and they were then asked to comment on it. Generally the comments were favourable, in terms of modeling flexibility conceptually.

Flexibility, when presented as such, with its character of "potential", sometimes, during the interviews, had seemed to be too abstract a concept for the most pragmatic managers. Possibly they feel more comfortable with a concept such as a reserve because they are in a way used to dealing with "reserves" e.g. inventory (reserves of material) and money (reserves of capital).

10.2. The Proposed Model and the Current Theory

The main points of the model proposed are discussed below (see chapter 9 for details of the proposed model):

In order to manage manufacturing systems effectively, it is important to understand better the concept of change in an increasingly turbulent competitive environment. The current literature approaches change invariably in a partial way. Either it concentrates on planned change (such as the Organization Behaviour and Development's approach) or, when dealing with changes which happen in an unplanned way, the approach is invariably partial and segmented.

Two large streams of research can be identified on the issue of managing unplanned change. In general, one stream is found under the label "flexibility" and although sometimes not rigourously defined, it aims at dealing with the change and its effects *ex-post facto* or, in other words, after the unplanned change has already occurred. In this stream, the literature's approach is also generally partial (with few exceptions), concentrating on specific resource types (such as machine flexibility or Labour flexibility) and failing to analyze flexibility at the manufacturing system's level consistently.

The second stream, although not explicitly, aims at reducing the amount or nature of the changes with which the system has to deal. Several management techniques and research fields are engaged in finding ways in order to control the dynamics and the magnitude of the changes which affect the manufacturing systems: forecasting techniques, maintenance systems, parts standardization techniques and manufacture focusing are some among numerous examples. Their aim is to try to avoid the occurrence of the change, *ex-ante facto* or in other words, preventively.

Although both streams aim at managing unplanned change, the current literature lacks an unifying framework which encompasses both streams and helps managers understand and analyze the concepts of unplanned change, control and flexibility and their inter-relation. The present research work proposes such a framework. Its main propositions and how they relate to the current literature are summarized below:

Main propositions of the proposed model:

1. Stimuli, or relevant unplanned changes, to which the manufacturing system is exposed, have dimensions: size, frequency, novelty, certainty and rate. It is important to classify stimuli because different stimuli dimensions may call for different managerial actions.

The current literature is very fertile when dealing with planned change. Numerous publications can be found on issues relating to "how to change the organization effectively", under various labels: "Organization Development", "Organizational Behaviour", "Management of Change", are some examples. However, it is scarce in terms of unplanned change. Flexibility is possibly the only research field where dealing with unplanned changing circumstances is an explicit objective. However, despite mentioning change when defining the field, interestingly enough, the authors do not appear to dedicate much attention to understanding and classifying change when developing the theme. Instead, some of the authors concentrate on some aspects of the changes such as uncertainty and variability of outputs.

Both variables are included in the framework proposed here, since one of its proposed change dimensions is exactly the uncertainty of the change. Variability, in the framework, is translated into the change dimensions novelty, size, frequency and rate.

2. There are two basic and complementary ways of managing stimuli in manufacturing systems: by controlling the stimuli and by being flexible or dealing with the stimuli's effects.

The following definitions are proposed:

Control is defined here as the ability to interfere effectively with the causes of the changes or with the way the system senses the changes, in order to alter one or some of the dimensions of which effects the system will otherwise have to respond to.

Flexibility is defined as the ability to deal effectively with the effects, sensed by the system, of the unplanned changes.

This complementarity between control and flexibility was suggested by Gerwin and Tarondeau (1989) in terms of dealing with uncertainties, but it had not been formalized. It is also being proposed here that this approach can be extended to deal with all dimensions of *change* and not only with uncertainty.

The proposed approach also allows for a somewhat more rigourous definition of manufacturing flexibility. In the literature, some loose definitions of flexibility can be found. Buzacott and Mandelbaum (1985), mentioned in Gupta and Goyal (1989), define flexibility as "the ability of a manufacturing system to cope with changing circumstances".

Rigourously, if control is not considered, flexibility should not be regarded simply as the ability to cope with changing circumstances, but rather, to respond to changing circumstances. The reason is simple: in a hypothetical situation, avoiding being involved with a change in demand, for instance, can be a good way in order to cope with the change. It can possibly even be good managerial practice, but it is hard to consider such practice as flexibility. That would be, for instance, the case of the corporate strategy of a hypothetical organization which focuses on a stable standard line of products aiming at a specific niche of the market, in order to prevent the manufacturing system from being exposed to frequent and novel demand changes. The adaptation may have been effective, but that does not make the manufacturing system flexible. Flexibility, according to one dictionary's definition seems to catch the point very well: "Flexibility is the ability to be changed to suit circumstances". (Oxford Paperback Dictionary, Third edition). The idea of "being changed" implies that the system is actually reacting and not avoiding having to react.

In order to be able to conceptualize flexibility rigourously, it seems to be important to bear in mind the complementarity of its concept with that of unplanned change control, which is scarcely addressed in this way in the operations management literature.

The unplanned change control methods used by the system, thus would work as a "filter", restricting the amount of change effects the system has to deal with. The changes which "pass through" the control filter, then, have actually to be dealt with by the system, through its system's flexibility characteristics.

3. Intra-system unplanned change control can be used in order to improve the level of the system flexibility.

Because unplanned change is in general disrupting and the level of flexibility of a system is also dependent on the speed with which it reacts to changes, some intra-system change control can help increase the system's flexibility, mainly in terms of its responsiveness. Many examples of intra-system change control can be found in the literature. Manufacturing focusing, preventive maintenance and MPC systems are all systems which attempt to control one or some dimensions of the changes within the system. This intra-system control can possibly help increase the levels of flexibility of the system as a whole (or the inter-system flexibility), because it allows for the system to be more responsive (e.g. via coordination) and less exposed to undesirable disrupting set-backs.

This makes the relationship flexibility-control more complex, system's approach-dependent and demonstrates once more the importance for the manufacturing system's managers to understand it well. The literature does not address this relationship explicitly.

4. There are 5 types of flexibility which are relevant for the analysis of manufacturing system's flexibility: new product, mix of products, volume, delivery and system robustness flexibility.

In general the literature on flexibility emphasizes the flexibility of particular resource types. Although these approaches can be useful to help address specific problems such as the comparison between two machines' flexibilities, from an operations viewpoint they are of limited use, because they generally do not link the flexibility of the resources with the strategic objectives of the manufacturing operation. To be able to do it, a system's approach to analyze flexibility appears to be more adequate, in which all the resources are analyzed and considered as the interacting elements which form the manufacturing system. Some research work found in the literature address flexibility at this level (which allows for analyses of the contribution that a flexible system can give to the organization competitiveness), but they concentrate on the application of flexibility concepts in order to allow for the system to be able to change its outputs. However, the use of flexibility concepts in order to prevent the system from being disrupted from unexpected setbacks with the supply side and with the process itself is neglected. These authors leave it somewhat implicit that if a system is flexible in terms of changing its outputs it would automatically have developed abilities to overcome setbacks with the process and inputs. We demonstrate that this is not always valid and that in some situations specific flexibility-related abilities should be developed in order to achieve desired levels of system robustness.

Some authors, on the other hand, emphasize the importance of flexibility in ensuring that the system's functioning is "protected" by the occurrence of these setbacks but they have not developed the concept further in terms of its application. Mandelbaum's state flexibility and Buzzacott's machine flexibility, for instance, both relate to the ability of the system to cope with changes and disturbances with its constituent elements. However, in their research work, the objective was to conceptualize types and dimensions of flexibility rather than to analyze the operationalization of such flexibilities. They also lack empirical evidence.

In this research, a 5th type of system's flexibility is proposed to be added to the 4 ones proposed by Slack (1989), which were considered appropriate to analyze demand-related flexibilities. The 5th type is called here "system's robustness flexibility". The proposed type has particular characteristics and aims at filling the gap identified above. The ways some managers use in order to operationalize such concept are also discussed in chapter 9, drawing from information from the field work.

5. There are several ways of exercising control over the unplanned changes. Some of them, drawn from the literature and from the field work findings are represented by the following general managerial actions: Monitoring / forecasting,

Coordinating / integrating, Focusing / confining, Delegating / subcontracting, Hedging / substituting, Negotiating / advertising / promoting and, Maintaining / updating / training.

The literature is fertile in ways of exercising control over the unplanned changes. Several managerial techniques, although not explicitly, aim at reducing one or some of the aspects or dimensions of the changes the system would otherwise have to deal with.

Some of them can be identified:

Vertical integration - it is a way of achieving control through Coordination / integration. The literature on vertical integration is vast. One of the reasons for a company to vertically integrate, according to the literature, is to reduce transaction costs. Putting it simply, transaction costs would happen due to reasons such as imperfections in the communication between the company and its suppliers and the less than complete and precise information about the supplier's processes. Integrating vertically, the company would improve communication and would also have more information about the supplier's behaviour and process. Vertical integration is therefore a way of exercising control over changes with the relationship with the suppliers.

Forecasting techniques - which are techniques used in order to achieve control through "Monitoring/forecasting". Quantitative (regression analysis, time series, among others) and qualitative methods (e.g. some market research methods) are numerous in the literature and they are used in order to try to predict and anticipate future events in an attempt to reduce the uncertainty and novelty aspects of the future changes.

Manufacturing planning and control systems - they are attempts to increase control through "Coordination/integration", trying to coordinate demand with supply from the customer's demand, along the internal supply chain and sometimes extending the coordination to external suppliers. MRP II system and Kanban system, for instance, are different systems aiming, at least, one common objective: controlling change along the organization's supply chain.

Preventive maintenance - another particular case of one of the proposed types of control - "Maintaining/updating/training", preventive maintenance aims at "building reliability" on the equipment, aiming at the reduction of the uncertainty, frequency and/or impact (size) of the changes brought up by machine breakdowns.

Suppliers development - again a particular case of "Maintaining/updating/training", supplier development aims at building reliability on the supply base, in order to control the frequency and uncertainty of problems regarding supplies, in terms of delivery dates and quality levels.

Make-or-buy analysis - which is related to "Delegating/subcontracting". Companies can control change dimensions by deciding, for instance, to buy in a component of which the technology is changing too fast. In this case, the uncertainty and rate of the possible changes, sensed by the company, regarding the involved technology would be controlled.

Standardization - from an operations viewpoint, standardization is a particular case of "Negotiating / advertising / promoting". Standardization has generally to be negotiated with the manufacturing internal customers (such as the Marketing function) and suppliers (such as the Design function), and intends typically to reduce the frequency of the changes (such as the machine changeovers) with which the manufacturing function has to deal.

Simultaneous engineering - a particular case of "Coordination/integration", between functions of the organization. People responsible for the several stages of development of a new product get together at early stages and coordinate their efforts to make the stages as simultaneous as possible, as opposed as the traditional sequential fashion. People from different functions such as production and process and product development, co-operating at early stages, can also make sure that things are designed/made right first time, reducing the frequency of future changes such as re-designs.

Manufacturing focus - which is a particular case of "Focusing/confining". By focusing production units on specific manufacturing tasks, the organization can either control the changes frequency (if it chooses to focus on large orders), the changes novelty and certainty (if it chooses to focus on standard parts) or the changes size (if it, for instance, chooses to focus on a specific range of order sizes).

6. The infrastructural resources play a major role in exercising control over changes.

This is demonstrated by analyzing the control types (see chapter 9 for details). All of them relate in one way or another to systems (e.g. information system, organization system, control system, supply system).

7. The contribution that the infrastructural resources can give to the manufacturing system flexibility is related to response rather than range flexibility, which is primarily dependent on the structural resources.

The literature on flexibility also does not discriminate conceptually the roles that structural and infrastructural resources play in the achievement of system flexibility. Such discrimination is important because in order to achieve desired levels of specific flexibility types, specific resources have to be developed in specific ways.

8. The contribution that structural resources can give to the manufacturing system's flexibility is through structural resource *redundancy* - in terms of capability, capacity and utilization, and *switchability*.

The idea that flexibility can be seen as an asset of the manufacturing system, drawn from the field study - in addition to Slack's suggestion that flexibility implies some sort of redundancy of resources - motivated the development of the "redundancy model". The analysis of the redundancies of the different resource types lead to the understanding of the differences in the role of structural and infrastructural resources in terms of supporting the system's flexibility. Because the redundancy model is original, the literature does not comment on it.

As a by-product of the redundancy model, the role of the stocks in terms of its relationship with system's flexibility was clarified. According to the present research's approach, there is not a clear conceptual difference between holding excess capacity, having abilities in excess or holding stocks of goods. All are manifestations of resource redundancies, in terms, respectively, of capacity, capability and utilization. The three of them are elements with which the managers can play in order to achieve manufacturing system's flexibility.

The current literature lacks a model which explains the relationship between flexibility and stocks, frequently seen as mutually exclusive alternatives. The complementary rather than exclusive alternatives' approach proposed here does not prescribe or recommend the use of stocks of goods in order to achieve flexibility, but is an attempt to call the attention to the fact that stocks are a possible complementary alternative to other ways of achieving flexibility. There are trade-offs to be considered in the process of configuring the resources, which should take into account all the costs involved with holding stocks - which possibly go beyond the financial costs, including the costs of "hiding problems", for instance (Schonberger, 1986) - holding capacity in excess and holding capability in excess.

10.3. Looking Forward: Some Questions Which Are Still to Be Answered

There are some questions regarding the relationship between uncertainty, variability of outputs and flexibility in manufacturing systems which are still to be answered. Some of such questions are discussed below.

The costs of flexibility and control and the trade-offs involved - The amount of control and flexibility used by a manufacturing system in order to manage its unplanned changes is, to a certain extent, a managerial choice. Although they are not the only considerations to be done, there are trade-offs to be considered between control and flexibility. In order to analyze such trade-offs, it is important that the managers have a good understanding of the costs of controlling the unplanned changes and the costs of developing flexibility and also of being flexible. This is an issue which is scarcely explored by the literature and surely needs further development.

The relationship between system flexibility and resource flexibility - The relationship between desired or required system flexibility levels, set by the manufacturing strategy, and the system's resource characteristics which are necessary in order to achieve them is something which, although addressed briefly in this research, needs further exploration. The literature, in general, do not discriminate properly between different levels of analysis with regard to flexibility. In some of the author's lists of "flexibility types" one can find flexibility "types" from two or even three levels - the machine, the system and the organization as a whole.

It is important to have a consistent set of flexibility types and dimensions, which can be linked to the organization's strategic objectives, when analyzing the flexibility of manufacturing systems. The model proposed here provides this classification. However, given the levels of flexibility which the particular manufacturing system has to achieve, what should be the resources to be developed in order to achieve such levels? That is a question which has not been sufficiently explored neither in the literature nor in the present research work and certainly is an issue which deserves further attention.

