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Agile manufacturing as 21st Century strategy for improving manufacturing competitiveness[1]

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1. DEFINITION OF MANUFACTURING STRATEGY

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

The first is the increased pressure owing to the growing international manufacturing competitiveness made more intense by the recent movement towards globalisation. The second is the increased potential to be gained from the development of new manufacturing technologies, the potential of which grows much faster than our ability to use it for competitive benefits and, the third is the development of a better understanding of the strategic role of manufacturing. Five characteristics can be listed to help understand the need for a strategic management of the manufacturing function:

* Manufacturing in general involves the bulk of the company´s assets and human resources
* Many decisions regarding manufacturing resources require a long time to take effect therefore requiring a long term outlook of the future to support them
* Once made, many of these decisions will normally take a long time and substantial amounts of resources to revert
* Manufacturing decisions affect directly the way companies can compete in the market place because it is increasingly accepted that there is not such a thing as a "best way" to manage manufacturing resources - different configurations of manufacturing resources will result in different levels of manufacturing performance in different aspects (e.g. delivery, flexibility, quality and cost)

  Manufacturing decisions have to support and be supported by other functions in order to properly support the business strategy of the company, therefore requiring strategic orientation

Manufacturing strategy can be defined as a framework the objective of which is the increased competitiveness of the organisation: to achieve that it should aim at designing, organising, managing and developing the company´s manufacturing resources and shape a consistent pattern of manufacturing decisions in order that they can result in an adequate mix of performance characteristics which will allow the company to compete effectively in the future.

2. THE CHANGING INTERNATIONAL MANUFACTURING COMPETITION IN THE ´60s, ´70s AND ´80s

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During the years ´60s, ´70s and ´80s, the relative competitive positions occupied by the formerly leading industrial countries changed substantially. Some traditional industrial nations were outperformed by other countries, of which Japan was the most evident example. The United States and the United Kingdom had their leading positions challenged and in many cases lost them, e.g. in the automobile market, long dominated by American companies.

Considering the Japanese manufacturing industry, Buffa (1984) notices that the industries in which they excelled during that period - motor cycles, domestic appliances, automobiles, cameras, hi-fi, and steel production - had existing, already developed markets with established market leaders. According to the author, Japanese companies may 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 initially were not able to match. Japanese companies were using the improvements which they had been achieving in manufacturing as their main competitive advantage, as opposed to 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 were Japanese companies on average more cost efficient than most Western companies (though there were many exceptions of Western companies which had maintained or improved their competitive position in the world market during those decades), but they were 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 had 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 of the ´70s.

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 are various, according to the literature. Hayes and Wheelwright (1984), in their now classic book, summarize some of them in five main points:

Financial considerations The assessment of companies and their manager's performance based predominantly on short term considerations may have induced managers to avoid long term investments which might have resulted in a more effective manufacturing. Managers may not have decided to invest in improvements whose results would only show in the long term because they needed short term performance.

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.

Excessive specialization and/or 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.

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 their resources and energy on one particular set of activities. Focused manufacturing is based on the idea that simplicity, repetition, experience and homogeneity in manufacturing tasks breed competence (Skinner, 1974).

Inertia Skinner (1985) observed that most factories in the Western world were not managed very differently in the 1970s from the way they were in the 1940s or 1950s. Such practices

might have been adequate when production management issues centered largely on efficiency and productivity. However, the problems of operations managers moved far beyond mere physical efficiency. On top of this, managers considered that the production problems were solved, directing attention and resources toward other issues such as distribution, packaging and advertising. According to Hill (1995), there had been a failure, conscious or otherwise, of Western industries and the society at large to recognize the size of the foreign competitive challenge, its impact on their way of life, and consequently to recognize the need for change.

The result of the concurrence of the five factors above is that Western plants and equipment were allowed to age in all senses. 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 1970s, US companies found themselves pitted against companies that did compete on dimensions such 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".

2.1. The development of a better understanding of the strategic role of manufacturing

Since the seminal work of Skinner (see e.g. Skinner, 1969), a number of authors have addressed the strategic role of the manufacturing function. Hayes and Wheelwright (1984) and later Hayes et al. (1988) called attention to the need to transform the manufacturing role from being primarily reactive to being *proactive*, where the manufacturing function contributes actively to the achievement of competitive advantage.

Another point which is made by some authors, e.g. Slack (1991) 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.

Hill (1995) argues that the need for a manufacturing strategy to be developed and shared by the business has to do not only 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 may take years to change. Changing them is costly and time consuming, but even more significantly, the changes will possibly come too late.

More recently some authors (Hayes and Pisano, 1996; Teece and Pisano, 1994; Pisano, 1997; Alher, 1998) have added to the debate by arguing that the recently developed resource-based view of strategic management should play an important role in the development of manufacturing strategy - the resource-based view would help manufacturing strategies to be more difficult to copy resulting in more sustainable competitive advantages. This concept will be further developed later in this chapter.

2.2. Focused manufacturing: a controversial 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, 1995). 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, 1991; Skinner, 1996). 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 and organised 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 existing complexity. One alternative approach which helps to avoid major investments is 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 organizationally 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.

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 into 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 broad support among academics and practitioners, a number of authors (see e.g. Schonberger, 1986) have challenged the idea of focus in manufacturing strategy. Inspired by the Toyota-developed Japanese just-in-time system, the "lean production" system advocates argue that trade-offs do not exist (since at a certain point in time some japanese companies outperformed western competitor companies in all aspects of performance) and that the principles on which "lean manufacturing" rests:

broadly trained rather than specialised people;
people empowered to identify and solve production problems in teams;
horizontal and informal communication rather than through hyerarchical paths;
emphasis on production throughput flow rather than resource utilisation;
production flows pulled by demand rather than pushed by centrally defined schedules;
product based rather than process based layout;
no acceptable level of defective production;
inventory is considered as waste and setups should be minimised;
continuous improvement and waste fighting initiatives are central;
cooperative and long term rather than adversarial supplier relationships; and,
product development related activities done concurrently by cross functional teams

would be the "one best way" to organise and manage manufacturing. But is it? Many authors disagree. Hayes and Pisano (1996) for example argue that although many companies experienced improvements by implementing one or more of the "lean manufacturing" principles, "this does not assure that it will be successful financially. For example, the winners of the [American] national Baldridge Award, which recognises American companies that have been unusually successful in improving their quality, productivity and customer satisfaction, have done well on average - however, some of them, entered Chapter 11 soon after receiving the Baldridge, and others (like General Motors, IBM and Westinghouse) soon thereafter began experiencing higly visible problems.

