LINKING ENTERPRISE FLEXIBILITY TO STRATEGIC OPTIONS: A CONTROL PROBLEM APPROACH

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Abstract- In order to operate effectively manufacturing enterprises must be able to coordinate and utilize their limited physical and managerial resources effectively in an effort to deal with uncertainty and complexity, following certain strategic enterprise guidelines. Manufacturing enterprises must be able to acknowledge the tensions between flexibility and stability forces operating within them, and then manage them in a way that best reflects their strategic options. This paper looks at manufacturing enterprises as complex, dynamic systems which ought to operate under certain strategic guidelines and constraints in order to be both effective and efficient, and at the same time, ought to be flexible enough to be able to deal effectively with perturbations, generated both within and outside the system, which affect the enterprise system differently, in order to guarantee, on the one hand, effectiveness and stability of operations, and the achievement of enterprise strategic objectives on the other.

In this control problem approach to enterprise flexibility we go to a higher level and examine how both properties, flexibility and stability, depend on what we call the metacontrollability of the enterprise system, that is the control of the very enterprise control system, the role of management in the metacontrollability of the enterprise, and how these control actions, which determine when, where and how much flexibility is applied, are linked to specific strategic needs and objectives that reflect the strategic options of the enterprise, which in turn must be part of the enterprise strategic framework at the operational, business, and corporate level respectively.

Keywords: Control system, Metacontrollability; Change and Flexibility; Stability; Strategic options; performance measurement

1. INTRODUCTION

In order to operate effectively, manufacturing enterprises must be able to coordinate and utilize their limited physical and managerial resources to deal with uncertainty and complexity, following certain strategic enterprise guidelines. Manufacturing enterprises must be able to acknowledge the tensions between flexibility and stability forces operating within them, and then manage them in a way that best reflects their strategic options.

This paper looks at manufacturing enterprises as complex; dynamic systems which need to operate under certain strategic guidelines and constraints and, at the same time, ought to be flexible enough to deal effectively with perturbations, generated both within and outside the system, which affect the system differently. In order to guarantee on the one hand effectiveness and stability of operations and, on the other hand, the achievement of the enterprise strategic objectives, we can think of the manufacturing enterprise as a dynamic

system in constant need of control, coping with both the need to be flexible and malleable in order to change and adjust itself in different orders of magnitude and frequency upon requirements being impressed upon it, and at the same time, the need to be robust and steadfast in order to maintain order and regularity of operations, in order for the system to hold itself together even when it is called upon to act in such a way as to push itself to the limits.

This control system and its hierarchy, which we will explain later, are in turn responsible for controlling the behavior and performance of the enterprise system at every level, accounting for and managing the stability and flexibility requirements that arouse within the system continuously as operations go on in the every day life of the enterprise. In our control system approach to enterprise flexibility, we view flexibility and stability as desired properties of the manufacturing enterprise and both are equally important and necessary for the enterprise system to be viable.

We will define now what we mean by Flexibility and Stability, as desired properties or qualities of the enterprise system.

Flexibility: it is first of all the capacity of an enterprise to respond to change. It is also the property of an enterprise system to be malleable and capable of adjustment in order to change and accommodate its operations to scenarios or environments other than those for which it was specifically designed. The need for flexibility arises when the enterprise system is faced with requirements which are exerted upon it which demand actions that go beyond the scope of its regular operations environment. The flexibility of a system may also be viewed as the capacity of an enterprise system to be managed or controlled successfully in order to meet its objectives, being capable of withstanding stress and strain without causing significant cost or any other type of impair or prejudice to the enterprise.

Stability: it is, on the other hand, the quality or attribute of an enterprise system of being firm and steadfast in maintaining regularity of operations even upon extreme conditions. It may also be viewed as the quality or property of an enterprise to preserve its equilibrium when undisturbed (or only slightly disturbed) but able to pass to a more stable equilibrium when sufficiently disturbed. In sum we may say that stability is the quality or property of an enterprise system to maintain its course in spite of forces acting upon it. This of course means that the enterprise is capable of maintaining its course and regularity even after incurring in major adjustments to withstand change.