The costs of the different redundant resource types - In order to achieve the appropriate mix of flexibilities required, choices of the adequate configuration of resource redundancy should be made. Some choices are quite clear. To achieve product range flexibility a firm has to use its redundant capability because neither goods nor capacity will help. However, in some situations, managers do have alternatives to choose between. For example, if a system is being designed to have a highly flexible response to volume changes, some alternatives are available: redundant stocks may be used as well as redundant capacity or still a mix of both. If a system needs high mix response flexibility, a choice between very flexible machines and workers and, some level of stocks of finished and semi finished goods has to be made. The trade-offs involved must be considered for each and every situation, contingently. At the system's level, therefore, a plant can be flexible via different configurations of the three types of redundant resources. Alternatives at the resource level represent trade-offs to be done at the system level. This research has not explored this aspect and the issue surely deserves further attention.

Contingency relationships within the model - The contingent aspect of the proposed model appears to be clear. There are specific actions to be taken, decisions to be made and resources to be developed which are contingently more appropriate to deal with specific environmental and internal conditions and objectives. However, the contingency relationships between the categories within the model still require further development:

Between the unplanned changes dimensions and the control types and flexibility types and dimensions.

Between the types of stimuli control and the specific structural and infrastructural resources.

Between the types of system flexibility and the types of structural resource redundancy and switchability and, infrastructural resource types.

An audit procedure based on the proposed model - The development of an audit procedure based on the proposed model seems to be important in order to make it possible that the managers can make further practical use of it. The procedure should include: a) the identification of the key types of change to which the system is subject, be them internal or external, related to the inputs, process or outputs. It should consider both types, those changes which represent opportunities and those which represent risks for the company's present and future competitive position, considering the manufacturing strategy of the company. b) the evaluation of the flexibility-related performance of the manufacturing system and resources. The model developed in this research could help managers decide how they should cope with the identified changes to which the company is subject. This way, comparisons between what is being done and what should be done could be made and actions could be planned based on the discrepancies.

A Rationale behind the unplanned change control types- The types of change control proposed deserve further attention. The list of seven types proposed do not pretend to be exhaustive. More types are possible to be found and also a general rationale behind the seven types seems possible to be determined.

10.4. Looking Back - A Critical Review of this Research Work

Some points are worth mentioning in an attempt to evaluate with hindsight the way in which this research work has been conducted. Such an evaluation can be of some help for researchers and students in order that they avoid repeating mistakes and that they can take advantage of the parts which proved to be successful.

The case-study approach - The case study based on semi-structured interviews approach used as the research method proved to be adequate for the objectives of this research. It allowed the researcher to adjust and, at a certain extent, redirect the focus of the research, from the one defined at the outset, which aimed at exploring the relationships between flexibility, uncertainty and variability to the broader view of managing unplanned change. It was then possible to build theory through the development of a model which is described in chapter 9. The semistructured interviews allowed that the researcher explored aspects which were not present in the research propositions defined at the outset of the project, such as the concept of stimuli control and its types, which ended up being one of the central aspects of the proposed model. The same comment is valid with regard to the treatment of flexibility of the manufacturing resources using the idea of resource redundancy. This idea would probably not be developed if a survey had been conducted based, for instance, on a structured questionnaire sent to the managers by mail, or in other words, without the presence of the researcher. The case study approach also allowed for the choice of polar and rich cases, because the cases were not chosen at random (see chapters 6 and 7). The companies in Brazil, as expected, provided polar examples which allowed the exploration of the concept of environmental uncertainty and how the managers deal with it and, the British companies provided examples of rich product variety and modern approaches to it. A random sample, which would probably be the case if the chosen approach had been a large survey would possibly not contain such rich and polar cases.

The difficulty to get "hard data" about flexibility. - Although already considered as an important feature of manufacturing systems by most of the managers interviewed, flexibility is still a concept which is scarcely measured and accompanied in the case companies. Most of the managers agreed that they should attempt to measure the system's performance in terms of flexibility but at the time of the research field work none of them had implemented procedures which measured important aspects of the ability of the manufacturing system to change. Hence the scarce hard data present in this research work which relied heavily on the manager's perceptions. Hopefully in the near future the organizations shall develop procedures in order to assess and accompany the flexibility of their manufacturing systems and so more objective analyses will be possible for future research.

The question of results generalization - There is no evidence that the results achieved are not analytically generalizable beyond the limits of the case companies analyzed and even beyond the automotive industry, to which the case companies belong. The present research did not aim at statistical generalizations about a population, but at analytical generalization. The categories present in the proposed model seem to be sufficiently general to be also suitable for other industries and manufacturing types. The case companies were chosen within the metal engineering automotive industry because they represent possibly one of the most complex industries in terms of operations management. Other industries will probably have less complex problems in managing their unplanned changes, but hopefully the richness and the complexity of the cases analyzed in this research will also help their managers to understand better the concepts involved.

Some problems in getting access to the case companies - The question of access turned out to be one of the major issues in the research field work. It was extremely difficult to schedule the interviews with managers of two out of the 4 companies, even after the first contact had been established (as a rule, with the Managing Director or Plant Director) and formal access gained. It took the amazing time of 11 months for all the interviews to be scheduled and completed in one of the companies. During this period, at least twice a month the researcher contacted the company, in order to remind them of the need to schedule the interviews. In another case, the access was initially gained via contact with the Managing Director (who accumulated also the position of Plant Director). The first interview, conducted with him, and a comprehensive visit to the plant (the researcher actually spent 2 full days in this company during this first visit) was also carried out. However, from then on, the Managing Director appeared to have changed his mind about access to other managers. Only after 3 precious weeks of unsuccessful attempts to schedule the remaining interviews the Managing Director clarified that access would not be given to the other managers. It was eventually decided to change plans and start establishing contacts with another company.

Although a limited number of managers were formally interviewed, a larger number of people were contacted in all case-companies and, following Mintzberg's (1979) advice (he argues that the multiple stimuli present in rich case data seem to encourage thinking in unusual ways), the researcher spent as much time as the constraints allowed, in the plants, trying to "sense" the atmosphere and allow for more rich interviews and analyses. This attitude proved to be both very educative for the researcher and effective for the research. The close contact with the companies and their managers gave the researcher very valuable insights.

A summary of the main apparent problems with the methodology used follows:

1. The sample is possibly not representative of the case companies industry and the findings are not statistically generalizable. In order that the results could be considered statistically generalizable, the sample should have been possibly much larger and chosen at random. In this case, however, the richness of the polar cases could have been lost. The research did not aim at statistical generalizations from the outset. The main aim, which has been achieved, was to build theory which should be analytically rather than statistically generalizable (see chapter 6).

2. The findings are largely based on the managers' perceptions which can be biased. Given the objectives of this research however any other method would probably have even more problems, because the variables involved in this research, such as uncertainty and flexibility are complex and the methods for their objective measurement found so far in the literature are controversial and highly arguable (see chapters 2, 3 and 7 for discussions on the measurement of flexibility and uncertainty).

3. The treatment of the data included the interpretation, by the researcher, of the opinions expressed by the managers, what can also bias the findings. However, given the need to use the manager's perceptions, no alternative was left except to interpret the manager's answers. If a closed structured questionnaire had been used, in order to avoid interpretation of the answers, the exercise of building theory would be jeopardized, since the managers would not have the opportunity to extend their comments on the researched topics. Developments such as the "redundancy model" of flexibility (see chapter 9, section 9.4.3. "The Flexibility of the Structural Resources"), among others possibly would not have been achieved. Additionally, the data treatment process was as systematic and careful as possible in order to try to avoid biasing the findings as much as possible.

4. The choice of the case companies and the managers to be interviewed was done arbitrarily and therefore there is no guarantee that it was the best choice possible. Once again, the alternative would have been a random sample, which, given the resource constraints of the researcher, could not have been large, given that the presence of the researcher in the data collecting process was considered essential (see chapter 6). With a small sample, it is possible that no rich polar cases would have been included, This would possibly have made the findings less "rich" in data. Additionally, any research design include a certain level of arbitrary choice. In large surveys, for example, using a

closed questionnaire sent by mail to companies chosen at random, the researcher has to face the choice of *to whom* to send the questionnaires. It is unlikely that any research design for this kind of organizational research would prescribe the choice of the respondents within a company in a random way.

5. It seems that the researcher was less flexible than he could have been, during the pilot study, in terms of changing the research instrument. Had he commenced amending the questionnaire's structure and even challenged the research question itself from the first interview, possibly he could have explored more some of the aspects such as the cotingent relationships mentioned in the section 10.3. "Looking Forward: Some Questions Which Are Still to Be Answered". It took some time before one of the main advantages of the case studies started to be used i.e. the possibility of redirecting the research during its course.

Concluding, although the methodology adopted does have problems, it seems that if any other research design had been adopted instead, it would have had even more problems, given the objectives established at the outset of this research.

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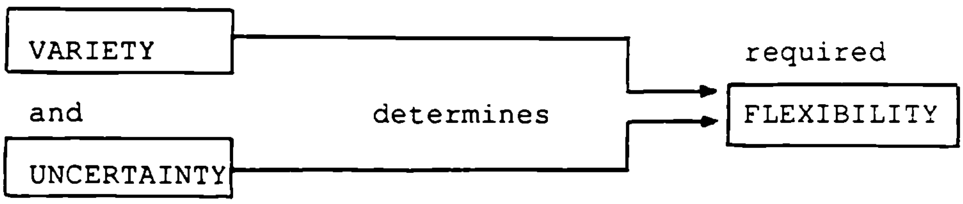
Appendix 1

The Research Instrument - First Version

MANUFACTURING FLEXIBILITY PROJECT

This list of questions is part of research being developed by the Department Manufacturing and Engineering Systems of Brunel University.

The research seeks to stablish the relationships between manufacturing flexibilities, the variety of products and tasks which the manufacturing function has undertake, and the uncertainty under which the company operates.



The list of questions will be used as a "basis for discussion" in a series interviews with specific people within the Organisation.

You are not asked to fill it in like you would a questionnaire. It is included here so that you can see the type of questions which we are interested in asking you.

Each interview should last between one and one and a half hours and will be carried out by one of the Research Associates of the Department Staff.

October 6, 1989

UNCERTAINTY

This part of the interview will deal with the various factors which make manufacturing environment uncertain. You will be asked how predictable the va- ous factors are, and how important they are to your operation.

	Not Predictable/ Predictable	Not important/ Important
Quality levels of b/o parts and materials	1 2 3 4 5	1 2 3 4
Delivery lead time of parts and materials	1 2 3 4 5	1 2 3 4
Changes in process technology	1 2 3 4 5	1 2 3 4
Changes in product technology	1 2 3 4 5	1 2 3 4
Equipment supply	1 2 3 4 5	1 2 3 4
Relationship with Union	1 2 3 4 5	1 2 3 4
Quantity of Labour	1 2 3 4 5	1 2 3 4
Skills of Labour	1 2 3 4 5	1 2 3 4
Capital supply	1 2 3 4 5	1 2 3 4
Mix of products	1 2 3 4 5	1 2 3 4
Length of product life cycle	1 2 3 4 5	1 2 3 4
Appropriate product characteristics	1 2 3 4 5	1 2 3 4
Aggregate demand	1 2 3 4 5	1 2 3 4
Machine down time	1 2 3 4 5	1 2 3 4
Labour absenteeism	1 2 3 4 5	1 2 3 4
Labour behaviour under changing circumstances	1 2 3 4 5	1 2 3 4
Management behaviour under changing circumstances	1 2 3 4 5	1 2 3 4
Organisational relationships across functional interfaces	1 2 3 4 5	1 2 3 4
Competitors behaviour	1 2 3 4 5	1 2 3 4

Government regulations	1 2 3 4 5	1 2 3 4

VARIETY

The following part will deal with the variety of products and tasks which manufacturing function has to undertake. You will be asked how many differ product families you conventionally use, some basic information about each them and the importance Variety has in terms of competitiveness to the Organi tion.

Product family groups	% sales turnover	# of products	How different they are *	How impo Variety : Very impor Irrel
1. ____	____	____	1 2 3 4 5	1 2 3 4
2. ____	____	____	1 2 3 4 5	1 2 3 4
3. ____	____	____	1 2 3 4 5	1 2 3 4
4. ____	____	____	1 2 3 4 5	1 2 3 4
5. ____	____	____	1 2 3 4 5	1 2 3 4
6. ____	____	____	1 2 3 4 5	1 2 3 4
7. ____	____	____	1 2 3 4 5	1 2 3 4
8. ____	____	____	1 2 3 4 5	1 2 3 4
9. ____	____	____	1 2 3 4 5	1 2 3 4
10. ____	____	____	1 2 3 4 5	1 2 3 4
11. ____	____	____	1 2 3 4 5	1 2 3 4
12. ____	____	____	1 2 3 4 5	1 2 3 4

*How different they are

1. Single product
2. Minor differences between products (colours, accessories)
3. Fairly different products made to stock
4. Assembly to order according to client specs (from stockable parts)

5. completely different products made to order according to customers' origi specs

FLEXIBILITY OF MANUFACTURING RESOURCES

The third part of the interview deals with the various resources used by the Organisation to perform its manufacturing function. You will be asked about their actual performance and the importance they have to the Organisation competitiveness.

Resource characteristics

	Performance Very good ... Very bad	Importance Very imp ... Irre
Range of process capability	1 2 3 4 5	1 2 3 4
Capability of design - range of skills	1 2 3 4 5	1 2 3 4
Capability of design - response time (CAD syst.	1 2 3 4 5	1 2 3 4
Process change times, set-up times	1 2 3 4 5	1 2 3 4
Degree of integration of the process (Design/Mfg	1 2 3 4 5	1 2 3 4
Standardization of parts	1 2 3 4 5	1 2 3 4
Total process capacity	1 2 3 4 5	1 2 3 4
Range of process skills	1 2 3 4 5	1 2 3 4
Transferability of direct labour	1 2 3 4 5	1 2 3 4
Direct/indirect task transferability	1 2 3 4 5	1 2 3 4
Overtime capability - amount	1 2 3 4 5	1 2 3 4
Overtime capability - time to organise	1 2 3 4 5	1 2 3 4
Quick supply of design and process labour	1 2 3 4 5	1 2 3 4
Ability to vary design and process labour levels through temporaries, self empl., subcontr., outsourc.	1 2 3 4 5	1 2 3 4
Ability to vary design and process labour levels through part time, job sharing, short term contracts	1 2 3 4 5	1 2 3 4

Ability of people to work in groups	1 2 3 4 5	1 2 3 4
Ability to modify process technology	1 2 3 4 5	1 2 3 4
Ability to get and keep purchased items l-times low	1 2 3 4 5	1 2 3 4
Ability to provide subcontract supply	1 2 3 4 5	1 2 3 4
Project management skills	1 2 3 4 5	1 2 3 4
Order processing and forecasting sensitivity	1 2 3 4 5	1 2 3 4
Ability to reschedule activities	1 2 3 4 5	1 2 3 4
Ability to get new product techn. information (timely?)	1 2 3 4 5	1 2 3 4
Ability to get new process techn. information (timely?)	1 2 3 4 5	1 2 3 4
Ability to change layout	1 2 3 4 5	1 2 3 4
Ability to create and manage multidiscipl. work teams	1 2 3 4 5	1 2 3 4
Communication between Marketing and Design teams	1 2 3 4 5	1 2 3 4
Communication between Design and Process teams	1 2 3 4 5	1 2 3 4
Ability of people to learn	1 2 3 4 5	1 2 3 4
Capability/responsiveness of the distribution syst.	1 2 3 4 5	1 2 3 4
Research and development activities	1 2 3 4 5	1 2 3 4

FLEXIBILITY OF THE MANUFACTURING SYSTEM AS A WHOLE

The last part of the interview deals with the manufacturing system Flexibil[illegible] The questions will be about the actual performance of the Organisation in te[illegible] of the various types of Flexibility and the importance they have to its compe tiveness.

