Artigo / Article
02

Framework to Analyze Flexibility and Unplanned Change in Manufacturing Systems

Língua / Language

Corrêa & Associados Estratégia de Manufatura e Serviços

R. da Consolação, 3367 – cj. 11 – São Paulo – SP – Brasil
CEP: 01416-001 – Tel./Fax: 55-11-3088-3291

Framework to Analyze Flexibility and Unplanned Change in Manufacturing Systems[1]

Henrique Corrêa and Nigel Slack
University of São Paulo and University of Warwick Business School

Abstract

The objective of this paper is to develop a conceptual framework aiming at helping to understand, analyze and manage what will be termed here the "unplanned changes" which affect the manufacturing system's operations within organizations.

In order to attain this objective, both the relevant literature and a field study 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 having to deal with the changes whereas *flexibility* is related with the decisions and actions which aim at dealing with the effects of the unplanned changes which are left "uncontrolled".

The literature, overall research direction and methodology

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 in manufacturing systems".

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 outline a theory-build exercise by constructing a model which reflects, organizes and possibly expands the perception of the managers of a number of manufacturing organizations, regarding the aforementioned variables and their inter-relationships. However, establishing research questions can 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 revisit the literature in this and related fields.

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

[1] Published in Computer Integrated Manufacturing Systems, Vol 9, Number 1, 1996

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) previous 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. According to Carter (1986), manufacturing flexibility could also be developed as an "insurance" against process short term uncertainty (Stecke and Raman, 1986).

The variability-flexibility relationship.

Variability together with uncertainty has formed the theoretical 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 with flexible systems 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, presently and for the foreseeable future, 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) propose some basic links between different types of variety and corresponding types of flexibility.

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) 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.

General comments on the literature

Although the existence of some kind of relationship between the three concepts - *variability, uncertainty* and *flexibility* is broadly 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 should be 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 further the above mentioned mechanisms as 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.

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[2] some propositions which emerge from the literature and are related to the research question. The propositions are listed below[3].

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).

---

[2] 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 unprovable: they can be tested by systematic attempts to refute them. (Popper, 1990)

[3] The 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.

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) .

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*[4].

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.* Taking the criteria into account, the general approach used in the present research work is predominantly qualitative, and the research design is case-studies. For details of the research method selection process, see (Corrêa, 1992).

To summarize what this means is:

1. A number of case-organizations were 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 was be used in the interviews.

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

---

[4] 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.

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' flexibility) which contributes most directly to the 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[5], 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 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 machine shop in a highly bureaucratic organization).

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 (to whom we are indebted), who had previous contacts with the case-companies. The access to Brazilian companies was possible because of contacts previously established by the one of the authors when working 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.

The Brazil/UK factor

The non-uniformity of the sample, in terms of the countries where the companies are located, 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[6]. 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

---

[5] 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).

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

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.

Number of cases

The number of cases was determined by research resource constraints: the number of researchers available[7], the length of the research project, the available time of the researchers 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 in depth apart from other 4 companies, more briefly analysed at the research pilot phase.

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. Such relative 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.[8]

The case studies were done based on semi-structured interviews with a number of managers within the organizations. The number of people interviewed varied from company to company (although in all companies at least 5 managers were formally interviewed), depending on the specific organizational structure, on their availability and willingness to cooperate. The companies choosen will be called A, B, C and D. Some of their characteristicas are mentioned below:

Company 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 research focuses in the engine manufacturing plant within Company A.

Company 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.

Company 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.

Company D - The British Vehicle Manufacture: 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

---

[7] 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.

[8] 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".

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.

Four more companies were analysed, 1 in England and 3 in Brazil when the researchers were refining the research instrument. They formed the pilot research sample. All of the pilot research companies were also in the batch range and either were automobile assemblers or suplied for the automotive industry.

Research results

Analysis of the 6 research propositions

The six research propositions formulated from an analysis of the literature are now discussed based on the elements drawn from the case studies.