In this control problem approach to enterprise flexibility we go to a higher level and examine how both properties, flexibility and stability, depend on what we call the metacontrollability of the enterprise system, the role of management in the metacontrollability of the enterprise, and how these control actions, which determine when, where and how much flexibility is needed at any one time, are linked to specific strategic needs and objectives, which are part of the enterprise strategic framework at the operational, business, and corporate levels respectively.

It is management the one which is called upon to establish the right balance between stability and flexibility in the enterprise, understanding that both are desired properties or

qualities of the system, which must be engineered in the enterprise system itself, not added onto and which do not oppose one another. Likewise, stability is just as important as flexibility, and stability may not be taken for granted as it is false pretense to assume that enterprise system's stability is the normal state of affairs, which occurs in the absence of flexibility, just as it is also false to assume that in the absence of change there will automatically be stability in the system.

1.1 The Metacontrollability of the Enterprise

Metacontrollability, as the term signals, is the highest level of control within the enterprise, the control of the enterprise's control system, and it rests basically on the shoulders of enterprise management. It is indeed the control of all other control layers of the firm, and it is responsible for coordinating, amalgamating and effectively leveraging the multiplicity of control actions taking place and resources being used at any one time in the manufacturing enterprise, whether these may be managerial, infrastructure, organizational and cultural, technological or strategic, in order to secure a coherent and successful use of the enterprise's limited physical and managerial resources to deal with uncertainty and complexity following a set of specific strategic guidelines, normally laid out on the enterprise's mission and vision statements.

As we all know there are multiple instances of control within a manufacturing enterprise, designed for very specific purposes and they are found in every level and area of the company, yet there must be a higher level of control, one which is above all other layers, and which makes sure that the enterprise system as a whole works in a way that satisfies the ongoing need for flexibility and stability within the firm, thus making it possible for the enterprise to deal effectively with uncertainty and perturbations affecting the organization, yet securing continuity of operations amid the various actions and changes in the operations taking place, aimed at providing greater flexibility for the firm to achieve its objectives.

1.2 Management of Uncertainty and the Organization

Manufacturing organizations are essentially open, living systems, which are constantly faced with various forms of uncertainty, instability and complexity, yet requiring continuity/stability, clarity of purpose and an adequate degree of flexibility at every level of the enterprise system to operate in a rational manner, as it has been pointed out by Slack (Slack, 1997 and 1987). Change and uncertainty in its various forms are familiar ghosts to enterprises of all types, yet a complex concept not always straightforwardly linked to flexibility, as the different approaches in literature show. In the case of uncertainty, flexibility can be seen as coinciding with the ability to deal with the unexpected, both within the manufacturing enterprise and outside (De Toni and Tonchia, 1998). The main issue appears to be whether the measurement of uncertainty is adequate for either perceived or objective approaches (Swamidass and Newell, 1987) and more recently the effort to link various forms of flexibility to the enterprise's strategy. The objective measures of uncertainty are classified and scaled based on the environmental conditions

and perturbations surrounding the enterprise system. Environmental uncertainty has been argued to be one of the main reasons for a firm to seek flexibility (Gerwin, 1987; Slack, 1989), and some researchers provide empirical support for such assertion (Swamidass and Newell, 1987), yet little attention has been given to sources of variation and the uncertainty emanated from it within the enterprise system itself.

The manufacturing enterprise is described as a complex system (Pritsker, 1990). Change and uncertainty and the tensions derived from them are all around us all the time. This is particularly true in a manufacturing environment, where resources at every level of the enterprise try to cope with ever changing conditions imposed by inside forces and by the system interaction with its environment. It is no doubt that the challenge of coping with change and the uncertainty derived from it begs the question of how much flexibility is needed and how do we apply it. It assumes that most of the managerial problems created by change derive from its nature and rate, but it is apparent that we cannot deal with change effectively unless we understand its nature (Ackoff, 1981). The problem of change and uncertainty affecting organizations and the way to deal with them from a systems' theory stand point have also been analyzed extensively by authors such as Chris Argyris (Argyris, 1973 and 1985), Carlsson (Carlsson, 1989) and by Alvin Toffler in The Adaptive Corporation (Toffler, 1985), correctly asserting that organizations need to be designed to deal with internal and external factors that cause perturbations effectively. That is to say, they must have flexibility as well as stability incorporated as properties of the enterprise system itself, inherently operating in the system as a whole, and being determined at all times not but independent forces but by the elements which comprise the control system of the enterprise. Hence if we want the enterprise system to transit from stable to flexible mode and vice versa quickly and effectively, we must make sure that the control system is engineered in such a way as to satisfy these requirements.