Desirable System Flexibility (Product, Mix, Volume, Delivery)

	Performance: Competitors Much better … Much worse	Importan[illegible] to compe[illegible] Very Impor[illegible] … Irrel[illegible]
Limits to what new products or modifications could be designed/made (product range)	1 2 3 4 5	1 2 3 4
Lead time of design/sourcing/make (product response)	1 2 3 4 5	1 2 3 4
Limits to what could be designed/made (mix range)	1 2 3 4 5	1 2 3 4
Lead time to change mix of products (mix response)	1 2 3 4 5	1 2 3 4
Limit to aggregate output fluctuation (volume range)	1 2 3 4 5	1 2 3 4
Lead time to effect output vol. change (vol response)	1 2 3 4 5	1 2 3 4
Limits to change normal delivery dates (delivery range)	1 2 3 4 5	1 2 3 4
Lead time to reschedule (delivery response)	1 2 3 4 5	1 2 3 4

Appendix 2

The Research Instrument - Modified Version

Manufacturing Flexibility Project

This protocol is part of research being developed by the School of Industrial and Business Studies, University of Warwick.

The research seeks to establish the relationships between manufacturing flexibilities, the variety of products and tasks which the manufacturing function has to undertake, and the uncertainty under which the company operates.

VARIETY		required
and	determines	FLEXIBILITY
UNCERTAINTY		

The list of questions will be used as a "basis for discussion" in a series of interviews with specific people within the organization

You are not asked to fill it in like you would a questionnaire. It is included here so that you can see the type of questions which we are interested in asking you.

Each interview should last between one and one and a half hours and will be carried out by one of the Research Associates of the Department Staff.

Uncertainty

This part of the interview will deal with the various factors which make the manufacturing environment uncertain. You will be asked how predictable the various factors are, and how important they are to the operation.

The point scale is:

1. Completely unpredictable
2. Low predictability
3. Fairly predictable
4. Very predictable
5. Certain

Parts and materials supply

quality levels
delivery lead time

1 2 3 4 5

Technology supply

product technological information
process technological information
equipment supply

1 2 3 4 5

Labour supply

quantity
level of skills

1 2 3 4 5

Capital supply

1 2 3 4 5

Labour behaviour

absenteeism
behaviour under changing circumstances
relationship with unions

1 2 3 4 5

Management behaviour

behaviour under changing circumstances

1 2 3 4 5

Machine downtime

1 2 3 4 5

Product characteristics

length of product life cycle
appropriate product characteristics

1 2 3 4 5

Aggregate demand

1 2 3 4 5

Mix of products

1 2 3 4 5

Competitors behaviour

1 2 3 4 5

Government regulations

price control
tax and incentive policies for investment
indexes for wage adjustments

1 2 3 4 5

Inflation

1 2 3 4 5

Are there other factors considered by yourself as important which weren't listed so far ?

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

6. ______________________________

How would you rank, in terms of importance for your operation, the six main uncertainty factors, among all the ones discussed above ? (first column)

1. ______________________ ______________________

2. ______________________ ______________________

3. ______________________ ______________________

4. ______________________ ______________________

5. ______________________ ______________________

6. ______________________ ______________________

How do you cope with them? (second column)

Variety

The following part deals with the variety of products and tasks which the manufacturing function has to undertake. You will be asked how many different product families you manufacture, and some basic information about each of them.

Product family groups	% sales turnover	# of products	How different they are
1. ________________	______	______	1 2 3 4 5
2. ________________	______	______	1 2 3 4 5
3. ________________	______	______	1 2 3 4 5
4. ________________	______	______	1 2 3 4 5
5. ________________	______	______	1 2 3 4 5
6. ________________	______	______	1 2 3 4 5
7. ________________	______	______	1 2 3 4 5
8. ________________	______	______	1 2 3 4 5
9. ________________	______	______	1 2 3 4 5
10. ________________	______	______	1 2 3 4 5
11. ________________	______	______	1 2 3 4 5
12. ________________	______	______	1 2 3 4 5

The point scale is (how different products within a group are):

1. Single product
2. Minor differences between products (colours, accessories)
3. Fairly different products made to stock
4. Assembly to order according with customer specifications (from stockable parts)
5. Completely different products made to order according to customers' original specs

How does aggregated output vary? (+or- %) in how long?

How frequent is the introduction of new products and how different they are?

1 2 3 4 5

How does the mix of products vary?

How do you cope with this variability?

Flexibility of Manufacturing Resources

The third part of the interview deals with the various resources used by the Organization to perform its manufacturing function. You will be asked about their actual performance compared to the needs and the importance they have to the Organization competitiveness.

Resource characteristics	Performance				
Technology	Very good				Very bad
Capability of design range of skills response time (CAD system)	1	2	3	4	5
Interface Design/Manufacturing response time (CAD/CAM links)	1	2	3	4	5
Equipment capability range	1	2	3	4	5
Equipment set up times	1	2	3	4	5
Total process capacity compared with utilization	1	2	3	4	5
Layout changeability	1	2	3	4	5
Labour					
Range of skills in direct tasks multi abilities transferability	1	2	3	4	5
Direct/ Indirect task transferability	1	2	3	4	5
Overtime capability	1	2	3	4	5
Ability of people to work in groups	1	2	3	4	5
Project management skills	1	2	3	4	5
Infrastructure					
Standardization of parts	1	2	3	4	5
Overtime capability - time to organize	1	2	3	4	5

Ability to provide subcontract supply	1	2	3	4	5
Ability to supply design and process people quickly	1	2	3	4	5
Ability to get and keep purchased items lead times low	1	2	3	4	5
Changeability of order processing/ dispatching disciplines	1	2	3	4	5
Forecast sensitivity	1	2	3	4	5
Ability to get new technological information (timely?) product technological information process technological information	1	2	3	4	5
Control systems effectiveness process monitoring fast corrective action	1	2	3	4	5

What is the logic behind the Inventory and Production Management techniques the company uses?

- Kamban or other visual technique
- Group Technology/Period Batch Control
- OPT
- Pure MRP
- Reorder point, dispatching lists
- MRP with safety stocks/time
- Other (which?)

Which do you consider ideally the most important of all the characteristics listed above to the organisation competitiveness? Please rank them. Why are they important?

Priorities

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________

Flexibility of the Manufacturing System

The last part of the interview deals with the manufacturing system flexibility. The questions are about the actual performance of the Organization in terms of various types and dimensions of flexibility and the importance they have to its competitiveness. The concepts involved will be defined during the interviews whenever necessary.

System Flexibilities Performance.

The 5-point scale is as shown below:

Much better than the competition				Much worse than the competition
1	2	3	4	5

Limits to what new products or modifications could be designed/made (product range)
1 2 3 4 5

Lead time of design/sourcing/make (product response)
1 2 3 4 5

Limits to what could be designed/made (mix range)
1 2 3 4 5

Lead time to change mix of products (mix response)
1 2 3 4 5

Limit to aggregate output fluctuation (volume range)
1 2 3 4 5

Lead time to effect output volume change (volume response)
1 2 3 4 5

Limits to change normal delivery dates (delivery range)
1 2 3 4 5

Lead time to reschedule (delivery response)
1 2 3 4 5

How would you rank, in terms of importance to the overall performance/competitiveness of your Organization, the eight System Flexibilities listed above? (first column)

1. ______________________________ ______________________________

2. ______________________________ ______________________________

3. ______________________________ ______________________________

4. ______________________________ ______________________________

5. ______________________________ ______________________________

6. ______________________________ ______________________________

7. ______________________________ ______________________________

8. ______________________________ ______________________________

Appendix 3

The 4 Case-Studies

Appendix 3

The 4 Case-Studies

A. Description

As described in chapter 6 - Methodology, the Research Method used in this research work is "case studies". The research problem is defined as "the relationship between manufacturing flexibility, variability of outputs and environmental uncertainty". The protocol used in the interviews with the managers as well as the method used to collect and analyze the data presented in this chapter are described in chapter 6.

B. The Case-Companies

Four plants were analyzed being 2 in Brazil and 2 in the United Kingdom. All of them are manufacturers of engineering products and all of them belong with the automotive industry. One of them is a vehicle manufacturer and three of them are vehicle sub-assembly manufacturers, one manufacturing carburettors, the other manufacturing engines and the last one manufacturing shock absorbers.

C. The Within-Case Analysis

1. Case A - The English Engine Plant

Case A - Company A

Company A is an automobile manufacturer located in the Midlands, England, manufacturing to stock and assembling to order. This case relates to the Engines plant within Company A.

Some figures

Number of Employees	
Direct	610
Indirect	278
Number of products/week	
4 cylinder - 32 derivatives	940
V-8 - 46 derivatives	440
approx % of components made in (in number)	40%
approx % of components bought in (in number)	60%
approx % of components made (in value)	60%
approx % of components bought in (in value)	40%

a) Organizational Issues

The Company A's engine manufacturing plant is organized in manufacturing cells by manufacturing task. There are 8 main cells each of them with one manager, one facilitator, one planner, between one and four conformance engineers and between 12 and 120 direct workers. The facilities layout of the cells not always follows the usual U-shape or circular shape suggested by many authors in the literature. In some cases, the term "cell" is broadly used to define a sector of the plant under the same manager. Although focused on a defined manufacturing task and, in general, organized on a product rather than on a process basis, the cells are not always able to manufacture a complete part or component although this was mentioned as a goal by the managers. The cells' management has considerable autonomy in deciding on scheduling and dispatching, employment, training and to a more limited extent, on investment budgets. There are statistical process control procedures implemented and the workers are responsible for the process quality. Maintenance is still performed by a separate team, although it is intended to be delegated to the operators and cell managers in the future. This arrangement also applies to the setting up of the machines.

The formal manufacturing planning and control system is basically MRP[1] for the planning of materials and master scheduling. The scheduling within each cell however is done on a "people-based" informal system by the cell manager and staff.

The engine plant works under a production director with a staff of one conformance manager and his team, who are responsible for manufacturing engineering, methods and quality control (precision components, final product tests).

The general approach regarding industrial relations has recently changed towards more stable relations. In the words of the production Director:

> " (regarding the variation of overall demand volume) ...the old choice is to drop the line rate and shed the labour. We now say no. We have a lot of training, a lot of money invested on them, let's keep them. So we keep the rates and on Friday morning we deploy everybody, from the four corners of the Company; training, quality action teams, and we are actually making people better. And we keep them. This is a major change in views. Now we say: 'We may not need to produce vehicles now, but we still need you. We need your brains'"

The payment system for direct workers is based on 4 grades, according to the breadth of skills of the worker.

b) The Interviews

Six people were interviewed in Company A:

---

[1] Manufacturing Resources Planning System is a computer based method for Planning Manufacturing Resources based on calculating the resource requirements in order for the orders to meet the due dates and checking with the available capacity. For a complete discussion on MRP systems, see Vollmann et al (1988)

the Materials Manager - referred to, in this case, as "Manager 1" - responsible for the material flow management - receipt, handling, storing and moving.

the Conformance Manager - "Manager 2" - responsible for finished product quality control, testing and industrial engineering

the CNC Cell Manager - "Manager 3" - responsible for the cells which manufacture a number of different parts made of aluminium or steel, using CNC machines

the Assembly lines Manager - "Manager 4" - responsible for the whole assembly operation of engines

the Transfer Line Manager - "Manager 5" - responsible for the milling and finishing of crank shafts and engine blocks, performed in two transfer lines

the Production Director - "Manager 6" - responsible for the whole production of power train units in Company A

Because of the cellular manufacture in Company A's plant, for some analyses, it is more appropriate to consider product variability issues in terms of the particular work units or cells since they vary considerably according to the manufacturing task of each cell. The crank shaft and blocks cell, for instance, has a low variety of products (only 4 different engine blocks and four different crank shafts) because the parts it manufactures are standardized building blocks and therefore common parts for a number of derivatives. On the other hand, the assembly line cell (which actually comprises two assembly lines - one, a simple conventional straight track which assembles 4 cylinder engines and another, a serpentine-type line based on AGV's - automatically guided vehicles - has a much greater variety with 78 different derivatives. The third cell studied, focused on milling steel and aluminium parts using CNC - computer numerically controled - and general purpose machines has an intermediate level of variety with approximately 65 products divided in two cells - one for pulleys and fly wheels not greatly different from each other which includes a robot to feed two CNC machines and another one for fairly different engine parts made to stock

c) Line of Products - Variety, Variation and Innovation

The variation in overall volume for the engine plant can be approximately 20% from month to month. The variation in the mix of products demanded can be very high. In each week 45 out of the 78 derivatives are produced, in average. Moreover every month at least 80% (or approximately 62) of the product range is produced; the remaining 20% being service parts for replacement of phased out vehicles or special low volume orders.

The introduction of new products or engineering changes is done on a batch basis, quarterly (or every 13 weeks). In general, around 15 changes are performed in each batch. Five are generally substantial, with changes in the process and ten are minor changes in the assembly line. A totally new product or a completely new derivative appears every year or every other year.

The process of launching a completely new product is briefly described by the Manufacturing Director as below. The description is based on a real engine development which was part of a new vehicle which was completely designed, developed and launched in 3 years (a record for the company):

> "If we are introducing a brand new engine, basically, first of all it is defined in terms of in which vehicle it is going. The big issue nowadays about engines is emissions controls. We are working on a lot of things like that, to make an engine which is cleaner. You measure in that, probably, a period of two years from the initial concept to when we actually start to make bits and prototypes. The director of product and process will have people there."

Recent changes in organizational structure resulted in process and product development being combined under the same Director, in order to improve integration and ensure simultaneous engineering.

> "For instance, now I'm sitting alongside this same guy, we are working on the same parts, he is developing our engines for 1994, four years ahead, and the beauty is now we can be talking about something, because I'm the manufacturing man, I can say: hang on it, don't do that because if you do that, we'll have a problem. We try to make sure that they design for manufacturing. So that concept starts, the period of time for the "X" engine (for the new vehicle "D") was about three years from when we thought we want a new vehicle, what are we gonna do to when we started producing parts for prototype units.
>
> We actually as a Company form teams of people, from all over the place, then we put them in this team, they work on the project, when it's ready to launch they go back to their original jobs. When another new one comes on we form another team, usually with different people. So, we formed the vehicle "D" team and it was right across the broad span from finance people, designers, product engineers, stress analysis people, technicians, manufacturing people, 12 people (the hard core) managed by the project Director for vehicle "D". Some 18 months before the final prototypes were decided on, manufacturing actually started building it, then, just then, right from me here there is a secure area, a prototype area. Then we, as manufacturing people, actually helped build the prototypes.
>
> That is a very powerful thing because what we do there is, every six months, we get 2 or 3 good guys off the tracks, and put them in this area and then they work with the project, and then, they fit the new parts and things like that. We then <u>rotate people so they are involved in the new project early, to utilize their local knowledge to modify the design and make it easier to build</u>. We are working now on our engines for 1993 and 1994. Right now it is clear what we are going to do. What we do now, this team of people, remember there is a hard core of the team, and we put more people in the team depending on the stage of the project. Very flexible thing, with people moving to and from the team to their normal jobs.
>
> At a certain stage, <u>probably 18 month to 2 years before prototypes, very early, suppliers are involved</u>. What we are moving towards now is we are getting similar to what the Japanese lean production companies are doing. <u>We say: that is the specification of the</u>

component we need, can you go and design it for us. And the company then owns the product. We want them to design it for us and work with us. So, you are the specialist, you design it for us. Company A traditionally designed and specified probably 90% of the bits and pieces and my view is that you've got to rely on the experts.