> ***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 could 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 different 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 being quite 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 severe uncertainties within the process (machine breakdowns and Labour absenteeism, for instance) and with the input side (e.g. unreliable supplies), 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 quickly fetch the necessary spare parts in the off-the-shelf 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 which 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). On the other hand, other managers 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 is also dependent on the ability of the structural resources - labour and machines - to switch between activities). However, when dealing with flexibility at the system's 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 framework to refer to, when discussing the different types of system's flexibility. When introduced to Slack's (1989) framework (according to which the manufacturing system's 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 research instrument (for details, refer to Corrêa, 1992).

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 variety of answers the mangers gave with regard to best ways to deal with different types of uncertainty and variability of outputs. The manager's answers show different flexibility-related ways which they 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 strongly 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 to which their systems are subject 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 studies. Invariably the managers would show a preference for reducing the levels of uncertainty which 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 use flexibility-related characteristics 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/predictive maintenance procedures as opposed as to carry on buffer stocks or to invest in quick corrective maintenance. Another situation in which the preference for unplanned changes control was clear refers to the uncertainty with the supplies. All the companies' managers showed preference for 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 assembles 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 (restraining), 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 to cope with internal uncertainties, poor communication, excessive or unnecessary variety of component parts, or any other imperfection regarding the inputs and process which are under the organization's control.

Some developments from the analysis of the research propositions

Some authors (Slack, 1989; Gerwin, 1986, among others) have suggested that flexibility is needed in order to deal with the uncertainties and the variability of outputs which are always present to some degree in manufacturing systems.

From the case studies, however, it was noticed that, at the level of analysis[9] 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 therefore 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 *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] The level of analysis is the level of production units

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/respond, 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 management 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 some 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 change (planned).

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.

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 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, calls for the flexibility of the manufacturing systems, at the level of analysis we are interested.

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.

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 presents some examples from the field study.

Types of stimuli identified in the field study

Novel changes - the marketing function of a Brazilian heavy military equipment manufacturer (one of the 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 problems 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.

Frequent changes - company A, which manufactures engines, usually 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 frequency

Unpredictable or uncertain changes - 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).

Large changes - 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.

***Figura size

Quick changes - Change in demand volume is one of the main concerns for Company C's managers. 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.

***Figura rate

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.

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.

Managers dealing with change

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. 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.

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 was confirmed by the field work developed in this research. 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.

In the context of this research, the term "control", when associated with change or one of its dimensions, means simply "a means of restraining or regulating"[10]. 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.

Examples of the use of unplanned change control and flexibility from the field work

When asked 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 replacement 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 variety of parts and products, and in doing so,

[10] According to The Oxford Paperback Dictionary, Third Edition. Oxford University Press. Oxford, 1988.

avoiding the need to cope with such variety. 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.

	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.

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.

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. Company A, for instance, has its engine plant organized in manufacturing cells[11]. 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 manufacturing 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.

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

[11] Groups of machines, generally in charge of completing one or some families of parts. See Burbidge (1989) for details.

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 can be 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[12] 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, for example, also have a rich research literature, but each of them, unfortunately, is invariably treated in isolation.

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, certainty and/or rate 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).

[12] Slack (1987) identified that managers would try to avoid being flexible, in his empirical work. He however does not explore this idea further.