Even more disturbing, a number of Japanese companies are beginning to question many of the same approaches [...] Toyota´s newest factory in Japan utilizes neither the JIT system nor mixed model assembly".

Arguments about the trade-offs in manufacturing have sometimes been polarised in two approaches - some of the advocates of "lean manufacturing" argue that trade-offs do not exist. Opposing to the them some of the more radical advocates of the trade-off idea sometimes neglect the fact that even considering that trade-offs exist, they are dynamic rather than static in nature and that trade-off relationships can be altered in a number of ways. One of the interesting models to describe trade-offs in manufaturing is Slack´s see-saw analogy. According to Slack (1991) manufacturing management is sometimes portrayed as consisting almost entirely of handling trade-offs. Trading off high finished goods inventory against good product availability, trading off expensive preventative maintenance against the reliable provision of capacity are some examples. Improvement in one place should be paid for elsewhere. Schematically this idea can be seen in Figure 1.

When performance objective 2 is improved, performance objective 1 suffers, at least in the short term (B). One example in the field of inventory management would be the trade-off between cost efficiency (associated with lower inventories) and custome service defined as good product availability. If in the short term a company decides to improve service level, one way of doing it is by increasing finished goods inventory. Having done that, it then may be possible to re-gain the lost level of cost efficiency (by reducing inventory levels) without jeopardising the newly acquired improved level of customer service (C) - for example by reducing lead times or improving future demand knowledge (via e.g. improving forecasting sytems or better coordinating with the customer and this way, with less uncertainty, less buffer inventory would be needed), represented by the movement of the see-saw pivot.

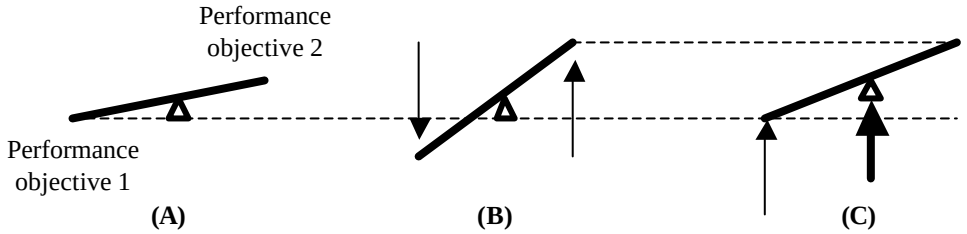

Figure 1. Slack´s (1991) see-saw represents the dynamic nature of trade-offs

None of these pivot moving alternatives however can normally be achieved in the very short term. They are initiatives which normally take longer than simply increasing inventory levels. This means that managing the trade-offs between performance aspects of manufacturing performance does not mean only managing the position of a static see-saw (which in many

situations can be altered in the short term), but it also means managing the movements of the see-saw pivot (which normally takes longer). Hayes and Pisano (1996) add to Slack´s point arguing that trade-offs should be managed considering not only the improvements in each of the performance objectives but also the knowledge and learning that each of different possible dynamic improvement paths will bring to the organisation. The idea of dynamic improvement paths is interesting. Let us use another form of representation for the idea of dynamic trade-offs in relation to the trade-off between service level and inventory level. One of the simplest models used to dimension safety stocks of inventory items (the demand of which is approximately constant is):

$$SS = SF \cdot \sigma_{LT} \quad (1)$$

Where:
SS = safety stock level
SF = safety factor
σ_{LT} standard deviation of demand (compared to forecast) during replenishment lead time

The SF (safety factor) is defined as a function of the service level intended to be offered to the customer (see Chase et al., 1998 for a detailed tretament of safety stocks - the idea here is just to use this simple model as an illustration). Assuming that demand forecast errors behave normally and with some help from statistics, the plotting of a graph relating safety stock level and service level, results in something like what is shown in Figure 2.

This somewhat simplistic model can be used to show the idea of dynamic paths. Movements along the trade-off borders 1 and 2 represent Slack´s "satic" pivot see-saw movements - if one wants to increase service levels one way to do it is surely to increase the levels of inventory (therefore jeopardising the objective of cost efficiency). However, as it can be seen by the formula (1), on can alter the level of service without changing the level of inventory - by changing the other factor of the right hand side term - the standard deviation of the demand forecast during replenishment lead time.