A good relationship is necessary between the company and its suppliers. This is a very long process, to develop this close relationships. This requires a fundamental change in the relationship with suppliers. You don't do that overnight. It takes many years. The first step is to reduce the number of suppliers. (we reduced the number of suppliers from 1200 to about 700) In many important areas we are single source supplied. You are a supplier, instead of a 2 year contract now you have a 5 year contract, and you get it right."

A number of important points can be underlined by the brief description of the process of launching a new product in Company A:

-*Integration* between process and product development and, production via organizational links (such as Product and Process development functions under one Director to ensure simultaneous engineering) or via effective inter-function communication (such as the Product/Process Director and the Production Director communicating to ensure manufacturability of the products)

-*Multi functional team approach*

-*Early involvement of direct workers* in the design and prototyping phases

-*Early involvement of suppliers* and delegation to "the experts" of the task of designing and developing the parts

-*Reduction of the number of suppliers* and tendency to establish long term contracts

d) Manufacturing - Flexibility Task and Performance

Although belonging to quite different manufacturing cells, the managers' answers are clear and consistent, concerning the flexibility-related task of the engine plant. All the respondents placed mix flexibility as their first priority. All but one of them specified mix response and one specified mix range as the particular mix flexibility dimension the engine plant should focus on. The next most mentioned flexibility type was volume flexibility. Table A.1. below shows the distribution of answers. The figures under the Manager's columns represent the priority each of them give to the individual flexibility types in terms of order-winning criteria.

"4" means that the manager gave the specific flexibility type first priority, "3" second priority, "2" third and "1" fourth priority or lower.

The column "Tot" sums up the total number of managers who mentioned each of the flexibility types.

The column "Tot weighed" shows a weighed total considering different weights for different priorities.

4 "points" are associated with first priority, 3 with second priority, 2 with third priority and 1 with fourth priority. So, for instance, in terms of product response, it was mentioned by Managers 4 and 5. The column "Tot" therefore shows 2. The column "Tot weighed" shows 2 (3rd priority according to Manager 4) plus 3 (2nd priority to Manager 5) equals 5.

	Mgr1	Mgr2	Mgr3	Mgr4	Mgr5	Mgr6	Total	Total weigh
product range				1			1	1
product response				2	3		2	5
mix range		2				4	2	6
mix response		4	4	4	4	2	5	18
volume range			3	3		1	3	6
volume response					2	3	2	5
delivery range							0	0
delivery response		3	2				2	5

Table A.1. - Priority given by managers of Company A regarding types and dimensions of Manufacturing Flexibility

e) Uncertainties Involved

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company A's competitiveness show a distinct pattern. All the managers, for instance, placed materials and parts supply uncertainty as one of their two main concerns. Three of the managers placed demand product mix uncertainty among their two main concerns, two managers placed labour behaviour - absenteeism and continuity - among their two main concerns. Other perceived uncertainties in Company A can be found in Table A.2 below. The figures under the columns "Managers" represent their perception on the ranking of risky factors to the organization competitiveness. 4 means first ranked, 3 second, 2 third and, 1 forth or lower. The managers were free to choose how many factors they would mention. The column "Tot" represents the total number of managers who mentioned the factor and the column "Tot weighed" sums up the number of times each manager mentioned each factor but considers different weights for different priorities. 1st ranked is associated with 4 "points", 2nd ranked with 3, 3rd with 2 and, 4th and lower with 1.

	Mgr1	Mgr2	Mgr3	Mgr4	Mgr5	Mgr6	Total	Total weigh
parts supply	4	4	3	4	3	4	6	22
labour behaviour	3	1	2	3			4	9
machine breakdown	1	2		2			3	6
systems accuracy		1					1	1
product introduction	1		1	1	1		4	4
mix changes	2	3	4	1	4		5	14
volume changes	1		1		1		3	3
general uncertainty			1	1	1	1	4	4

Table A.2. - Importance given by managers of Company A regarding sources of uncertainty as potentially jeopardizing for competitiveness

f) Coping with Change, Uncertainties and Variabilities

When asked how they coped with the different types of uncertainty and variability, the managers showed, in general, both different approaches and different levels of understanding of the variables involved with manufacturing flexibility. The manager responsible for the CNC machines cell not surprisingly showed a higher level of concern about the issue than the manager of the transfer line cell. Some of the managers were able to classify types of uncertainty and discriminate different types of action which would be necessary to cope with them. Others, on the other hand, felt more comfortable talking about "general uncertainty of the process", suggesting accordingly general aspects of flexibility to cope with it.

Important to mention a certain "hierarchy" in the general approach adopted by a number of managers in terms of the ways they find the most appropriate to deal with uncertainties. They generally seem to prefer trying to reduce the level of uncertainty they suffer rather than to deal with its effects. This can be noticed in a number of situations such as the following:

Manager 6, referring to machine downtime, prefers to control the occurrence of machine breakdowns by means of developing a preventive maintenance system than to have to deal with it by having excess inventory or capacity:

> "... at the moment, we deal with it by carrying high inventory. In certain areas, we keep excess capacity. But the way we intend to cope with it in the future is total preventive maintenance"

Talking now about the frequent and unexpected changes in schedule caused by problems in the paint shop which is physically remote from the engine shop, manager 6 prefers to control the change by reducing its uncertainty via coordination between his shop and the origin of the change itself:

> "... at the moment we deal with it through the ability of people have to react quickly and reschedule. What we are now moving into is when a body is launched, when it is determined, when that happens, if you can have that information at that stage, probably one or two days in front of my process, we know what vehicle is gonna get out of that line. We actually bought some computer equipment which talk to my own equipment directly: when a vehicle is launched, they can tell me exactly what that unit is requiring one or two days in front."

Manager 6, now talks about keeping up with all the technological change which has happened in recent years. He describes a situation where Company A decided to control (reduce) the change they would have to deal with (the technological change in the design of engines) by subcontracting a contractor to do it for them:

> "Company A, traditionally designed and specified probably 90% of all bits and pieces... What we are moving towards now is we are getting similar to what the Japanese lean production companies are doing. We say that is the specification of the components we need, can you go and design it for us. They are the specialists and can keep up with the changes in the engine technology..."

Manager 2, talking about manufacturing flexibility in general:

> "Because of the way the site runs, without having a huge amount of resources or a huge amount of inventory, you have to have a certain amount of flexibility. We got to the point that we don't like it, but we are good at it. It would be nice to have it done in a more controlled fashion"

It seems therefore that Manager 2 also prefers to control and reduce the causes to be flexible. Nevertheless he not always sees very clearly the relationship between reducing the change and havimg flexibility, as can be noticed by his words:

> "Being flexible eliminates the pain of not having the system in place. If you had the perfect information, it would eliminate all the need for flexibility"

This does not appear to be totally valid, because if a plant decides to have a very variable output and if, at the same time, it has scarce resources, even if such a demand is perfectly known, the firm will have to have some sort of manufacturing system flexibility developed in order to cope with it.

The words of Manager 6 seem to agree with the preference for the uncertainty reduction, when commenting on the uncertainties they face with the supply of material and parts:

> "...if it is a short term problem, we can change our schedule to accommodate it... We work more in terms of reducing uncertainty, but the inevitable happens and we have to cope."

and also talking about standardization, which is a way to reduce the overall number of changeovers:

> "... standardization of parts is important because it reduces the need to be flexible."

Thus Managers in Company A generally see flexibility as a way to deal with change when its causes can not be eliminated.

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below, together with some representative quotations regarding to them. The first column represents the number of managers who mentioned the relationship. The second and third columns represent the relationship itself, the second being the source of the uncertainty and the third, the capabilities or ways managers see as worth developing to be able to cope with the uncertainty shown in the second column.

number of managers who mentioned the relationship	uncertainty relating to	-->	best way to cope with it is by developing
4	parts and materials supply		rescheduling capability

> "...we tend to resequence to work with what we've got or more and more we tend to if possible, if the component is the sort of component which stands alone, or in other words if we can fit it afterwards, we build without that component. If we can resequence, fine. If we can build without it, fine. If the effect of that is so severe that we can't do that then we stop the line." - Assembly lines cell Manager (Mgr 4)

4	labour behaviour (absent, continuity)		multi skills of labour, transferability

> "... if there is uncertainty with labour, the labour force has to be flexible enough to be able to move around and they have the flexibility of skills to move around within certain limits, to be able to produce a variety of parts" - CNC Cell manager (Mgr 3)

4	product mix changes	rescheduling capability

"... if they change the plan, again, it comes to the flexibility and the people that we've got. We can fairly rapidly change over and reschedule to produce the parts that they need on time" - CNC cell Manager (Mgr 3)

2	parts and materials supply	materials control systems effectiveness

"... anything that goes wrong with the schedule of material, straight away there is a warning bell from the system to our material control department and then they talk to the supplier..." - Materials Manager (Mgr 1)

2	product mix changes	multi skills of labour, transferability

"...the broad range of skills our workers have gives us the flexibility to go and react to changes in the environment ...(such as)... program changes." - Materials Manager (Mgr 1)

2	overall volume changes	excess capacity

"... we use some excess capacity to absorb some level of fluctuation in overall production volume." - Assembly lines Manager (Mgr 4)

2	general uncertainty	ability to work in groups

"The level of knowledge and experience out there has to be harnessed as a group, so I enjoy being supported by those groups and when they work well as a team, the problems I have I see resolved" - Assembly lines manager (Mgr 4)

2	general uncertainty	multi skills of labour, transferability
2	product introduction	integration design/ manufacturing

2	variety	standardization of parts

"Standardization is quite important to reduce variety and therefore the need to be flexible" - Materials manager (Mgr 1)

2	variety	multi skills of labour, transferability

"About the variety the flexibility I need comes from people" - Assembly lines Manager (Mgr 4)

Although some managers had a perception about the relationships between types of uncertainty and variability and ways to cope with them, when asked about priorities, they did not seem to priorize the actions they considered effective to cope with the uncertainty aspects they considered the most risky even when they had a low degree of certainty. There are two possible reasons for this behaviour:

i) they could be answering only what they perceived as expected answers about the relationships. This is not likely because of the measures the researcher took in order to increase the research instrument reliability (see chapter 7 for details).

ii) they may not have a consistent framework of reference to base their analysis on and therefore they cannot analyze the large amount of information they have in a systematic and comprehensive way. They would be able to perform analyses of parts of the overall problem but not to build a consistent decision model which takes into account the main variables and their inter relationships.

Manager 5 for instance, understands that Parts supply and Labour behaviour are the most risky uncertainty factors. He also considers these two as being among the most uncertain factors (he sees "parts supply" as only fairly predictable and "labour behaviour" as having low predictability). He also understands that Rescheduling capability and Development of multi-skills of labour are the best ways to cope with them respectively. Nevertheless, these two are not among his priorities or his critical success factors. He gave first priority to "capability of machinery" and "excess capacity".

Another interesting point to notice is the emphasis given by the management in the achievement of manufacturing flexibility through the Labour resource. At least three of the managers mentioned it:

> "The main thing is - the flexibility is with the people. If people are not flexible, it doesn't matter how flexible your machines are, how flexible your processes are, if people aren't flexible then it's not worth anything, you remain static." - CNC cell manager (Mgr 4)

Another point made by some managers, mainly the ones who were most concerned about Flexibility is that they see Manufacturing Flexibility as a sort of "reserve", something that the organization possesses although it is not continuously using. In the words of three of the managers:

> "Flexibility is definitely an asset, something that is not currently being used but you can use when you need. I can use that asset, the flexibility to change things. It could be a reserve of ability, capacity or both." - Assembly lines Manager (Mgr 2)

> "Flexibility is like a commodity, something you have to poses, the willingness to change, the experience, the knowledge. ...It is a little accumulator of knowledge, abilities and capacity. It is an actual thing - either you have it or you don't." - Conformance Manager (Mgr 2)

> "Flexibility is like a reserve, a reserve that has been planned" - CNC cell Manager (Mgr 3)

g) The Relationship Between the Flexibility-Related Competitive Criteria and Resource Characteristics or Critical Success Factors

In general there seem to be consistency about the perception of the various managers interviewed about the flexibility-related competitive criteria they should pursue.

All of them, for instance, ranked "mix flexibility" as the first flexibility related priority. All but one of them specified mix response and one specified mix range as the particular mix flexibility dimension the engines plant should focus on. The consistency between the flexibility-related competitive priority and the resource characteristics which they considered critical success factors was also high. The list below shows the two first flexibility related priorities and the two first critical success factors according to the perception of each manager:

Manager	Two first flexibility-related competitive criteria	Two first critical success factors
1	n/a	n/a
2	mix response delivery response	fast set-up times multi-skills, transferability
3	mix response volume range	change of line rates capability excess capacity
4	mix response volume range	capability of machinery excess capacity
5	mix response product response	re-scheduling capability control systems effectiveness
6	mix range volume response	multi-skills, transferability ability to work in groups

Table A.3. - Relationship between flexibility-related competitive criteria and critical success factors, according to managers in Company A.

The only inconsistency is with Manager 4 who places a high priority to machine capability which can not be directly related to Mix response or Volume range which are his priorities in terms of order winning.

For the rest of the Managers, the two columns seem to show consistency between system objectives and means to achieve them.

h) Some Conclusions of the Within Case A Study

Managers in Company A see flexibility as a way to cope with uncertainties when the causes of such uncertainties cannot be eliminated.

Managers in Company A understand that variability and different types of uncertainty should be dealt with by developing different types of resource flexibilities.

Managers in Company A do not seem to have a consistent decision model which includes different types of uncertainty, variability and different types of resource and system flexibility.

The most flexibility-conscious Managers in Company A see flexibility as a "reserve", something which has to be planned for, developed, maintained and seen as a valuable asset.

Managers in Company A have a high degree of consistency in their perception of the flexibility related order winning criteria they should pursue.

2. Case B - The Brazilian Carburettor Manufacturer

Company B is a carburettor manufacturer located in São Paulo, Brazil. It is the main supplier of carburettors to the Brazilian car assembly companies and for the spare parts market. Company B is part of a large transnational corporation with headquarters in Europe and interests in a broad range of industrial products.