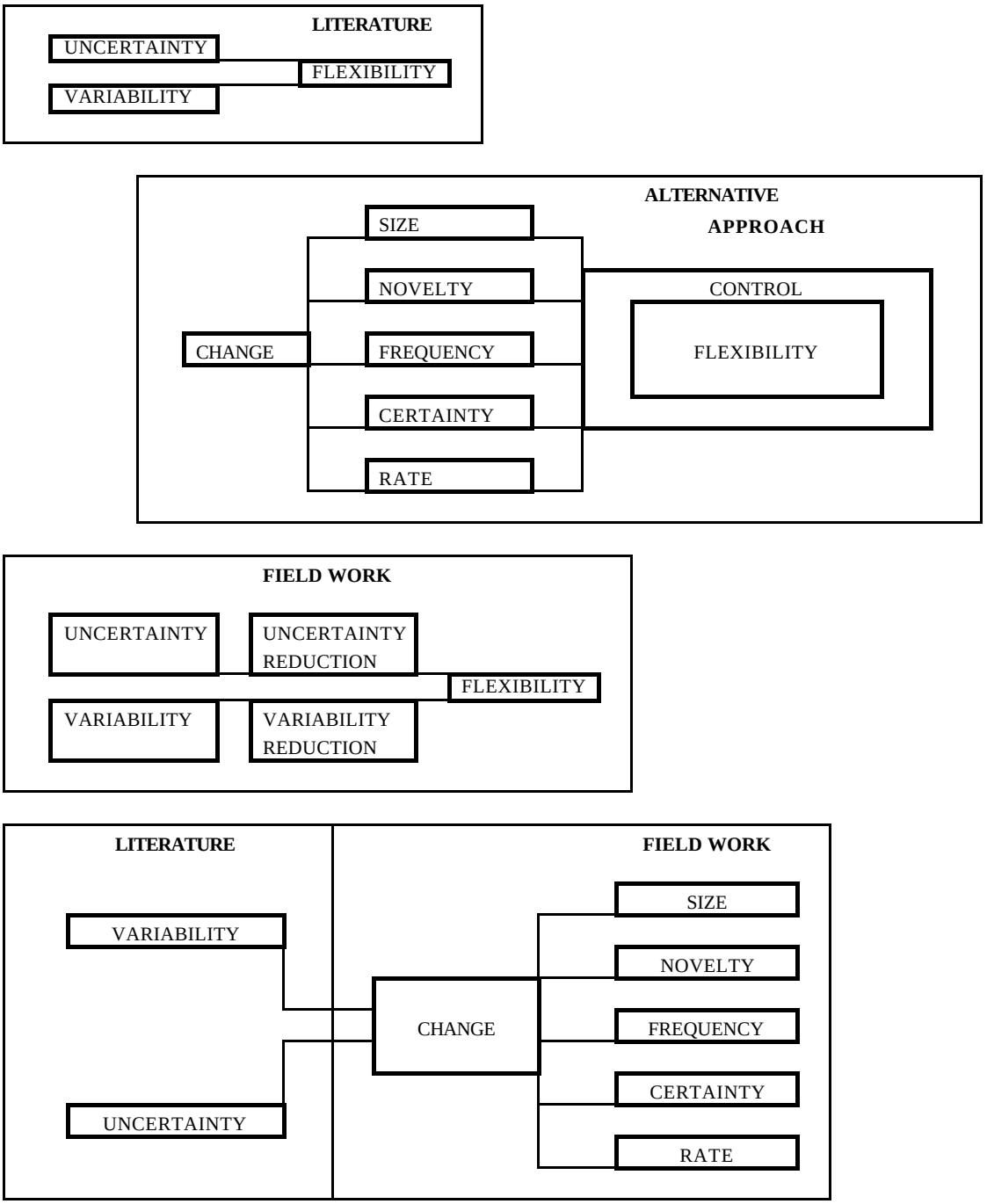

Figure 9.11 - Schematic development of the proposed alternative approach for stimuli management.

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.

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[13] in order to coordinate downstream demand with upstream operations, using visual techniques such as Kanban cards[14]. 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. ***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[15], 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

---

[13] Production control systems in which downstream operations' consumption of materials triggers upstream operations' production, "pulling" material throughout the production process.

[14] See Schonberger, 1982 for a detailed description of the Kanban technique.

[15] 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).

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 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. 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:

	monitoring/forecasting coordinating/integrating

Control types	focusing/confining delegating/subcontracting hedging/substituting negotiating/advertising/promoting maintaining/updating/training

Unplanned change control types identified in the field work.

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"[16]. 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 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.

---

16 "The capacity to continue functioning effectively despite the change" (Mandelbaum, 1978).

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:

<table>
<tr><td rowspan="6">System flexibility types</td><td>New product</td><td rowspan="6">primarily related to changes</td><td rowspan="5">in the output side</td></tr>
<tr><td>Product mix</td></tr>
<tr><td>Volume</td></tr>
<tr><td>Delivery</td></tr>
<tr><td>System robustness</td><td>in the input side and in the process</td></tr>
<tr><td rowspan="2">System flexibility dimensions</td><td>range</td><td rowspan="2">related to the change dimensions</td><td>size
novelty</td></tr>
<tr><td>response</td><td>frequency
certainty
rate</td></tr>
</table>

Detailing the alternative approach: system flexibility types and dimensions.

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.