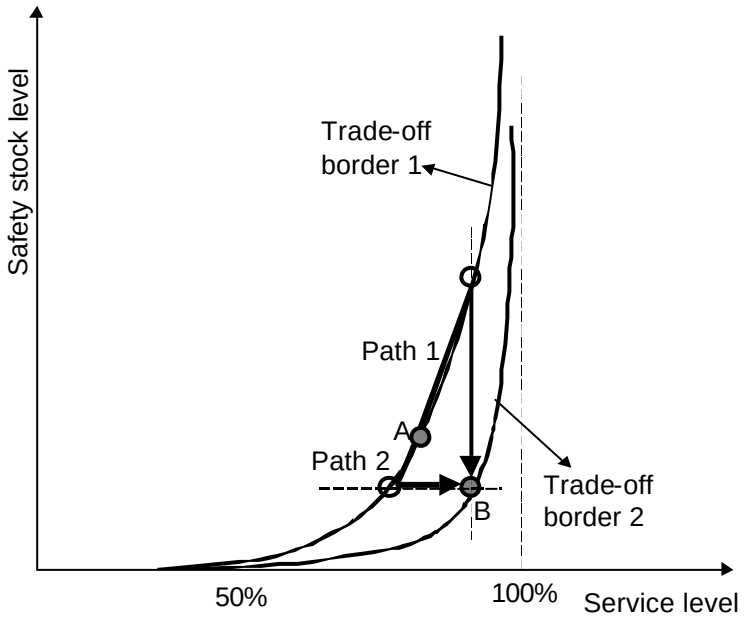

Figure 2. Graph representing Hayes and Pisano (1996) dinamic trade-off paths

If the standard deviation is reduced for example, the trade-off border changes from trade-off border 1 to trade-off border 2. To illustrate Hayes and Pisano (1996) dynamic path idea, one can imagine a manager intending to go from state A to state B, in figure 2, therefore improving both aspects - service level and inventory-related cost efficiency. Several paths of improvement could be choosen. Among them, two are used to illustrate the point: path 1 and path 2. Path 1 would mean first to increase inventory levels (which can be done relatively quickly) to achieve increased service level ("static" pivot see-saw movement) and then to set off efforts to reduce inventory levels without reducing service level through e.g. improving forecasting methods (which takes longer and requires a particular set of capabilities development). The other path which could be used to achieve the same state B (coming from state A) which is path 2, means a different sequence of actions. First, the inventory levels would be reduced and then efforts would be made to increase service levels without increasing inventory levels again, by for example, using JIT-type techniques of identifying production problems by reducing inventory levels and then acting selectively and constantly to tackle such problems (which will rersult in a rather different set of capabilities being developed). Path 1 is more centred in the traditional methods whereas path 2 is more towards JIT-type management. The final state (B) is the same, but Hayes and Pisano (1996) argue that depending on the path chosen the learning experience which the hypothetical company would go through would differ considerably and therefore the ability of the company to face future competitive challenges would also differ considerably. The conclusion is: trade-off analysis is not as simple as the radical advocates of "lean manufacturing" (one best way) would have liked and they are not as simple as a "static" analysis would have made believe either. Trade-offs exist and will probably always exist but their treatment requires an in depth understanding of the dynamics and dynamic paths involved in each particular situation under analysis.

2.3. Why Manufacturing Strategies for Improving Productivity and Quality

Basically the whole movement set off by Skinner´s seminal articles in the beginning of the ´70s was basically an attempt of western astonished manufacturing academics and practitioners to understand and respond to the competitive challenged posed by the suddenly successful Japanese companies who had quickly taken a substantial share of the world export market from them. In terms of Slack´s see-saw model, Japanese companies had found out how to move the pivots while western companies had been complacently managing the "static" pivot see-saw movements only. One of the formerly accepted trade-offs which the Japanese companies challenged was one between high levels of conformance quality (the ability of the production system to produce outputs according to specifications) and cost efficiency. In the traditional manufacturing systems inspectors would sort good from bad products at the end of the production line - if a company wanted more quality, more inspectors (with the corresponding increased inspection cost) would be needed. Quality used to cost. Japanese companies changed this paradigm (they moved the pivot), by giving operators the responsibility and the ability to detect and solve quality problems, re-directing the attention from product quality to process quality. More conformance quality therefore would not necessarily mean more costs. Quality started to be considered as free (Crosby, 1979).

Western managers started to realise that their role should change: the traditional mass production approach which had reduced the manufacturing strategic contribution to "reducing costs" to something more complex and relevant: the purpose of the strategic management of manufacturing would have to change to specifying the kind of competitive advantage that a company is seeking in the market place and to articulate how that advantage is to be achieved (Hayes and Pisano, 1996). However, the challenge in the ´80s was basically one of catching up with the Japanese companies and the most important trade-off involved was the one between cost efficiency and quality: Western companies had to manage better the things which were

under their control e.g. levels of deffect and wasted manufacturing resources. The ´90s brought a different environment. Japanese companies used the lead they had simultaneously achieved in quality and cost and while the western companies spent all their efforts to catch up with them, they had started directing efforts towards moving more pivots - e.g. that between flexibility and cost efficiency, for example, based on set-up time reductions via both technology (flexible automation) and methodology (quick changeover techniques based on different more rational non-technology based methods - see for e.g. Shingo, 1985). At the same time, markets had became increasingly turbulent, globalisation had taken place and technology had reached umprecedented development rates. The challenge then was not only to manage better things which were under control (such as product quality variability) but to manage better things which were not completely under control - to manage better the unexpected change.

3. THE NEW MANUFACTURING ENVIRONMENTS OF THE ´90s AND THE 2000s:

The manufacturing environments of the ´90s and the 2000s have been and will be considerably different from those of previous decades.

Information technolgy has remarkably changed the patterns of integration and communication within as well as between companies and between companies and consumers. The ERP-type integrated management systems have broadly been adopted and although one could argue that the results were not as spectacular as the consultancy companies and software houses had announced, the levels of integration and communication between customers and suppliers (internal end external) which the companies have achieved so far are superior than the levels they used to work with without the integrated systems. With the integrated systems being connected with the internet (a reality now) new virtually endless opportunities are available to the companies who are competent enough to use them for competitive benefit. However, one can not make the usual mistake - assuming that it is enough to *possess* the technology to ensure a *good use* of the technology. These are actually different things and anyone who has managed a manufacturing operation knows that. Sometimes some authors tend to neglect this fact considering that operational excellence is easily copied because manufacturing operations are increasingly technology oriented and technology is easily traded. They sometimes mix concepts. Having an integrated software system plugged in, for example, is in fact easy and increasingly cheap. However when one looks at how comparatively well companies use the resources made available by such systems one starts seeing huge differences. So having the same technology is easy; using that technology for the company´s competitive benefit is not - and therefore it is not easily copied.

The rate at which technology has evolved requires, more than ever, that manufacturing managers are *proactive* in anticipating and understanding the newly available technologies and their impact on the company´s competitive performance, both in terms of information, product and process technologies.

Customer requirements are increasingly demanding because competition is increasingly global and fierce and, competitors are increasingly competent. Customers already want it "here, now and customised" (McKeena, 1997) - that means achieving levels of agility never required before from the production systems. That means a level of ability to ensure consistency between manufacturing actions and strategic direction never required before. Requierd changes in the strategic direction must be quickly mirrored by changes in the pattern of manufacturing decisions. The same way, changes in the manufacturing resorces, newly developed competences and newly available technologies should also be able to quickly change the strategic direction of the company changing for example the marketing aim to market segments which better value the newly acquired or developed competencies.

4. ROLE OF NEW MANUFACTURING CONCEPTS AND TECHNOLOGIES

4.1. The development of new manufacturing technologies

Manufacturing Technology is regarded as one of the most important decision areas within the manufacturing management function. 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 quickly 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 once well established concept of *economies of scale* because they have the potential of making changeover times negligible. The concept of *economies of scope* started to gain importance. Economies of scope (Goldhar and Jelinek, 1983) 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, each producing one product at the same level of output.