Some figures about Company B are shown below:

Number of Employees	
Direct	788
Indirect	680
Number of product types	121 derivatives
approx % of components made in (in number)	40%
approx % of components bought in (in number)	60%

a) Organizational Issues

The Company B plant is organized functionally, on a conventional "job-shop" type of layout, although they are now at early stages of the migration into cellular manufacturing. Some pilot cells have just been established with promising results, according to the managers.

The Company is presently in a very particular situation. It has always been regarded as a carburettor manufacturer. Nevertheless with the new (for the Brazilian market) technological advent of the fuel injection, Company B has changed its mission into being an "engine feeding systems" manufacturer. The carburettor is going to "die" as an OEM (original equipment manufacturer) product in 1997, according to corporate plans. Therefore, no large investments are being made in the conventional carburettor technology and therefore no major changes in the line of carburettors are expected to be introduced in the future.

On the other hand, investment is being made to qualify the company to compete in the new market, that of fuel injection systems. In order to do that, managerial and technical staff are being sent abroad, to be trained in the company's headquarters. Changing into the fuel injection technology is regarded by the Managers in Company B as a major change. They reckon that the change is bound to bring many problems to the company since the new technology is based on microelectronics, rather than mechanics principles, therefore demanding completely different skills, machinery and systems in order for the company to compete with other and comparatively more experienced competitors in the new market (The German Bosch, for instance). The change is supposed to be gradual, resulting in the end of the carburettor (except for the remaining spare parts market) in 1997.

Company B's organizational structure is conventional and hierarchical although they are currently trying to include some aspects of the matrix organization, establishing several multi disciplinary "work-groups" with specific goals, such as product introduction, lead-time reduction, an so on, aiming at "breaking the barriers" between separate functions. There are statistical process control procedures implemented and the workers are responsible for the process quality, what they call "self-control". Equipment maintenance is still performed by a separate team, though the very basic maintenance procedures are performed by the operators themselves. This arrangement also applies to the setting up of the machines.

The formal manufacturing planning and control system is basically MRP for the planning of materials and master scheduling. The scheduling however is done on a "people-based" informal system by the logistics manager and staff.

There are 4 directors under a general managing director in Company B: the industrial director (plant management, quality, maintenance, process development, production and after sales services), the materials director (supply management, production planning and control, materials handling and storing), the technology director (product research and development), the marketing director (relationship with the customers and market) and the finance and administration director (accounting, finance and sales). The human resources manager reports directly to the general managing director.

The general approach regarding industrial relations has recently changed, favouring the company, what has partially been caused by the Brazilian recession, resulting in high levels of unemployment. The payment system for direct workers is based on grades, according to an internal merit assessment system, not directly linked to the breadth of skills of the worker nor to output rates.

b) The Interviews

Six people were interviewed in Company B:

the Industrial Director - referred to, in this case, as "Manager 1" - responsible for the plant management, maintenance, process development, production and quality assurance.

the Logistics manager - "Manager 2" - responsible for the production and materials planning and control systems

the Product Engineering Manager - "Manager 3" - responsible for the product engineering

the Production Manager - "Manager 4" - responsible for the production

the Industrial Technology Manager - "Manager 5" - responsible for process design and development

the Quality Control Manager - "Manager 6" - responsible for the quality control and assurance engineering

c) Line of Products - Variety, Variation and Innovation

Company B has currently a line of 7 basic product families, with minor to considerable differences between products within a family, depending on the specific family. The overall number of products or "derivatives" is 121. The variation in overall volume can be approximately 50% from month to month. The variation in the mix of products demanded can be very high. E.g. in each week 30 out of the 121 derivatives are produced. Moreover, every month at least 60 % (or approximately 72) of the product range is produced.

The introduction of new products or the engineering changes of the existing ones are done on a continuous rather than on a batch basis. Six to eight engineering changes are made each month, being 50% minor changes concerning process improvement and 50% changes in the application of the products, due to changes in the fuel composition, emission regulations and other customer requests.

Launching a completely new carburettor is not in the future plans of the company, since the carburettors have a certain date to "die" as an OEM product in Company B. In the past, although the managers consider that Company B's performance in terms of introduction of new products and product changes have been clearly better than that of the competitors, this has been accomplished at very high costs in terms of resources and organizational disruption. In the words of the industrial director:

> "It's is somewhat similar to a football match played by kids. The whole team is always running after the ball, disregard of their positions; when something crops up, everybody

suddenly change priorities and start running to try to "fight the fire". It looks like flexibility, but it is not, because the effort it is poorly coordinated, not planned for and very stressful" (Mgr1).

Historically, the time period to introduce a completely new product has been two years. Nevertheless, as a preparation for the new line of products, the fuel injection systems, the company has established a task force to develop a new system for the introduction of new products ("Sistema *Company B* de Novos Produtos" or, "System *Company B* for New Products"), trying to incorporate concepts of multi-functional work groups and simultaneous engineering (which are relatively new concepts in Brazil). The system now exists in the form of a written document but most of the managers recognize that there is still a long way to go in terms of breaking the barriers between functions and make it work fully. Managers consider that the ability to introduce new products quickly and reliably (in terms of quality) will play a major role in the future competitive scenario.

d) Manufacturing - Flexibility Task and Performance

The managers' answers concerning the flexibility-related task of the plant are consistent, at a certain extent. Four out of six managers specified product range as the particular flexibility dimension the company should primarily focus on. The other two managers (Managers 4 and 6) mentioned delivery range and mix response as their first competitive priorities respectively. Table B.1 below shows the distribution of answers. The figures under the Manager's columns represent the priority each of them give to the individual flexibility types in terms of order-winning criteria. One of the managers (Mgr 2) did not feel comfortable in ranking the criteria. Rather, he preferred only to mention the ones he considered relevant. That is the reason why in his column there are 4 numbers "4".

Number "4", in the table, means that the manager gave the specific flexibility type first priority, "3" means second priority, "2" third priority and, "1" forth or lower priority. The column "Tot" sums up the total number of managers who mentioned each of the flexibility types. The column "Tot-weighed" shows a pondered total considering the different weights for different priorities. So, for instance, delivery range was mentioned by 2 managers (Mgrs 2 and 4). The column "Tot" therefore shows 2. The column "Tot-weighed" shows "8" (4 - 1st priority according to Manager 2 - plus 4 - 1st priority according to Manager 4 - equals 8).

	Mgr1	Mgr2	Mgr3	Mgr4	Mgr5	Mgr6	Total	Total weigh
product range	4	4	4		4		4	16
product response	3	4	3				3	10
mix range		4					1	4
mix response						4	1	4
volume range					3		1	3
volume response						3	1	3
delivery range		4		4			2	8
delivery response				3			1	3

Table B.1 - Priority given by managers of Company B regarding types and dimensions of Manufacturing Flexibility

e) Uncertainties Involved

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company B's competitiveness show a distinct pattern. All the managers, for instance, placed "materials and parts supply" uncertainty as one of their two main concerns in Company B. Four of the managers placed "manager behaviour under changing circumstances" among their two main concerns. Other aspects mentioned as being among the two main concerns are: uncertainty of "machine breakdowns", uncertainties regarding the "specification of new products" and uncertainty related to the "availability of technological information". The perceived uncertainties in Company B can be found in Table B.2 below. The figures under the columns "Managers" represent their perception on the ranking of risky factors to the organization competitiveness. "4" means first ranked, "3" second, "2" third and, "1" forth or lower. The managers were free to choose how many factors they would mention. The column "Tot" represents the total number of managers who mentioned the factor and the column "Tot-weighed" considers the different weights for different priorities.

	Mgr1	Mgr2	Mgr3	Mgr 4	Mgr5	Mgr 6	Total	Total weigh
parts supply	4	4	4	4		4	5	20
managers behaviour	3	2		3	3	3	5	14
machine breakdown	1	3		2		1	4	6
quality of products	1	1		1		1	4	4
products introduction		1	3				2	4
mix changes		1		1	1	1	4	4
volume changes					1		1	1
technologic. resources					4		1	4

Table B.2. - Importance given by managers of Company B regarding sources of uncertainty as risky for competitiveness

It seems that the uncertainty sources which concern the managers most are those related first with "parts and materials supply" and second, interestingly, with the "management behaviour under changing circumstances", here understood as the unpredictable response, by supervisors and middle managers to changes in current practices. At a certain extent this assessment can be explained by the difficulties the managers predict they will have with the major changes the company is going to face in the near future, with the introduction of the fuel injection systems technology.

f) Coping with Change, Uncertainties and Variabilities

When asked how they coped with the different types of uncertainty and variability, the managers showed, in general, both different approaches and different levels of understanding of the variables involved with manufacturing flexibility. The managers in Company B also seem to show a greater concern with issues related to product quality than with flexibility.

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below, together with some representative quotations regarding to them. The first column represents the number of managers who mentioned the relationship. The second and third columns represent the relationship itself, the second being the source of the uncertainty and the third, the capabilities or ways managers see as worth developing to be able to cope with the uncertainty shown in the second column.

number of managers who mentioned the relationship	uncertainty relating to	-->	best way to cope with it is by developing
4	parts and materials supply		rescheduling capability

"... we try several alternatives, we analyse the impact of the delay and if that is the case, we re-schedule and do whatever product we can ..." (Mgr 4)

4	parts and materials supply		supplier development, partnership

"... we have some plans to overcome these difficulties (of having an uncertain supply) and they consider the supplier as a partner; we have to work together with them, we have to pass on the idea that if Company B is successful, the supplies will also profit...so, in the long term, the idea is to reduce the supplier base and develop co-operation rather than confrontation..." - (Mgr 4)

4	management behaviour		training, awareness

"... the middle management is considerably more resistant to change than the direct labour. If a new idea is proposed, in maybe 50% of the times, the middle managers react against it, sometimes with no apparent reason. The way to deal with this is by training them, increasing the level of their awareness, and as a last resource, substituting them..." (Mgr 1)

3	labour behaviour		multi-skills development

"... to prevent against lack of continuity, caused by absenteeism, we have to develop a multi-skilled workforce...(Mgr 1)

3	product mix changes		set-up times reduction

"...because the mix changes much and frequently, with short set-up times it is much easier to respond...(Mgr 6)

3	quality		interface prod design/

	changes	proc design/manufact

"... we have to have a good system to guarantee the integration of these functions because shortening the time for designing gives the process designers time to conceive the process properly; otherwise, the scrap rates will be higher and the probability of achieving good conformance will be lower...(Mgr 6)

2	product mix changes	rescheduling capability

" ...we have to be good at rescheduling to fight the instability of the demand mix (Mgr 5)

2	machine breakdown	re-routing capability

"...to face it I have to have alternative machines, alternative process routings...(Mgr 2)

2	product introduction	integration design/ manufacturing

"...we have to invest in design technology to be able to deal with changes which are requested at the last moment, so you have to be very quick in designing and therefore you give more time and alternatives for the process designers and production people...(Mgr. 3)

2	variety	standardization of parts
2	product mix changes	ability to get/ maintain lead times low

"... (we need short supply lead times) to keep our own lead times short. With shorter lead times your programming is more flexible, you can change the program with short notice and respond better to changes in the customer demand" (Mgr 4)

2	parts and materials supply	machine capability

"...when a part arrives and it is below the quality specified, we assign one person to try to find alternative solutions...can we use the part for that particular case? can we correct the problem by reworking the part using our internal capability? - and that is very frequent..." (Mgr 6)

2	labour behaviour (absenteeism)	extra capacity

"... we program a load which is lower than the total system's capacity, because of the uncertainty with the absentees..." (Mgr 2)

2	machine breakdowns	ability to organize over time/subcontract

"... beside alternative machines, I have to have the alternative to outsource the part quickly..." (Mgr 2)

2	materials and parts supply	ability to organize over time/subcontract

"...some times I can rework the part in, but because I hadn't programmed it, I have to do it in overtime...(Mgr 1)

2	quality	ability to work in groups

A point which is worth mentioning is the lack of emphasis given by the managers in the achievement of manufacturing flexibility through the resource Labour. Technological (fast set-ups, capability of machinery) and Infrastructural resources (integration design/production via a formal system, re-routing the production flow ability through a system) seem to play the major roles in the view of Company B's management as ways to achieve system flexibility.

Another point is the great emphasis placed on quality by the majority of the managers. Some unexpected associations of the resource aspects (meant to represent characteristics associated with flexibility) with quality appeared , such as the importance of having an agile product design function in order to give the process design function time to design a proper process which can guarantee the product quality rather than the more obvious relationship that fast design keep with fast product introduction (Mgrs 2, 3 and 6).

That may be caused by the present stage in which the company is, still struggling with quality problems. If that is the case, this comes to confirm De Mayer's (1986) hypothesis that there are stages which the companies progressively go through. De Mayer found out that flexibility had not yet become a major competitive priority for the American manufacturers of his sample, whereas it was a major priority for the Japanese companies. De Mayer suggests that the reason could be that the American managers would be subscribing to the view that a flexible response to competitive threats is only possible if the basic quality and process problems are solved. Company B would still be stuggling with basic and process problems and therefore flexibility woul not yet be one of their priority concerns.

Furthermore, it seems that some of the managers see flexibility as something they are "forced" to have to cope with uncertainties. Ideally they would prefer to control the causes of the uncertainties, aiming at reducing them, but since this is not always easily achieved in the short term and also because it is impossible to eliminate completely the stochastic components of the processes, they are "forced" to develop flexibility.

Four of the managers (Mgrs. 1, 2, 3 and 4) pointed the need to co-operate with the suppliers in the long term (or in other words, to increase the coordination between Company B and the suppliers), in order to reduce the uncertainties that Company B has to deal with. In this case they see the flexibility of the process as a means to deal with the effects of such uncertainties in the short term.

The same happened to the uncertainty regarding machine breakdowns. Three managers (Mgrs 1, 4 and 5) mentioned that in the long term, preventive maintenance should be used to reduce the uncertainty level of the process continuity. Again, in the short term, they point out flexibility-related solutions such as alternative routes, multi-capable machines to deal with the effects of the uncertain events.

g) The Relationship Between Flexibility-Related Competitive Criteria and Resource Characteristics or Critical Success Factors

In general there seem to be some consistency about the perception of the various managers interviewed about the flexibility-related competitive criteria they should pursue.

Four of them (Mgrs 1, 2, 3 and 5), for instance, ranked "product flexibility" as the first flexibility related priority Company B should pursue. All of them specified product range as the particular product flexibility dimension the plant should focus on. The other two (Mgrs 6 and 4) ranked mix and delivery flexibility as the priorities. The consistency between the flexibility-related order winning criteria and the resource characteristics which they considered critical success factors was also high. The list below shows the two first flexibility related priorities and the two first critical success factors according to the perception of each manager:

Managers	Two first flexibility-related competitive criteria	Two first critical success factors
1	product range product response	integration design/production ability to work in groups
2	product range product response mix range delivery range	re-scheduling capability integration design/production
3	product range product response	integration design/production supplier development
4	delivery range delivery response	fast set-ups ability to work in groups
5	product range volume range	standardization rescheduling
6	mix response volume response	integration design/production fast set-ups

Table B.3. - Relationship between flexibility-related competitive criteria and critical success factors, according to managers in Company B.

The only apparent inconsistency regards Manager 5's answers who places a high priority to "rescheduling capability" and "standardization of parts" which can not be directly related to "product range" or "volume range" which are his priorities in terms of competitive criteria.