1.3 Establishing the right balance between Flexibility and Stability

Organizations no doubt need stability as much as they need flexibility in order to operate, because if everything about the organization were to be always changing or change without latitude, the organization would be crippled by chaos and disarray. Hence some aspects of organizations must change in a controlled fashion when it is necessary to do so, making it possible for the enterprise system to survive, and even exploit the benefits of changes both inside the organization and in its environment. We can try to understand how to establish the right balance between enterprise flexibility and stability, by looking at the manufacturing enterprise as a control system. Thus depending on the need or objective being presented upon the system, the enterprise alternates between flexibility and stability phases all the time, in different measures and extent, depending on the situation being faced. Furthermore, we assert that the system needs to apply its different types of flexibility constructs to compensate for uncertainty and risk at different levels of the system, but always in correspondence with the strategic needs and objectives of the enterprise. This is in our view the ultimate proof of enterprise flexibility's effectiveness.

The importance of flexibility management for organizational effectiveness may not be

underscored. We cannot cope effectively with uncertainty and change unless we develop an appropriate set of flexibilities of different types and metrics, and at the same time we have to make sure that these flexibility types and metrics are in tune with specific set of strategic options, which are part of the enterprise global strategic model. Flexibility is desired in order to handle uncertainties and variations in both internal and external environment (Ramasesh and Jayakumar, 1991). It has been correctly asserted that flexibility is a multi-dimensional concept (Gerwin, 1993; Upton, 1994), and like agility and simplicity, it is also a property of manufacturing enterprises that can be interpreted and measured differently (Upton, 1995) at different levels of an enterprise system, and as it has been said, it holds a different meaning at different levels of the enterprise system depending on the means by which it is to be achieved (Cheng et al., 1997).

Since at any point in time there are multiple situations and conditions affecting the enterprise system, and these are associated with different levels of uncertainty and variations, therefore they call for different sorts of flexibility at different levels of the enterprise system. These levels are impacted by the different elements which comprise the organization. Flexibility is generally seen by some authors as a situation specific in nature (Gupta and Buzacott, 1996). Gerwin (1993) advocates the need for further research to be aimed at an applied orientation, and the need to link flexibility (in terms of the methods and technology used), as well as to the benefits they carry in different situations. Correa (1994) when referring to the manufacturing system, requests that a clear link be made between desired or required system flexibility levels, and the resources necessary to achieve them. These resources, in our view, are those which must be engineered in the enterprise as parts of its control system. The enterprise control system is responsible for providing the necessary flexibility and stability to the system when it needs it and, at the same time, it controls how much of both are needed over a certain time frame. Hence it is none other than the control system of the enterprise, the key element which determines the enterprise system viability by generating the necessary control actions to attend the enterprise's flexibility and stability/continuity requirements and it achieves this by operating its different components at different levels of the enterprise system, thus generating the said control actions that account for and manage the various disturbances occurring inside and outside the enterprise system as a whole.

Research on flexibility is extensive and abundant, where important works surfaced particularly in the 1990s decade. Sethi and Sethi (1990) and De Toni and Tonchia (1998) provided broad literature reviews. The major interest in research appears to be the classification of flexibility. Several authors have used organizational, hierarchical, temporal, or objective criteria to build flexibility taxonomies (De Toni and Tonchia, 1998). Most authors focused on either exploring the relationship between flexibility and performance or building conceptual typologies or taxonomies (Narasimhan and Das, 1999), but without addressing the flexibility issue as a property which must be built in the enterprise system. Likewise, few studies have focused on the links between flexibility and operations improvements under a certain strategic framework. Among those, Collins and Schmenner's (1993) rigid flexibility model appears to provide one of the most consistent answers to producers squeezed by market volatility.