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 would not apply any more (Stecke and Raman, 1986).

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.

4.2. The resource-based view

The more popular paradigm for approaching competitive strategy has been based on the notion of strategic fit (Hayes & Pisano, 1996). Porter´s (1980) book, Competitive Strategy became possibly the most celebrated book in the field. Recognising the existence of trade-offs, Porter argued that the goal of business strategy is to seek sustainable competitive advantage by positioning oneself within industries and businesses that are either structurally attractive or can be made so through deliberate actions. According to Porter, competitive advantage is strongly linked with the idea of good positioning. In the ´90s, Prahalad and Hamel (1990) added to this debate challenging Porter´s ideas by advocating that companies should focus on building "core competencies" that could create competitive advantages in a variety of markets. They argue that only competencies which are difficult to copy actually make a company sustainably competitive and therefore a company who positions itself and then develops the needed competencies will have their recently acquired competencies easily copied and therefore the advantage will not be sustainable. Teece and Pisano (1994) called the attention to the dynamic aspects of the resource-based view, arguing that not only are the capabilities to be developed important but that the mechanisms by which new skills and capabilities are built have an important role to play because they influence the learning processes and knowledge base of the company and these will influence the ability of the company to compete in the future.

The resource-based approach is markedly different from the traditional manufacturing strategy paradigm.

According to most of the early authors, the manufacturing strategy development should follow a predominantly top-down approach. Skinner (1985), Fine and Hax (1985), Gregory and Platts (1990), Slack (1991) and, to a certain extent, Hill (1995), suggest hierarchical models in

which the corporate strategy drives the business strategy. This in turn drives the strategies of manufacturing and other functional areas within the business unit. In fact, the manufacturing strategy formulation process has not received as much attention as the manufacturing strategy contents - objectives and decision areas - in the literature (Leong et al., 1990). Among the pioneers in the field, Hill (1995) seems to have been one of the few who actually delved into a more detailed discussion on it, proposing a specific framework to guide the development process on a (also predominantly top-down) step-by-step basis. Rather, the authors in the field tend to focus their work primarily on the manufacturing strategy objectives and decision areas. This approach, according to Leong et al. (1990), seems to consider some sort of implicit process, which depends on breaking manufacturing down into a number of decision areas and making the goals of manufacturing explicit in terms of a number of performance criteria. The steps of identifying these criteria, prioritising them and relating the decision areas to them would form the implicit process. Hayes and Wheelwright (1994), for instance, although describing four stages along a "continuum", which represents the evolution of manufacturing's strategic role, where the key aspect of evolution is the increasing, more proactive involvement of manufacturing in the firm's strategic needs, do not describe how a company should go about reaching the more advanced stages.

The exclusive top-down traditional planning approach does not seem to be adequate for the future - planning is only of use when a good level of stability is present. Otherwise it may easily become a futile exercise. In the future the only certainty companies will face is that changes will be larger, more sudden and quicker than ever before therefore requiring more agile manufacturing strategy development and implementation processes.

5. NEED FOR AGILE MANUFACTURING STRATEGY PROCESSES

The authors in the field of manufacturing strategy are more prolifc in prescribing *what* to do than *how* to do it. There are however some authors whose work can help in the difficult task of developing a manufacturing strategy in real situations. Two examples are the worksheets developed by Gregory and Platts (1990), which are interesting tools for helping define the priorities for manufacturing and, the importance-performance matrix proposed by Slack (1991), which is both simple to understand and use and effective in giving managers a clear idea of what performance aspect needs urgent action in manufacturing. Both however arestill predominantly top-down planning-based tools. As can be seen, although some very valuable contributions can already be found in the literature, some increasingly important aspects of the manufacturing strategy development process still lack proper operationalization methods in the literature.

The proactivity of the manufacturing function is an example. Proactivity, particularly in turbulent environments, is not something that simply can give companies an edge. It is the only way to survive. In fact, manufacturing proactivity is suggested by a number of authors (Hayes and Wheelwright, 1994 maybe is the most eloquent example) but few of them actually prescribe how the function should be organized and managed to achieve it. Proactivity relates to the concept of the resource-based view - it is no doubt desirable, but how to actually go about reaching it? You will not find much about this in the current literature.

Breaking functional barriers is a second example. In turbulent environments, where change is not an exception, but the rule, inter-functional communication becomes essential in order to allow for rapid responses to frequent and sudden changes. The authors in the literature generally agree that for an effective manufacturing strategy to be put in practice it is necessary that functional barriers are broken down. Much of the reengineering discussion gravitates around this aspect. However, few authors in the field of manufacturing strategy deal specifically with methods to operationalize ways to break down or at least reduce the negative effects of the inter functional barriers.

The propositions described here aim to contribute to the manufacturing strategy process development debate addressing specifically aspects such as manufacturing proactivity and inter-functional integration, drawing some conclusions that may help companies operate under the turbulent conditions of the future when dealing with unexpected change is central.

5.1. Change is rule, not the exception

Change is a central concept in managing organisations in the future In recent years, the turbulent industrial/economic environment makes long-term planning a difficult task for many companies around the world. The high and unstable levels of inflation and exchange rates, the constantly changing government industrial policies, high interest rates, the political turmoil in which many countries have found themselves in recent years, the globalisation with constant mergers and acquisitions, the break down of trade barriers, the development of communication technologies, e-commerce and e-business changing drastically the way companies relate to each other and the way companies relate to customers, have forced companies to adopt predominantly "fire-fighting" reactive approaches to management.

Responding effectively to change is a dominant part in the manager's activities of the future. Any framework which aims to be effective in supporting the development of manufacturing strategy has to consider *change* and *dealing well with change* as central concepts. By analysing this reality and at the same time bearing in mind the models found in the current literature, some aspects start to emerge as relevant to be taken into consideration for the development of a framework to help the development of more agile manufacturing strategy in the future:

The internal and external changes affecting the organisation will be so frequent and relevant that *change* should be the main trigger for the strategy reviewing process rather than only time, as the literature generally suggests. Companies cannot afford to wait for, say, 6 months to alter its strategic direction, once a relevant change (such as a drastic change in import taxes affecting the products it makes - favouring competitors or affecting the goods it buys - favouring the company itself) has happened.