For the rest of the managers, the two columns seem to show consistency between system objectives and means to achieve them.

Although some managers had a definite perception about the relationships between types of uncertainty and variability and ways to cope with them, when asked about priorities, they did not seem to priorize the actions they considered effective to cope with the uncertainty aspects they considered most risky even when they were considered uncertain. Two among the possible reasons for this behaviour are:

i. they may not have a consistent framework to base their analysis on and therefore they cannot analyze systematically the large amount of information they have on a systematic way. They would be able to perform analyses of parts of the overall problem but are not able to build a consistent decision model which takes into account the main variables and their inter relationships.

ii. they may give more importance to aspects related to the aggressive response to the market needs than to the preventive development of "safeguards" against risks to the company's competitiveness. That can be noticed by the high consistency between their ranking regarding types of system flexibility and types of resource flexibility. The managers can identify factors which represent risk to the company's competitiveness. They also have an idea about which would be the "antidotes" to deal with them, but do not give the same strategic importance to these "antidotes" (or in other words what we could call defensive competitiveness) as they give to the factors which lead to what they perceive as market needs. It would be somewhat similar to a coach who emphasizes the development of the team's attack, not giving the same emphasis on reinforcing the team's defence.

Manager 1 for instance, understands that "parts and materials supply" and "management behaviour under changing circumstances" are the most risky uncertainty factors. He also considers these two factors among the most uncertain ones (he perceives "parts and materials supply" as being only fairly predictable and "management behaviour" as having low predictability). He also understands that a number of ways can be used to cope with such factors (he coherently regards supplier development, ability to reschedule, some excess capability and capacity as appropriate to cope with uncertainties relating with supply and, training as a way to cope with uncertainty in the behaviour of the management). Nevertheless, none of these factors are among his priorities or his main critical success factors list. He gave first priority to "integration product design/process design/production" and to the "ability to work in groups", both not directly linked to his "antidotes", although highly consistent with the way he sees how the company competes in terms of flexibility (his firs and second priorities are respectively "product range" and "product response").

Such pattern of perception is somewhat general among the managers. Summarizing, it seems that managers see the relationships between flexibility-related order winning criteria and the critical success factors to achieve high performance in them. They seem to be able to focus their attention and give priority attention to these factors. Nevertheless, less importance seems to be given to the factors which would represent the insurance or the safeguards against the uncertainty factors considered by themselves as risky to the company's competitiveness.

h) Some Conclusions of the Within Case B Study

Managers in Company B see flexibility as a way to cope with uncertainties when the causes of such uncertainties cannot be eliminated

Managers in Company B understand that different types of uncertainty should be dealt with by developing different types of resource flexibilities

Managers in Company B seem to have a greater concern towards quality issues than towards flexibility issues.

Managers in Company B seem to place more importance in the "competitive weapon" aspect of flexibility , something which could be aggressively and proactively developed and sold than on the "safeguard against uncertainties" aspect.

Managers' perceptions in Company B have a reasonable consistency in terms of the flexibility related competeitive criteria they should pursue.

3. Case C - The Brazilian Shock Absorber Manufacturer

Company C manufactures and distributes, to the automotive market, components having a high technological content. It is an entirely Brazilian-owned company whose capital is open to the general public and whose shares are traded on the country's stock exchanges. As the largest domestic producer of automotive parts, it ranks 71st, based on sales, among private sector companies in Brazil.

Company C aims at the high technological content automotive parts market and with this objective invests approximately 3% of its operational revenue in product and process research and development

Some figures about Company C's Group referring to 1988:

overall turnover	US$ 500 million
market breakdown-invoicing	
original equipment	42%
spare parts market	40%
exports	18%
market share in Brazil	
piston rings	92%
shock absorbers	75%
castings	60%
employees	15000

a) Organizational Issues

Company C is organized in divisions. There are 6 main industrial divisions: shock absorbers, engine components, castings, exhaustion systems (mufflers), sintered parts, and polyurethanes.

In 1987, Company C began operation of its first production cells in various divisions, as part of a comprehensive group program called "Programa de Qualidade Total *Company*

C", or "*Company C* Total Quality Program". That includes statistical process control implementation, cell manufacturing, set-up reduction programs, MRPII implementation and better industrial relations. To support the program an ambitious training program was designed in which more than 10 thousand men.days per year are dedicated to off-the-job training.

The results so far have been considered satisfactory by the managers. They have now a number of cells in operation. They also claim reductions in the average production lead time for piston rings, for instance, from 25 to 14 days, 5% reduction in work in progress and "substantial" (not quantified) improvement in conformance quality levels.

The operators are nowadays in charge of the cleaning of the work place, basic machine maintenance and statistical process control.

The formal manufacturing planning and control system is MRP II for the planning and control of materials supply and inter-cells coordination. The dispatching and very short term shop floor control activities are made by special task forces, called "follow-up teams", responsible for keeping up with recent program changes.

The industrial relations and payment schemes are conventional, the payment of direct labour is linked to good output levels and the approach to benefits is considered by one of the managers as "patronizing". According to him, a trade mark of the group founder-president. Emphasis is given to training, but not to multiskills development, what is at a certain extent unusual when companies migrate to cell manufacturing. The relationship with the powerful "ABC"[1] Unions have not been very smooth with a number of disruptive strikes cropping up during the last years.

The divisions are reasonably autonomous, with division directors leading teams of within-division managers. Nevertheless, when the group decided to implement the reforms in production processes, a new post was created, that of director of productivity and quality (who is one of the interviewees in this case-study) , who reports directly to the group's president. The recently appointed director assembled, then, a multi-functional, multidivision team to be the "agents of change" within each division, aiming at implementing the planned manufacturing changes.

<u>b) The Interviews</u>

Three people were interviewed in Company C:

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1 The "ABC" is a very industrialized region in Sao Paulo, where most of the automotive industry plants are located. It is a place where the Unions are very powerful.

the Operations Manager of the shock absorber division, responsible for the division's materials flow, industrial engineering and quality assurance. In this case-study, he is referred to as "Manager 1".

the Senior Sales Manager of the shock absorber division, responsible for the division's relationship with the market and interface with the operations function, which is very intense in Company C. He has been working for the Company C group for a number of years and has actually worked for most of the divisions in various positons including Production Management. having a broad experience and knowledge of the group. Here he is referred to as "Manager 2"

the Director of Quality and Productivity of the group, responsible for the design and implementation of "*Company C* Total Quality Program", an ambitious program aiming at making Company C a World Class Manufacturer. The shock absorber division is leading the quality program and has served as a "lab" for pilot studies for the group, in terms of new techniques. He is "Manager 3".

The case-study will focus on the shock absorber division, although some of the examples given by the interviewees refer to facts which happened in other divisions.

c) Line of Products - Variety, Variation and Innovation

The shock absorber division has approximately 2000 active products, according to the operations manager, being in general similar products which are also not very different from each other in terms of process.

A shock absorber has about 30 different parts and components. In Company C more than 90% of them are made in. The company used to buy some components, mainly sintered and polyurethane parts. Nevertheless, as part of the group's policy of vertically integrate (another "trade mark" of the President, according to one of the managers) to reduce transaction costs, the group bought out two companies in the 80's which are today the sintered parts division and the polyurethane division.

Approximately 150 product changes are performed each year in the shock absorber division, being 20 to 30 new designs. The changes are not made in batches but on a continuous basis.

The process of launching a new product was, at the time of the case-study interviews, done on a conventional fashion, with well defined sequential stages of product design, process design, prototyping and finally production. CAD is in the company's plans but it hasn't been implemented yet.

The variation in volume is what seems to worry the operations manager most, since the group have an aggressive policy aiming at new export markets. The overall demand can vary 30%.

> "Last week, for instance, an American buyer came to us and ordered 128000 shock absorbers. That is 10% of our annual production. Now I have to decide what orders I will delay, because we are bottlenecked, working in three shifts. We will have to struggle to deliver in the 4 months period we promised..."(Mgr 1)

That is a concern, especially because the factory is "bottlenecked", with very high occupation rates. This is due to another policy of the group which is the "chasing-the-demand" policy for investments. Investments in new equipment are made only when there is a guarantee that the equipment will be fully utilized. The group can afford to do that, mainly in terms of the domestic market niche where Company C operates, which is a "seller's market". The company is virtually a monopolist in one of the product lines (piston rings) and almost so in others (75% of the shock absorber domestic OEM market and 85% of the replacement market, for instance).

d) Manufacturing Flexibility Task and Performance

Regarding the manufacturing task in general, some inconsistencies were noticed between two managers' (Mgr 1 and Mgr 2) views, which reflects a possible communication problem and/or lack of an uniform understanding of the company's manufacturing task. In the words of the two managers:

> " For the export market, the order winning criteria is price. Nothing else. Quality is needed anyway. You must have high quality just to qualify for the market . Delivery speed is not relevant either..."(Mgr 1)

> " The export market today represents 30 to 40% of our turnover, we are competing at the world level. And at the world level, it is not enough that the products have quality and price. They have to be delivered fast and on the right time. I am in contact with this market every day, and they want fast and reliable delivery. I have just had a meeting with an Italian customer who came to complain about our delay in performing a modification he ordered... We have to improve our times..." (Mgr 2)

The two interviews were done in the same week.

Regarding the flexibility-related manufacturing task, two out of three managers specified new product flexibility as the particular flexibility type the company should primarily focus on (response seconded by range). The other manager (Mgr 3) mentioned delivery response and mix response as his first and second competitive priorities respectively. This inconsistency may be caused by a lack of common understanding of the company's manufacturing strategic task. Since all of them gave great importance to fast response to customer orders, the lack of agreement seems to be between serving better the orders regarding existing products or giving priority to winning new orders for new products. Table C.1. below shows the distribution of answers. The figures under the Manager's columns represent the priority each of them give to the individual flexibility types in terms of competitive criteria.

Number "4", in the table, means that the manager gave the specific flexibility type first priority, "3" means second priority, "2" third priority and, "1" forth or lower priority. The column "Tot" sums up the total number of managers who mentioned each of the flexibility types. The column "Tot-weighed" shows a pondered total considering the different weights for different priorities. So, for instance, new product range was mentioned by 2 managers (Mgrs 1 and 2). The column "Tot" therefore shows 2. The column "Tot-weighed" shows "6" (3 - 1st priority according to Manager 1 - plus 3 - 1st priority according to Manager 2 - equals 6).

	Mgr1	Mgr2	Mgr3	Total	Total weigh
product range	4	4		2	8
product response	3	3	1	3	7
mix range				0	0
mix response		2	3	2	5
volume range				0	0
volume response		1	2	2	3
delivery range				0	0
delivery response			4	1	4

Table C.1. - Priority given by managers of Company C regarding types and dimensions of Manufacturing Flexibility

e) Uncertainties Involved

The uncertainties mentioned by the managers as the ones which represent the highest risk to Company C's competitiveness are basically related to two aspects: the supply chain and the government intervention. The lack of clear and stable rules and policies, set by the government, under which the company has to operate affects, according to the managers, several aspects of the company's operations, such as export market demand. They argue that, because of lack of consistency between the progression of inflation rates and exchange rate mechanisms, for example, some times what seems to be good and profitable business, at the time a deal is set up to export goods, becomes a loss at the time you actually deliver the goods and receive the payment. In the words of Manager 3:

" We never know for sure what will be our revenue with exports and our expenses with imports. It is hard work planning in an environment like that..."

That gives product prices an uncertain component and causes, some times, a sudden increase in demand because the company suddenly becomes more cost-competitive in external markets due to an unexpected change in the exchange rates. Managers 2 and 3 ranked "government intervention" as the most risky uncertainty source for Company C's competitiveness. Manager 3 ranked "demand uncertainty" as one of his main concerns what, in a way, is related to the government intervention aspect, as explained earlier. He also considers uncertainty with "parts and materials supply" in terms of delivery times as risky. However, although the operations manager mentioned the problem as a local one ("in general, 10 to 20% of the supplies miss their delivery dates"), it could well be the case that the problem is not with the suppliers alone. As Manager 3 puts it:

"About the suppliers, we don't have major problems in terms of quality. Nevertheless, we demand more flexibility from them (in terms of volume and delivery) than they can cope with. It is difficult therefore to identify who is the responsible for the faulty deliveries. The uncertainty of the demand end of the chain, which is linked to the uncertainties with the government policies, is transmitted backwards and destabilizes the supply side of the chain. I'll give you an example: we developed a new product for a new car. The initial demand forecast of our customer was 5000 products per month. We contacted our suppliers and they quoted the raw material and parts we would need, and they got prepared for a demand of 15000 products per month. That is because our material planners knew that we weren't the exclusive suppliers of our customer and we know that historically we end up winning more share making our demand to go up. So they had planned 15000. Well, two months ago the customer called us to complain that his assembly line had to stop because they were short of the product. I went to check how many products they were consuming: 48000 products per month. And that was after 5 months. How can I complain with my suppliers? And I can't complain with the customer either. He is struggling with his own problems. We have to do our best to accommodate the situation ..." (Mgr 3)

The managers also mentioned several other uncertainty sources, but they were quite clear that their first and second ones (actually only first one in the case of Manager 2, who regards all the others as mere consequences) were the most relevant.

The uncertainties perceived as the most risky by the interviewed managers in Company C can be found in Table C.2. below. The figures under the columns "Managers" represent the manager's perceptions regarding the ranking of risky factors to the organization competitiveness. "4" means first ranked or most risky, "3" second, "2" third and, "1" forth or lower. The managers were free to choose how many factors they would mention. The column "Tot" represents the total number of managers who mentioned the factor and the column "Tot-weighed" considers the different weights for different priorities.