Changes may frequently affect so many functional areas that it is impossible that just one or a few of them keep such changes monitored and under control. Each and every function should adopt a proactive attitude, trying to anticipate changes and thinking contingently about possible future changes with regard to its main field of interest. In the literature, although most of the authors advocate the need for proactive manufacturing, most of the frameworks suggested are, in fact, almost totally top-down planning-based tools. No formal means for the manufacturing function to exercise its contribution proactively seems to be provided. They seem to rely solely on people's attitudes in order to make the manufacturing "proactivity" to happen. It seems to be risky though to assume that managers will assume a proactive attitude in the short term, mainly in environments in which the manufacturing managers have historically had a reactive role.

5.2. Two ways of dealing with unplanned change: control and flexibility

There is an extensive literature under the heading "management of change", generally by researchers on Organisational Behaviour who strongly emphasise the management of planned change rather than unplanned change. The literature on Production Operations Management usually deals with the issue of managing unplanned change under a number of different headings. One of them is "manufacturing flexibility". Although very valuable contributions can be found (mainly in the ´80s) in the manufacturing flexibility literature (Browne et. al., 1984; Slack, 1983; Gerwin, 1986; Upton, 1994), since their emphasis is on flexibility, they do not explore sufficiently the fact that unplanned change can also be dealt with by unplanned change *control* - that means avoiding being affected by the changes.

An alternative approach is proposed here, according to which there are two distinct and complementary ways used by managers in order to manage unplanned change in manufacturing systems (Corrêa, 1994):

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, certainty and/or rate of the changes, before the changes.

b. by dealing with the effects of the unplanned change by being flexible which is the ability to respond to the changes left uncontrolled, after they happen.

5.3. Unplanned changes control

Below are some real examples of unexpected change control mechanisms (Corrêa and Slack, 1996).

Monitoring/forecasting - one company (a first tier supplier in the automotive industry), facing turbulent industrial relations, monitors closely the trends of the Labour Unions' behaviour, in order to avoid being taken by surprise by a possible Labour strike. In doing so, the company is trying to reduce the *uncertainty* of some of its unplanned change.

Co-ordination/integration - one company´s (a manufacturer of tractors) engine manufacturing shop reduced its short-term demand changes *uncertainty* by establishing on-line computer links in order to *coordinate* the engine assembly line with the paint shop. With on-line information, the engine assembly line has now accurate and timely information about the car bodies which are coming out from the paint shop and therefore better information about the next few hours' demand for engine derivatives. Now the schedule of the assembly line can be done under less uncertainty.

Focusing/confining - one company´s (a manufacturer of off-road vehicles) manufacturing cells are generally *focused* on making a narrow range of parts. The cell which machines engine blocks, for instance, uses transfer lines to perform only a few slightly different engine block type. This focusing aims at reducing the number of changeovers. Not always however is this possible because there are numerous components which cannot be made in any one of the product-focused cells. In order to cope with this, one cell exists, which is equipped with expensive computer numerically controlled machines and multi-skilled operators, to perform a multitude of different engine components. This way, the need to be flexible is *confined* to one production cell whilst the others work only on a limited range of parts. 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 can be altered.

Delegating/contracting - one company (an auto assembler) had always designed its own diesel engines. However, some years ago, they decided to *delegate* this task, by *contracting* an European expert firm to design the engines, mainly because the technology involved with Diesel engines' design was changing substantially and at a very fast *rate* due to new emission control regulations. The company decided not to have to deal themselves with such changes.

Hedging/substituting - one company (a second tier auto assembler supplier), dealing with erratic supplies, decided to run programs on supplier base reduction and supplier development. However, while the suppliers are not sufficiently dependable, the company decided to keep some of the standard components supplied by a number of sources rather than one or a few, *hedging* against their individual *uncertainty*. Other way to limit the stimuli level is by *substituting* the source of the stimuli, replacing it with a less "changeable" one. This applies to either unreliable suppliers, equipment or workers.

Negotiating/advertising/promoting - one company´s (shock absorber manufacturer) manufacturing plant is running a program of parts standardisation aiming to reduce the variety of parts they manufacture to avoid unnecessary changeovers. Such an effort involves *negotiation* with the plant's internal customer, the marketing function. *Negotiating* is an

attempt to interfere directly with the customer in order to reduce the changes she/he can possibly demand. Another way to interfere with the demand curve shape is by *advertisement* and *promotions*. Promotions and advertisement campaigns are usual ways to stimulate off-peak demand in order to level the overall demand curve, or in other words, to reduce demand change *size* and *rate* along the time.

Maintenance/update/training - Many manufacturing managers use preventive *maintenance* as a desirable way to deal with machine breakdowns, which would be one way to reduce possible equipment availability changes with regard to *frequency* and *size*. The idea of maintenance is not only suitable for machines. The maintenance of computer systems' records to ensure data integrity is other way of exercising control over future changes. Managers also emphasised *training* as an appropriate way of reducing the uncertainty and variability of people's behaviour.

5.4. Flexibility - dealing with the effects of the unexpected change

There are several classifications of manufacturing flexibility in the literature. Slack's (1989) classification seems to be one of the most consistent at the manufacturing strategic level. Slack's flexibility 4 types are product, mix, volume and delivery.

Product flexibility: the ability to develop or modify products and process to the point where regular production can start.

Mix flexibility: the ability to produce a mix, or change the mix of products within a given time period;

Volume flexibility: the ability to change t he absolute level of aggregate output which the company can achieve for a given product mix; and

Delivery flexibility: the ability to change delivery dates effectively

We suggest the definition of a 5th and complementary type of system's flexibility:

"System robustness" flexibility: the ability of the system to overcome unplanned changes either in the process (such as machine breakdowns) or in the input side (such as faulty deliveries).

The need for a 5th systems flexibility type comes from the observation that even a system with high levels of performance in the 4 Slack's flexibility types could lack flexibility to deal with some of the changes which may happen to the process or to the supply side.

Each flexibility type can be understood in two dimensions: range and response flexibility, acording to Slack (1989):

Range flexibility would be the ability of the system to adopt different states. One production system will be more flexible than another in 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 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 and/or organizational disruption. The way the system moves from one state to another would define Slack's other flexibility dimension, *response* flexibility.

Agile manufacturing strategies will have to treat flexibility (in its different types and dimensions) as a central concept. That is a fact. We suggest here however that there must be some sort of baseline stability for the manufacturing systems to be adequately flexible to deal

with the changes to which it is increasingly subject. This means that in any manufacturing strategy exercise managers should have flexibility as a central concept, however they also should decide what kind and intensity of changes they are willing to deal with flexibly and what kind and intensity of changes they would prefer to "filter" or control via unplanned change control mechanisms. It means that being flexible is desirable, but since it normally comes at some cost, it is important to consider at least as a managerial tool, the possibility to limit the changes with which the company is willing to deal.

6. BASIC ELEMENTS FOR AGILE MANUFACTURING STRATEGY

A general approach is now proposed to the formulation of agile manufacturing strategy. Because of the huge variety of particular situations different manufacturing companies face, we consider that it is impossible to prescribe a step-by-step generic method for companies to develop their manufactruing strategies. However it is possible to outline, based on the previous discussions and concepts, some features, some foundations on which the companies should base the development of their manufacturing strategies in order that they face the challenges of the furture. Some of these features are described below.

6.1. Flexibility is central; and so is change control

Given that change is a central concept in the manufacturing management of the future, manufacturing strategies have to treat change management with the corresponding priority. Change is so broad a concept and so variable change may be that companies will normally prefer to prepare for having a certain level of "protection" against some types / levels of change. This is convenient among other reasons because there are environmental chages which affect the whole market (giving an edge to companies who outperform competitors in dealing with them - such as the unexpected requirement of a customer for a product customisation) and changes affecting only the company under analysis (such as changes in the availability of human resources because of high or uncertain turnover rates) - therefore only having the potential to hinder competitiveness. The right balance between control and flexibility should be sought for by companies who decide to strategically manage manufacturing in the 2000s. Being flexible is no doubt increasingly desirable but it seems that in order to achieve effective flexibility some level of baseline stability should be present. Change control mechanisms may be a valuable resource for companies to achieve this baseline stability.

6.2. Breaking barriers through customer-supplier negotiation

Breaking organisational barriers is absolutely essential for the company to adapt and respond effectively and as a coherent whole to changes.

In order to break down the organisational barriers, the approach proposed here is based on negotiation between the functions on a "customer-supplier" basis. The basic assumption is that everybody in the organisation has customers (either internal functions or external customers) and should serve them in the best possible way, given the constraints imposed by the availability of resources and also bearing in mind the corporate objectives, policies and strategy. Customer and supplier functions should negotiate and agree on the levels of service or goods which the supplier is to provide. They have to agree on a specific set of performance criteria which represents the "point of contact" between the two functions. The "negotiation", it is suggested, can be based on "gap analysis" between the required (by the customer function) set of performance criteria and the set which is "offered" by the supplier function. The "point of contact" between marketing and manufacturing, for instance (the one emphasised in figure 3) may be the list of prioritised *order winning* and *qualifying* criteria (levels of delivery, product quality, costs and flexibility) which manufacturing should pursue (borrowing from Hill's (1995) framework). Between other pairs of functions, other "points of contact" are

required, although the particular pairs of functions should negotiate and agree on their particular points of contact. Between manufacturing and finance, for instance, the relationship customer-supplier can be defined by the service which finance supplies manufacturing: availability of capital over a period of the time. Therefore, one aspect, which has to be agreed upon, is the capital cash flow to be made available to manufacturing.

6.3. The time-phased approach

The points of contact or, in other words, the points which have to be agreed upon between customer and supplier, are not related to a single point in time, either present or future. Instead, they should be "time-phased". This helps the functions agree not only upon objectives on a future point in time but also on the path through which the company will go about reaching some future competitive situation, stage by stage. The list of prioritised competitive criteria is no exception. Competitive criteria and also the other "points of contact" should be considered on a "time-phased" basis. The idea of improvement paths is present here and given the implications of these choices for the knowledge base of the company (Teece and Pisano, 1994), it is suggested that this process is carefully monitored to avoid local optimisations and wrong improvement path choices.

6.4. Proactivity achieved by using scenarios: the role of "contingency models"

In the proposed approach, proactivity is achieved through the explicit consideration of future possible alternative scenarios by all functions. In order to develop these scenarios, the function representatives and analysts have to be aware of current and prospective developments in their fields of interest. In the negotiation process, people from other functions will eventually demand alternatives from them in order that they are able to achieve a better performance in their own functions. Manufacturing people, for instance, will demand from finance people that they are able to offer alternatives for obtaining cheaper capital, in order to make investments. Marketing people will demand alternatives of possible future sets of competitive performance levels with regard to delivery, quality, costs and flexibility in order that they can choose from a broader array of markets to be targeted in the present and in the future. This should motivate the representatives from the different functions to act proactively, in search of new alternatives in their specific fields. For the people within the particular functions to be able to devise scenarios, and also for them to be able to negotiate with other functions, they have to develop what we call "contingency models". Contingency models are defined here as formal conceptual models which link possible present and future contingencies (characteristics, actions and decisions) with the various "points of contacts" between the function and other interacting functions. In terms of the manufacturing-marketing interface, manufacturing people should develop contingency models which associated possible future decisions and actions (such as investments in equipment, hiring and training of people, adoption of control systems, developing particular capabilities, among others) with the resulting alternative set of order winning and qualifying criteria. This would require that manufacturing people monitor and acknowledge new developments in production processes in order that they are able to assess the possibility of attending or not to the marketing "time-phased" requirements and also to produce alternative scenarios for them. Marketing people, on the other hand, should develop contingency models which should allow them to associate sets of order winning and qualifying criteria with different market segments, in order that they are able to reformulate marketing plans (target-market, frequency of new product introduction, among others) given that some change happened in the possible set of "time-phased" competitive criteria which the manufacturing function is able to provide either in the present or in the future.

The contingency model approach is in line with the resource-based approach - capabilities may be proactively developed but what resources and capabilities to develop will be the result

of an interactive discussion process to guarantee consistency between resource and capabilities development and strategic directions.