	Mgr1	Mgr2	Mgr3	Total	Total weigh
parts supply	1	4		2	5
labour behaviour/supply	1	2		2	3
equipment supply	1			1	1
machine breakdown	1			1	1
technological information supply			1	1	1
product introduction	1			1	1
mix changes	1		3	2	4
volume changes	3		1	2	4
information systems			1	1	1
government intervention		4	4	2	8

Table C.2. - Importance given by managers of Company C regarding sources of uncertainty which represent risk for the company's competitiveness

f) Coping with Change, Uncertainties and Variabilities

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below, together with some representative quotations regarding to them. The first column represents the number of managers who mentioned the relationship. The second and third columns represent the relationship itself, the second being the source of the uncertainty and the third, the capabilities or ways managers see as worth developing to deal with the uncertainty shown in the second column.

number of managers who mentioned the relationship	uncertainty relating to	-->	best way to cope with it is by developing.
2	parts and materials supply		improve coordination with suppliers

"... Today, we use buffer stocks to prevent running out of critical parts, but with MRP we intend to improve our coordination with the suppliers, we will give them a delivery program ..." (Mgr 1)

" We have established longer term contracts and now we are working together with them (the suppliers) to develop ways of improving the dependability of their delivery" (Mgr 2)

2	labour supply	training

"...because we have adopted more sophisticated production processes, we can't find any more as many people as we need ready, in the community. As a consequence we had to intensify our training programs. So we recruit people without qualifications and make them qualified workers by training them within the company. We have recently bought a school in which we subsidize the education of 4000 children and teenagers. We teach them professional skills at the levels we need ..." - (Mgr 2)

2	Machine downtime	preventive maintenance

"... we have an occupation rate which is too high and we don't have as much time as we needed to do preventive maintenance, which is preferable. Then we have to work fast to identify the problem and put the machine up again ..." (Mgr 1)

2	Government intervention	short lead times

"... if I have long cycle times, I make myself more susceptible to the effects of uncertainties, such as the exchange rate mechanisms. The strategic issue nowadays is to be fast. So we have to work on the time elapsed since the customer orders a change in one of its products until the production acknowledge it, we have to work on the time that it takes for us to reschedule and accommodate a change in demand, the time our supplier takes to react to the changes we request and so on. We have to reduce all the cycle times involved in our operation. The nervous system in this regard is the flow of information. We have to create information systems, and I am not talking about large information systems which know everything and decide everything. The idea that you perform well with an intelligent mind and an obedient body is not valid any more. Now each part of the body has to be able to react as well as proact.(Mgr 3)

2	volume changes	forecasting systems

"... I have done an analysis of our forecast deviations and I concluded that the main factor which caused deviation in our forecasts is the circumstance in which the forecast was done. If the forecast was done in a good period, it was in general optimistically biased and the other way round. They were too "nervous". Good volume demand forecasting is very important for us...(Mgr 3)

2	unions behaviour	monitoring environment

"... we have to be constantly monitoring the situation with the Unions, otherwise, we are taken by surprise by a strike...(Mgr 3)

2	new product introduction	ability to subcontract

"... We have this culture of vertical integration, of doing everything in house and that constrains us. If we were good at subcontracting, we could respond quicker to customer needs. We now have a queue of 6 months in our die machining shop.(Mgr 2)"

A number of other relationships were mention by not more than one manager. Nevertheless they are worth mentioning:

1	information flow	buffer stocks

"... Today materials planning and production are not well coordinated. Because of that we keep some stock buffers to react better(Mgr 1)"

1	demand mix	reduce set-up times

"... We now have a large set-up reduction program running. The goal is to reach 2 minutes for every set-up. When we get there, we will be able to respond to changes in demand mix...(Mgr 1)"

When asked how they coped with the different types of uncertainty and variability, the managers showed, in general, a similar approach. Maybe because of the company's conservative "culture", mentioned by all the managers interviewed, a greater emphasis was put by them to developing ways to control the sources of uncertainty than to developing ways to deal with the effects of such uncertainty (such as developing flexibility)

Among the ways used by the Company C managers to control the environmental change, vertical integration seems to play an important role. They vertically integrated the supply of parts (sintered and polyurethane parts), equipment (a division was established to manufacture machines for the group to avoid the usual problems with supply), labour (they acquired a school to educate people from the community at the levels they needed) and technology (Company C has established a large research and development centre to reduce the need to rely on other companies as their technology suppliers).

About the relationship with their suppliers, after vertically integrating up to the point in that almost 100% of the parts were made in, they still try to control further the uncertainties with suppliers by improving the coordination Company C-suppliers, by means of establishing long term contracts and co-operation. In terms of demand, improving forecast systems is considered another important way of controlling the predictability of the changes the company has to deal with.

It seems that, generally, the managers see flexibility as something they have to develop to cope with the uncertainties or, more broadly, the changes which have not been reduced or eliminated (controlled). Ideally, though they would rather control the causes of the uncertainties, aiming at reducing them, but since this is not always easily achieved in the short term, they are "forced" to develop flexibility.

Managers in Company C seem to rely more in infrastructural resources (particularly systems) than in human or technological resources to achieve desired levels of system flexibility. The three interviewed managers mentioned the need to develop more responsive systems, whereas they consider that labour multiskills are not very important for Company C's operation. Manager 3 puts it this way:

> "Resistance to change is the normal attitude amongst human beings. The companies which respond better to change invariably are the ones which created systems to be more flexible. When you change, you always create problems. To change, people have to be convinced that the pain for remaining unchanged is worse than the pain of changing... so, the only way out is to install a system designed to be dynamic, which guarantees the change. If companies could live in an "aseptic bubble" free from environmental stimuli, it wouldn't have to change. The company changes when the environment in which it is immerse "pushes" it. From then on, it is a matter of managerial competence to drive the change... (Mgr. 3)"

g) The Relationship Between Flexibility-Related Competitive Criteria and Manufacturing-Related Critical Success Factors

There seems to be some inconsistencies about the perception of the various managers interviewed about the flexibility-related competitive criteria.

Two of the managers (1 and 2), ranked "product response flexibility" as the first flexibility-related competitive priority Company C should pursue, seconded by product range flexibility. The third manager (Mgr 3) ranked delivery response and mix response as the ones he considers as priorities.

The relationship between the flexibility-related order winning criteria and the resource characteristics which they considered critical success factors is listed below. The list below shows the two first flexibility related priorities and the two first critical success factors according to the perception of each manager:

Manager	Two first flexibility-related competitive criteria	Two first critical success factors
1	product response product range	fast set-ups re-scheduling capability
2	product response product range	fast design standardization
3	delivery response mix response	information flow coordination with suppliers

Table C.3. - Relationship between flexibility-related competitive criteria and critical success factors, according to managers in Company C.

For managers 2 and 3 the two columns do not seem to show clear inconsistencies between system priority objectives and factors they consider critical for the company's competitive success.

Manager 1, however, see new product flexibility as the main flexibility-related competitive criteria but his critical success factors do not seem to keep a close relation with them. They are related, though with the uncertainty factors which he pointed out as the most risky ones (materials and parts supply and demand variation). That could well represent that Manager 1 has priorities which primarily aim at reducing the risks for the company's competitiveness. Managers 2 and 3, on the other hand, would have priorities which aim at winning orders in the market place (priorities which are consistent with their flexibility-related competitive criteria).

It could also mean that not all the managers have a consistent framework to help them establish priorities which are consistent with the overall company's objectives.

h) Some Conclusions of the Within Case C Study

Managers in Company C see flexibility as a way to cope with changes when the causes of such changes cannot be eliminated

Managers in Company C understand that different types of changes should be dealt with by developing different types of control systems and/or resource flexibilities

Managers in Company C do not seem to have a consistent decision model which includes different types of uncertainty, variability and different types of resource and system flexibility.

Managers' perceptions in Company C have a reasonable consistency in terms of the flexibility related order winning criteria they should pursue and the ways they should achieve them. Nevertheless there are discrepancies regarding which are the flexibility-related competitive criteria for the division.

Managers in Company C do not seem to have a clear view about the differences between controlling the uncertainties and dealing with the uncertainties.

4. Case D - The English Vehicle Manufacturing Plant

Company D is a vehicle manufacturing plant located in the Midlands, England and part of a large transnacional corporation with head-quarters in North America and interests focesed on automotive products, industrial machinery and engines. It is one of the largest factories in the world dedicated to the prodution of that class of motor vehicle and it specialises in the design, manufacture and supply for worldwide markets. Ninety per cent of the 65000 vehicle sets produced at Company D's plant each year are exported to over 140 countries. The annual turnover of the plant is approximately 120 million pounds.

Some figures with regard to Company D are shown below:

Number of Employees	
Direct	1600
Indirect	400
Number of possible vehicle configurations	3640
approx % of components made in (in number)	15%
approx % of components bought in (in number)	85%

a) Organizational Issues

The Company D plant is organized functionally, on a "job-shop" type of layout, although they are now at early stages of the migration into cellular manufacturing. Two pilot cells have just been established with promising results, according to the managers.

Company D's organizational structure is hierarchical although they have recently gone through organizational changes. Such changes included the substitution of a number of directors, the re-design of the organizational chart, the inclusion of many aspects of the matrix organization, with the establishment of several multi-functional groups with specific goals, aiming at "breaking the barriers" between separate functions. Presently, the team members are dedicated to the projects on a part time basis, keeping links with their functional departments. According to the managers, the dedication of the members to the projects is planned to become full time in five years.

There are statistical process control procedures implemented and the workers are responsible for the process quality. Equipment maintenance is still performed by a separate team, although the very basic maintenance procedures are performed by the operators themselves. This arrangement also applies to the setting up of the machines.

The formal manufacturing planning and control system is MRPII, although the managers consider the use of MRPII as an intermediate stage towards the JIT production. The day-to-day changes in the schedules nevertheless are done by a "people-based" informal system, because, according to the managers the MRPII software packages don't provide the company with the flexibility it needs to cope with its broad product range and highly variable demand.

There are 6 directors under a general managing director: the manufacturing director (plant management, quality, maintenance, process development, production and after sales services), the director of supply (supply management, production planning and control, materials handling and storing), the technology director (product research and development), the marketing director (relationship with the customers and market) and the finance and administration director (accounting, finance and sales).

b) The Interviews

Four people were interviewed in Company D:

the Supply Director - referred to, in this case, as "Manager 1" - responsible for the management of the supply system, relationship with suppliers and related issues.

the Product Design Manager - "Manager 2" - responsible for the product design and development and management of the bills of material.

the Advanced Manufacturing Engineering Manager - "Manager 3" - responsible for the analysis and design of the manufacturing systems

the Production Manager - "Manager 4" - responsible for the production and plant management

c) Line of Products - Variety, Variation and Innovation

Company D builds vehicles to order and has currently a line of 2 basic product families, with considerable differences between products or configurations within a family. The overall number of products or "derivatives" is theoretically 3640, of which, approximately 2000 are made in any one year, considered exaggerated by two of the managers interviewed:

"... I think we offer too many product variables, but they say that is what the market wants..."

A third manager (Manager 3), on the other hand, considers product variety as the main competitive advantage of Company D. The variation in overall volume can be approximately 20% from month to month. The demand is seasonal and the variation in the mix of products demanded is also high.

The introduction of new products or engineering changes of the existing ones is done on a continuous rather than on a batch basis. In avarage, thirty minor engineering changes are made each month and one substantial change per quarter in functional aspects of the products.

Historically, the time period to introduce a totaly new product has been five years. Nevertheless, according to the managers, the company has recently made efforts in creating the conditions for the simultaneous development of new products, with multi-functional teams participating in the process since early conceptual stages, to ensure "design for manufacturing". Although no results have yet been noticed in terms of time to develop a product, partially because the emphasis has been in designing out unnecessary variety, the managers believe that reductions in time will soon follow. Some managers commented on the issue of launching new products and also the problems they are finding with implementing simultaneous development concepts:

"If you get the right type of people and put them together at the right time to design the products, you reduce the causes of complexity and the variability, you design out long lead-times, design out complexity, variability and this way you solve a lot of the problems at the back of the system."(Mgr 3)

Company D decided to put a tremendous amount of effort in simultaneous engineering because we believe that we can get the turbulence down, 30 to 40% and still keep the product variety. The effort is to make the products to vary only in the bits which the customers need to be different. The main aim of the program is to make the manufacturing more effective and responsive ... controlling factors which are not purely design factors such as the bill of materials, not "exploding" the bill of materials, not "exploding" the variability of parts... We do it by creating an environment without any brick walls. We have to build a team, a disciplined team, with people from different parts of the business all brought in at the conceptual stage... All the concepts have to be addressed: reducing costs, shortening lead-times, design, production, supply, etc... We actually work physically together. The leadership has to be from the top. The directors of the company and the managing director, they've got to say: "I want to do it", they've got to allow people time, etc. People are part-time in the teams. We needed a cultural change because a new perspective is needed." (Mgr 3)

"The general process (of product introduction) is that there is an engineering proposal responding to a marketing request. When the proposal has been bought off, we have some economics done on it. These analysis have been done for the last couple of years by project teams, across functions. They have been very good at getting to launch the product up to the prototyping but useless to getting the thing into production volumes. As soon as we get the project "go-ahead", because it makes economic sense, engineering will start to go into detailed design and development. That will continue to be reviewed by marketing, purchasing and manufacturing. But because generally they are too busy with day-to-day activities, they don't want to get too involved at this stage. They don't have the design engineer mentality, they want absolute detail, definition before they say: yes, I am happy or not. But when they are not, it is often very late in the process. Some of it is caused by lack of understanding of the process and some of it is caused by the way things have always been done. This department used to be 5 miles down the road. There was a large gap. Actually everything used to be designed in America and that was absolutely awful. Beside, the person who comes to take part in the project team can be a problem because in general he is not the representative of his dept, but of the small part of the department he works in. We are not very good at freezing the design. We are also not very good at launching new products... Then we make the formal release to manufacturing, the bill of materials, then manufacturing do their routings etc, which are also input for the process guys. It takes in general 12 months to 5 years, depending on the change. The new transmission has been around for 5 years."(Mgr 2)

A number of points can be highlighted as relevant, based on the managers comments, regarding the conditions which they regard as necessary for the successful and responsive product introduction:

-the need for top-management comittment

-the need for "breaking the brick walls" by adopting inter-functional team approach since early conceptual stages, but making sure that the team members are really involved and that they have the appropriate level of influence and representativeness in their home functional departments.

-the need for strong, high rank team-leadership

d) Manufacturing Flexibility Task and Performance

The managers' answers concerning the flexibility-related task of the plant are somewhat consistent, despite the fact that the answers are not exactly the same. The answers, regarding the priority flexibility-related tasks which the company should focus on, varied mainly between product and mix flexibility. That is understandable in a build-to-order environment, in which the distinction between mix and new product flexibility is not clear cut. The managers also seem to priorize the range dimension of the flexibility types rather than the response dimension. Table D.1 below shows the distribution of answers. The figures under the Manager's columns represent the priority each of them give to the individual flexibility types in terms of manufacturing task.

Number "4" in the table means that the manager gave the specific flexibility type first priority, "3" means second priority, "2" third priority and, "1" fourth or lower priority. The column "Tot" sums up the total number of managers who mentioned each of the flexibility types. The column "Tot-weighed" shows a weighed total considering the different weights for different priorities. So, for instance, product range was mentioned by 2 managers (Mgrs 2 and 3). The column "Tot" therefore shows 2. The column "Tot-weighed" shows "3" (2 - 3rd priority according to Manager 2 - plus 1 - 4st priority according to Manager 3 - equals 3).

	Mgr1	Mgr2	Mgr3	Mgr 4	Total	Total weigh
product range	4	1	2	3	4	10
product response			3		1	3
mix range	3	4		3	3	10
mix response		3			1	3
volume range			4		1	4
volume response		2	1		2	3
delivery range					0	0
delivery response					0	0

Table D.1 - Priority given by managers of Company D regarding types and dimensions of Manufacturing Flexibility

e) Uncertainties Involved

The uncertainties mentioned by the managers as the ones which represent the highest potential risk to Company D's competitiveness show a distinct pattern. All the managers, for instance, placed "demand mix" uncertainty as their main concern. As a second main concern, two managers (Mgrs 1 and 2) pointed "overall demand volume" uncertainty and two (Mgrs 3 and 4) pointed uncertainty with "parts and material supply". The perceived uncertainty types in Company D can be found represented in Table D.2 below. The figures under the columns "Managers" represent their perception on the ranking of risky factors to the organization competitiveness. "4" means first ranked, "3" second, "2" third and, "1" forth or lower. The managers were free to choose how many factors they would mention. The column "Tot" represents the total number of managers who mentioned the factor and the column "Tot-weighed" considers the different weights for different priorities.