Figure 3 illustrates the negotiation process and Figure 4 is an example of worksheet for the operationalization of proactivity of the various functions. For an example of an application of this concept in a real situation, see Prochno and Corrêa (1995).

6.5. The consideration of dynamic trade-offs and dynamic paths of improvement

Basically when considering the development of manufacturing strategies one has to be concerned with strategic fit (between the manufacturing task required to win orders in the market place and the manufacturing capabilities) and focus. As already discussed in previous sessions of this chapter, the rationale behind these two concerns is the existence of trade-offs between different aspects of manufacturing performance. The concept of trade-offs is actually not a new one. It has been present since the early works published in the field of manufacturing strategy. What has some novelty is the idea that trade-offs are dynamic. What we propose here is that the analysis of strategic fit and focus in the developmente of agile manufacturing strategies are done considering carefully the dynamics of trade-offs involved and the alternative dynamic paths the company can go through (see section 2.2.).

Hayes and Pisano (1996) have indicated that these paths may have an important effect in the knowledge base and on the learning experience of the company. The knowledge base is directly linked to the capabilities and competencies of the company and competence-based (or resource-based) approaches seem to be increasingly important to compete in the turbulent environment of the future in which the planning or top-down approaches tend to become more difficult to use because of the difficulties to anticipate changes. On top of that several authors in the literature argue that managerial rationality (planning) on which the traditional manufacturing strategy paradigm is based (the more traditional notions of strategic fit and focus) can not by itself result in a sustainable advantage because it would be too easily copied.

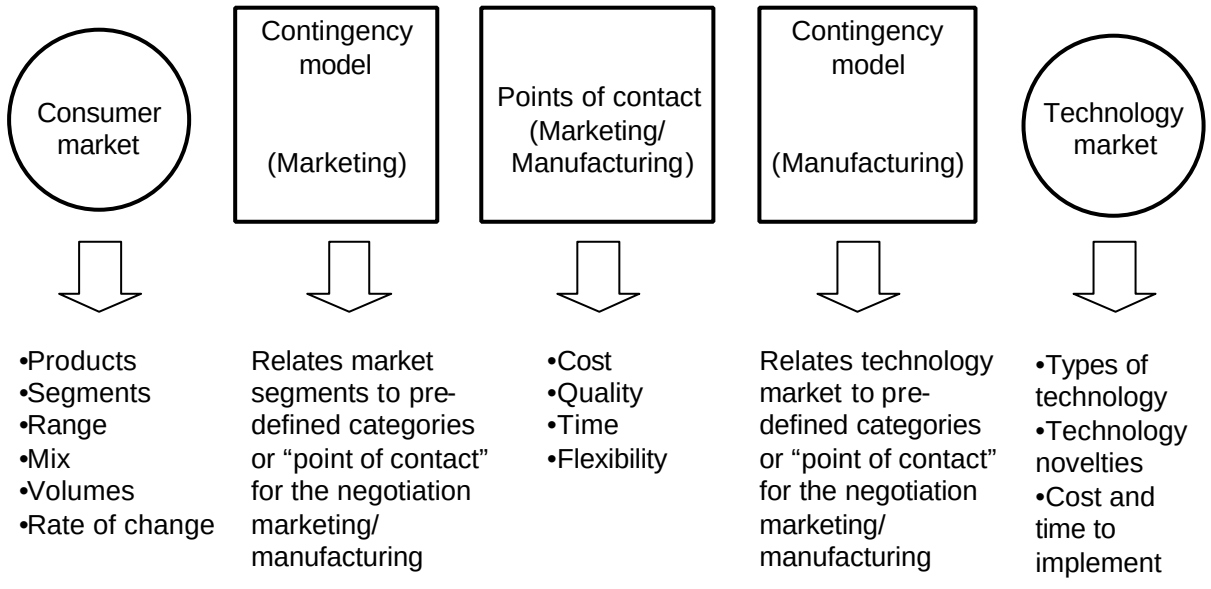

Figure 3. Negotiation Process for the operationalization of proactivity - example for the marketing / manufacturing interface (Prochno and Corrêa, 1995)

Example of worksheet for building contingency models

Function: _____

Scenario A

Main Characteristics:
Cost&resouces required to have it operational:
Time to implement:
Future decisions and actions:
Reflex in criteria:
Criteria A - _____; Criteria B - _____; ... Criteria n - _____
.
.

Scenario X

Main Characteristics:
Cost & resouces required to have it operational:
Time to implement:
Future decisions and actions:
Reflex in criteria:
Criteria A - _____; Criteria B - _____; ... Criteria n - _____

Figure 4 - Example of worksheet for building contingency models (Prochno and Corrêa, 1995)

According to this idea, for the company to achieve real distinctive capabilities management should start paying more attention to the repertoire of organisational routines - which are actually the carriers of knowledge and experience an organisation has (Alher, 1998). Although this may be only partially true (since these repertoires are difficult and time consuming to change and in a turbulent environment, sometimes companies have to perform sharp turns in direction), this is in line with the porposal that dynamic improvement paths are considered and that a time-phased approach is adopted, together with the customer-supplier continuous negotiation because they all have impacts on the organisational routines.

6.6. The replanning process - triggered by relevant events and time

In the proposed approach the replanning process can be triggered by relevant events and time as opposed to that triggered only by time as the main frameworks in the literature suggest. This can prevent the company from delaying to respond to relevant changes which occur between replanning points in time. The replanning process can also be triggered by any function which considers that something relevant has changed or may come to change relevantly in his field of interest. A sudden and significant change in import rates is typically a change which can trigger a replanning process in order that the whole of the company realign their efforts in face of the new situation brought about by the change. The worksheet explained in the last section (see Figure 4) helps to formalize the process: the function that wants to trigger the replanning process fills in the worksheet and send it for the other functions; a meeting is then set to decide the need for a strategy review or just minor adjustments to the new reality.

7. SUMMARY

The manufacturing environments of the present and of the next decade differ substantially from the past. Technology and consumer markets have become extremely difficult posing difficulties for the use of traditional top-down planning-based methods for developing manufacturing strategies. More agile manufacturing strategies are needed in an environment in which dealing with change becomes the central point. In this chapter we discussed some

aspects which are increasingly important to be taken in consideration in the development of more agile manufacturing strategies:

It is actually very difficult that companies are able to develop flexibilities enough to deal with the whole envelope of changes it is subject to. We argue therefore that in order to achieve a basic baseline stability upon which to develop flexibilities, companies should direct some efforts to define what types and what magnitude of changes they are willing to be able to deal with. We develop the concept of unexpected change control which are management mechanisms which help the company limit the changes with which it intends to cope with flexibly. The types of unexpected change control are: monitoring/forecasting, co-ordinating/integrating, focusing/confining, delegating/contracting, hegding/substituting, negotiating/advertising/promoting and, maintaining/updating/training.

Breaking down organisational barriers is another feature which will have to be taken care of carefully in the development of manufacturing strategies in the next decade. We propose an approach which is based on internal and external customer-supplier negotiations on levels of service which the supplier is to provide. This will add to the still prevalent functional organisation of most companies the process orientation needed to quickly react to internal and environmental changes.

Another feature we propose is that this customer-supplier negotiation is done on a time-phased fashion in order that the dynamic paths of improvement are incorporated in the process - not only gap analysis (comparing present state and desired future state) is taken into account, but also the time-phased evolution of the improvements which will take from the current state to the desired future state.

The turbulent environment of the future will require that all functions within the company adopt a proactive stance. Proactivity in the proposed approach is achieved by using scenarios and what we defined as "contingency models" - these are tools which can help companies to achieve the desirable levels of proactivity in a systematic way, rather than by leaving it purely for the initiatives of the individuals involved.

We also propose that any manufacturing strategy in the future should be subject to more frequent reviews. The static model in which it is reviewed periodically, say every year does not seem to be adequate for the turbulence of the future - so we propose that reviews of the manufacturing strategy should be triggered by both - time and possible relevant events which might happen between default review periods.

Finally we also propose that the traditional analyses of strategic fit and focus will still have to be done since there is no such thing as "one best way" for managing manufacturing resources. However, these analyses should be done considering all the dynamics of the trade-off relationships between different aspects of manufacturing performance and also the dynamic paths of improvement which will directly impact the knowledge base and therefore the future competencies of the company.

REFERENCES

Alher, F. (1998) *A strategic model of operational performance improvement*, Ph.D. Thesis, University of Warwik Business School, U.K.

Browne, J. et al. (1984) Classification of Flexible Manufacturing Systems, *The FMS Magazine*, Vol. 2, No. 2

Buffa, E.S. (1984) *Meeting the Competitive Challenge*, Irwin

Chase, R.B., N.J. Aquilano and F.R. Jacobs (1998) *Production and Operations Management* (8th Ed) Irwin McGraw-Hill

Corrêa, H.L. (1994) *Linking flexibility, uncertainty and variability in manufacturing systems*, Avebury, Gower Publishing, U.K.

Corrêa, H.L. and N.D.C. Slack (1996) Framework to analyse flexibility and unplanned change in manufacturing systems, *Computer Integrated Manufacturing Systems,* Vol. 9, No. 1, London

Crosby, P. (1979) *Quality is Free*, McGraw Hill

Fine, C.H. and A.C. Hax (1985) Manufacturing Strategy: A Methodology and an Illustration, Working Paper, Sloane School of Management, MIT, Cambridge, Massachusetts

Gerwin, D. (1986) An Agenda for Research on the Flexibility of Manufacturing Processes, *International Journal of Operations and Production Management*, Vol. 7, No. 1

Goldhar, J.D. and M. Jelinek (1983) Plan for Economies of Scope, *Harvard Business Review*, Nov-Dec

Gregory, M.J. and M.J. Platts (1990) A Manufacturing Audit Approach to Strategy Formulation, *Proceedings of the 5th International Conference of the Operations Management Association U.K.*, University of Warwick, Vol. 2.

Hayes, R and G. Pisano (1996) Manufactruing strategy: at the intersection of two paradigm shifts, *Production and Operations Management*. Spring

Hayes, R.H. and S.C. Wheelwright (1984) *Restoring Our Competitive Edge*, John Wiley

Hayes, R.H., S. Wheelwright and K. Clark (1988) *Dynamic Manufacturing*, The Free Press

Hill, T. (1995), *Manufacturing Strategy - Text and Cases*, Irwin

Leong, G.K., et al. (1990) Research in The Process and Content of Manufacturing Strategy, *OMEGA, International Journal of Management Sciences*, Vol. 18. No. 2

McKeena, R. (1997) *Real Time*, Harvard Business School Press

Pisano, G. (1997) *The development factory*, Harvard Business School Press

Porter, M (1980) *Competitive strategy*, Free Press

Prahalad, CK and G. Hamel (1990) The core competence of the corporation, *Harvard Business Review*, May-June

Prochno, P.J.L.C. and H.L. Corrêa (1995) The development of manufacturing strategy in a turbulent environemnt, *International Journal of Operations and Production Management*. Vol. 15. No. 11

Schonberger, R. (1986) *World Class Manufacturing* The Free Press

Shingo, S. (1985) *A Revolution in Manufacturing: The SMED System*, Productivity Press

Skinner, W. (1969) Manufacturing - Missing Link in Corporate Strategy, *Harvard Business Review*, May-Jun

Skinner, W. (1974) The Focused Factory *Harvard Business Review*, May-Jun

Skinner, W. (1985) *Manufacturing: The Formidable Competitive Weapon*, John Wiley

Skinner, W. (1996) Manfacturing strategy in the "S" curve, *Production and Operations Management*, Spring.

Slack, N.D.C. (1983) Flexibility as a Manufacturing Objective, *International Journal of Production and Operations Management*, Vol. 3, No. 3

Slack, N.D.C. (1991) *The Manufacturing Advantage*, Mercury, London

Stecke, K.E. and N. Raman (1986) Production Flexibilities and Their Impact on Manufacturing Strategy, Working Paper No. 484, Graduate School of Business Administration, University of Michigan

Teece, D. and Pisano, G. (1994) The dynamic capabilities firms: an introduction, *Industrial and Corporate Change*, Vol. 3, No. 3

Upton, D. (1994) The management of manufacturing flexibility, *California Management Review*, Vol. 36, No. 2