	Mgr1	Mgr2	Mgr3	Mgr 4	Total	Total weigh
parts supply			3	3	2	6
machine breakdown		1			1	1
product introduction	1	1			2	2
demand volume	3	3	2		3	8
demand mix	4	4	4	4	4	16

Table D.2. - Importance given by managers of Company D regarding sources of uncertainty as risky for competitiveness

It seems that the uncertainty sources which concern the managers most are those related with the demand. Three of the managers qualified Company D's suppliers as very good and reliable. The ones which pointed "parts and materials supply" as an uncertainty source recognize that the uncertainty with the supply was a consequence of the uncertainty with the demand rather than caused by the suppliers themselves. The demand uncertainty is due to the broad range of customers Company D has all around the world (they export to 140 countries) with the demand therefore depending on factors such as the different government regulations, the unstable economic and political conditions in different countries and the weather conditions in different regions of the globe.

f) Coping with Change, Uncertainties and Variabilities

The two factors which most concern the managers at Massey-Ferguson, in terms of uncertainty and variability are the demand uncertainty, mainly in terms of mix and the large variety of products. Although 2 of the managers considered the variety of products offered by Company D as exaggerated, Manager 1 considers the variety of products the most important competitive advantage for Company D:

> "Fast delivery hasn't been considered a competitive advantage. Variety, yes, this is our competitive advantage, so therefore we need to build as far as we can ultimate flexibility into the business."

The most mentioned relationships between types of uncertainty, variability and ways to deal with them are shown below, together with some representative quotations regarding to them. The first column represents the number of managers who mentioned the relationship. The second and third columns represent the relationship itself, the second being the source of the uncertainty and the third, the capabilities or ways managers consider as worth developing to be able to cope with the uncertainty shown in the second column.

number of managers who mentioned the relationship	uncertainty relating to	-->	best way to cope with it is by developing
3	demand mix		rescheduling capability

"... if we take as a given that the forecast is going to be uncertain and we still have to respond to the demand, what we really need is a tool, a scheduling tool, to at least at a very early stage, identify the discrepancies between what you previously provisioned and what you now know you are going to consume..." (Mgr 4)

2	parts and materials supply		supplier development, partnership

"... I believe the key is to have suppliers which you can trust and they can trust you, who have compatible processes, manufacturing processes ... we've got to compress our supplier base, if you actually make the partnership, you get better comittment. They also become more responsive. They have more data accuracy about my demand, more visibility to the schedule, we have greater control and support from them, so you both begin to have a great afinity and partnership, it reduces the uncertainty of the supplier. We've got to know about our process as much as we've got to know about theirs..." (Mgr 3)

2	demand mix		suppliers development, partnership

"... what we have done as a business is to recognize that we had to change some of our logistic processes to give our suppliers more opportunities to be aware about the changes, and to respond to them ... we have to try to increase the flexibility of our suppliers helping them reduce their lead times..." (Mgr 1)

2	demand mix		buffer stocks

"... so you've either got to convince yourself: I'm going to hold inventory strategically of certain components in places and if there is a peak, I'm going to consume it and give supplier tome to react or not..." (Mgr 4)

"...in the past we've had a very sequential way of working and therefore product changes had been very slow. In the future, we'll have simultaneous engineering and methods of working, and that will speed up the overall elapsed time. That's how we compete..." (Mgr 1)

2	demand mix	fast set-ups

"... we, in the past, have put loads of excess labour out, we also used inventory (finished goods) to buffer that, so we made a lot of complete and unsaleable vehicles, we still do a lot of expediting, that means a lot of premium time. Now we are starting to work more on set-up times." (Mgr 2)

2	demand mix	forecast sensitivity

" ...the demand mix is very unpredictable. We have to improve our forecasting systems." (Mgr 1)

Managers in Company D also showed great concern about the large variety of the company product-line. They commented on some ways which they consider as appropriate to deal with it:

number of managers who mentioned the relationship	variability relating to	-->	best way to cope with it is by developing
3	product variety		standardization

"...We can now build, theoretically, 3640 different vehicles. I believe that what we should be doing is to simplify our products, standardize." (Mgr 2)

2	product variety		supplier development/ partnership

"...we are trying to tackle lead-times by trying to make our suppliers to reduce their set-up times so that we can have smaller batches and increase flexibility"(Mgr. 1)

2	product variety	buffer stocks

"...I can hold level of inventory at a very low cost, which takes so much of lead-time. You are actually increasing your inventory, but very low cost inventory. That actually gives you flexibility" (Mgr 3)

2	product variety	fast set-ups

"Developing fast set-ups is important because we can't afford to carry on stocks of such a broad product range ..." (Mgr 1)

A point which is worth mentioning is the emphasis given by the management in the achievement of manufacturing flexibility through the resources people and infrastructure.

"The real fast response and day-to-day re-scheduling is made by people. We actually have to get the right balance between people and systems" (Mgr 4)

"...we deal with variability by having control systems, manufacturing methods to optimiza resources, regrouping the factory in cells, focusing the cells to become a flow environment..." (Mgr 3)

Technological resources do not seem to play a major roles in the view of Company D's management as ways to achieve system flexibility. This is possibly due to the inherited inflexibilities of the machinery mentioned by Manager 2:

"We did the classic. This factory was setup for high volume, low variety. It has diversified afterwards."

If that is the case the managers would be conscious that they could not do much in terms of improving the flexibility of the system by using the technological resources apart from attempting to reduce set-up times as much as possible.

Another point worth mentioning is the great concern placed on product variety by the majority of the managers. All of them mentioned variety as a source of complexity and argued that parts variety should be reduced although they seem to recognize that product variety is a competitive advantage for Company D.

It seems that some of the managers see flexibility as something they have to develop in order to achieve product variety - seen as a competitive advantage - but they generally prefer to control variety and uncertainty as much as possible via parts standardization, focus, improved forecasting systems and so on, in order to reduce the need to be flexible. Generally, when asked how they dealt with variability and uncertainties, they first mentioned control-related measures (e.g. standardization) aiming at reducing the environmental changes which Company D would have to deal with. Then, when asked how they dealt with the effects of the changes, given that the changes have already occurred, they woud mention flexibility-related measures (e.g. re-scheduling).

In terms of the uncertainty regarding demand mix, for instance, managers firstly mentioned the development of a cooperative relationship with suppliers and the development of better forecast systems aiming at reducing the uncertainty the system would have to deal with. On the other hand, they pointed out that fast set-ups and buffer stocks and rescheduling capability should be used to cope with the effects of the mix demand uncertainty, when the uncertainty and the variability are taken as given.

The number of managers mentioning the ways they use to cope with demand mix uncertainty gives a dimension of the importance they give to this factor. Aditionally, they also emphasized the product variability, with 9 mentions by the managers. They suggest standardization and co-operation with suppliers (control-related) and, buffer stocks and fast set-ups (flexibility-related) as ways to deal with variability. This is a similar list (except for the item "standardization" - exclusive for the variability and "forecasting" - exclusive for the uncertainty) to the one the managers suggested as appropriate ways to deal with mix uncertainty. That suggests that in an environment like Company D's, with a broad product line and where products are built to order, the uncertainty of the mix and the variability of products are regarded by managers as calling for similar sort of resource characteristics.

g) The Relationship Between Flexibility-Related Competitive Criteria and Resource Characteristics or critical Success Factors

In general there seem to be some consistency about the perception of the various managers interviewed about the flexibility-related competitive criteria.

The four of them, for instance, ranked either "product flexibility" or "mix flexibility" as the flexibility-related priorities Company D should pursue (except for Manager 3 who also included "volume range"). In an environment like Company D's which builds to order, it is understandable that mix and product flexibilities are treated in a way indiscriminately. The consistency between the flexibility-related order winning criteria and the resource characteristics which they considered critical success factors was also high. The list below shows the two first flexibility-related priorities and the two first critical success factors according to the perception of each manager:

Manager	Two first flexibility-related competitive criteria	Two first critical success factors
1	product range mix range	design capability fast set-ups
2	mix range mix response	re-scheduling capability coordination with suppliers
3	volume range product response	re-scheduling capability integration design/production
4	mix response mix range	re-scheduling capability coordination with suppliers

Table D.3. - Relationship between flexibility-related competitive criteria and critical success factors, according to managers in Company D.

The only apparent inconsistency is with Manager 3's answers who places a high priority to "rescheduling capability" and "integration design/manufacturing" which can not be directly related to "volume range" which is his first priority in terms of flexibility-related manufacturing task.

For the rest of the managers, the two columns seem to show consistency between system objectives and resource characteristics, or in other words, means to achieve them.

The relationship between the uncertainties considered risky by the managers and the flexibility-related manufacturing task they regard as priorities was also found high. The reason for the consistency is possibly that the uncertainty which mostly concerns the managers is demand-related. Such uncertainty is probably caused by conditions which are intrinsic of the market Company D serves. That means that these uncertainties are also opportunities for the companies which manage to respond and cope with such uncertainties. therefore, the demand-related flexibility types used in the interviews are able to capture the needs to cope with the mentioned demand-related uncertainties. This would possibly be different (as it can be seen in the other three cases of this research work) if the managers' main concerns regarding uncertainties were in the input side or in the transformation process itself.

Summarizing, it seems that managers in Company D are able to identify the relationships between flexibility-related order winning criteria and the critical success factors which are needed to achieve high performance in them. They seem to be able to focus their attention and give priority attention to these factors.

h) Some Conclusions of the Within Case D Study

Managers in Company D see manufacturing flexibility as a way to cope with environmental and internal uncertainties when the causes of such uncertainties cannot be eliminated or reduced.

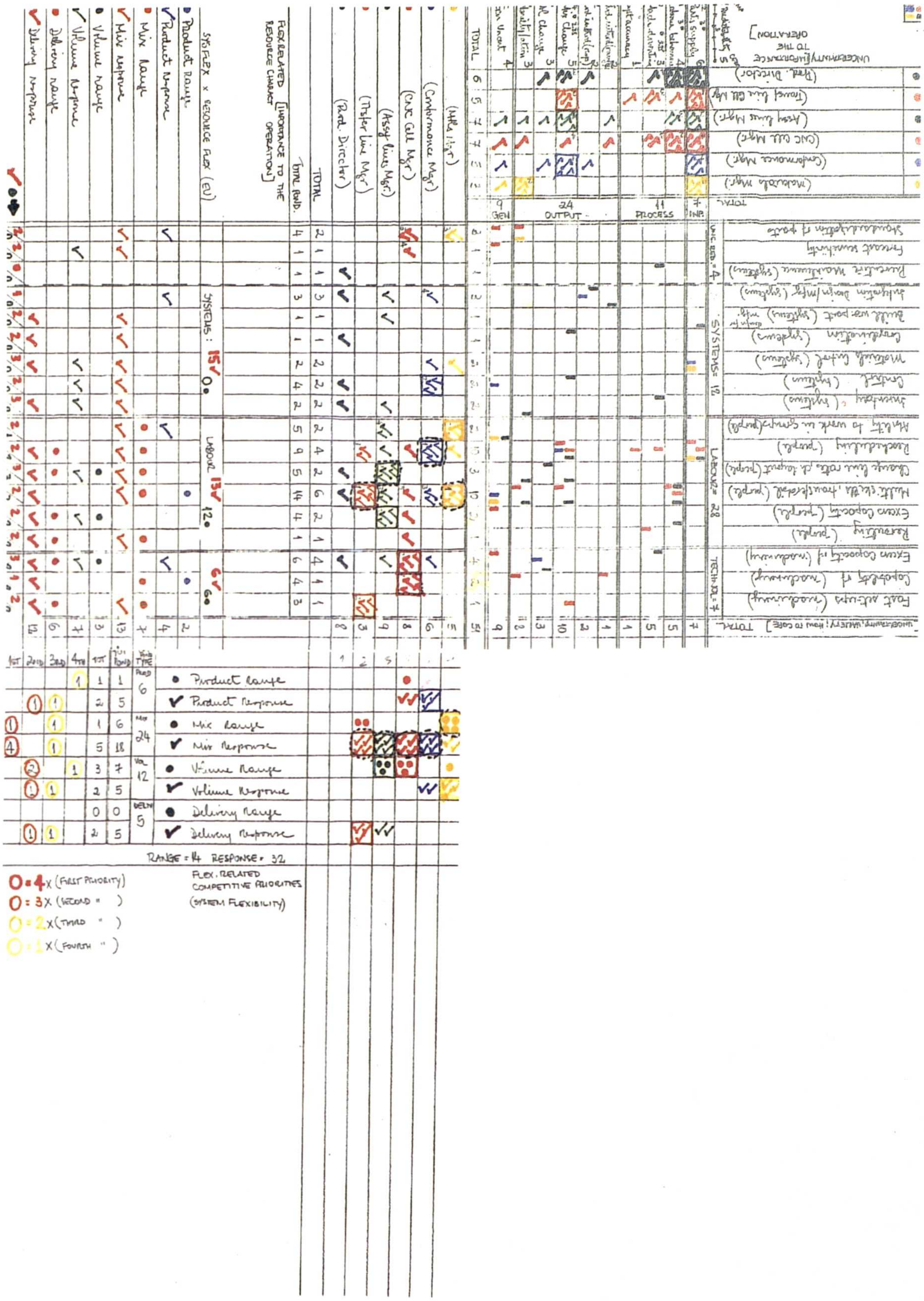
Managers in Company D consider that variability and different types of uncertainty call for different types of flexibility-related resource characteristics.

Managers perceptions in Company D are reasonably consistent in terms of the flexibility-related manufacturing task they should pursue. They also seem to have a consistent understanding of which would be the ways to achieve such manufacturing task.

Managers in Company D consider that manufacturing flexibility is generally necessary to deal with broad product lines even when the demand is predictable. They also prefer controlling the variety of products (when such variety does not represent a relevant competitive advantage) and parts as much as possible, rather than developing the flexibility necessary to deal with it.

Appendix 4

An example of a chart used in the data treatment process



UNCERTAINTY [IMPORTANCE TO THE OPERATION]
TOTAL
GEN
OUTPUT
PROCESS
INP.
(Prod. Director)
(Tr/fer Line Mgr)
(Assy Lines Mgr)
(CNC Cell Mgr)
(Conformance Mgr)
(Materials Mgr)
SYS.FLEX x RESOURCE FLEX (EU)
FLEX-RELATED [IMPORTANCE TO THE RESOURCE CHARACT. OPERATION]
TOTAL
TOTAL POND.
SYSTEMS: 15✓ 0•
LABOUR: 13✓ 12•
TECH: 6✓ 6•
Product Range
Product Response
Mix Range
Mix Response
Volume Range
Volume Response
Delivery Range
Delivery Response
RANGE = 14 RESPONSE = 32
FLEX. RELATED COMPETITIVE PRIORITIES (SYSTEM FLEXIBILITY)
O = 4x (FIRST PRIORITY)
O = 3x (SECOND ")
O = 2x (THIRD ")
O = 1x (FOURTH ")