In this very point we think it is essential to understand that flexibility, as well as stability,

is an important property of the enterprise system as a whole, not only at the manufacturing system's level. Both stability and flexibility are indeed indispensable for the enterprise's viability as a dynamic system, but more importantly, they are not properties which are independent of the enterprise system, nor may they be added to it or taken away from the system simply as an accessory. These are both fundamental properties of the enterprise system itself. They are built into the enterprise, and as part of the enterprise's control system toolbox they must be engineered effectively in its control system in order for this to adequately respond to the enterprise's needs and objectives.

1.4 The entropy analysis: a road not taken

Unlike other authors such as Shuiabi et al (2005); Kumar (1986 and 1987) and Piplani et al (2006) who choose to view entropy as a measure of operational flexibility and seek to analyze entropy and entropy generating factors as determinants of manufacturing flexibility within manufacturing systems, following the logic of entropy maximization as a way to foster and generate higher degrees of flexibility in manufacturing, we don't believe that flexibility is directly linked to entropy and therefore we do not advocate entropy analysis and much less entropy maximization as a means to maximize flexibility. On the contrary and based on experience in various manufacturing enterprises of different size and industry sector, we think that entropy is not necessarily a good thing, and indeed too much entropy might be detrimental to the purpose of generating higher degrees of flexibility.

We can think of entropy as a measure of disorder in the manufacturing enterprise system, and the more information (in all its forms) there is in the system, the more entropy there is. Too much information and too many choices can lead to disorder and immobility, just as we feel overwhelmed when going into a supermarket and looking for soap only to find that there are so many options to choose from that to even think of analyzing which one is better is just mind boggling. Although we agree that having a prudent number of alternatives of action in operations (a controlled approach to flexibility) is absolutely desirable, and that such flexibility must exist ideally in every one of the elements that comprise the enterprise system as a whole and determines its operational viability, we also believe that having stability and order is just as equally important as having enterprise flexibility, and thus we feel that flexibility, as a desirable property of the manufacturing enterprise, is much too complex to simply analyze it in terms of the possible entropy linkage between flexibility and entropy, much less to explain it in terms of entropy.

More over, we think that looking to maximize entropy as a means to maximize flexibility is the wrong approach, not only because flexibility is a complex property of the enterprise system that must be studied and analyzed from multiple angles and can not be simply explained as a byproduct of entropy, but also because entropy in our view is a measure of disorder and, although it may seem at first that having as many options or alternatives of action in operations is a positive fact that generates conditions for higher flexibility, it is only apparent. The truth is that unless flexibility has been carefully engineered in the enterprise system by judiciously designing which alternatives ought to be present in every element of the enterprise control system, too much to choose from can be negative, and lead to rigidity, inefficiency and disorder.

In general, disorder and entropy in work environments, and in manufacturing enterprises in particular, arise when there is too much information going around in the system (sales targets, work orders, products/parts routing options, different stock volumes as buffer, etc.) making it difficult for the system to handle itself adequately and timely given a certain time constraint. There is also the degradation of this information, as it is being handed down and applied from higher to lower hierarchical ranks.

Also disorder emerges from internal perturbations of the enterprise system when, for example, there are conflicting goals and needs emerging from such information when involving common resources to accomplish a certain objective. That is the case when two or more products of a production plan dispute their access to a machine so that they can continue their production sequence and finish an order. The same thing happens with various other scarce resources within the enterprise system, particularly human resources and time. Examples of this type are most commonly observed in manufacturing enterprise environments when there are a limited number of key resources (time, machines, skilled operators, work orders to be processed and limited raw materials, dispatching/delivery, etc) and multiple requirements/needs set upon them.

Likewise, manufacturing systems, being open, dynamic systems are constantly struggling between stability and change. Variations and disorder have different sources, and come in different forms and magnitude at different levels of the manufacturing enterprise system. Perturbations come from outside and from within the system, and both have to be dealt with differently. While flexibility needs are important in hindering adverse effects of unexpected changes and disturbances coming from outside the system, it is equally important and necessary for management to deal with disorder and chaos springing within, at different levels and sections of the manufacturing system. Both types of uncertainty and change are different in nature and require a different treatment. Therefore the enterprise control system is called to act upon the different types of perturbations affecting the enterprise system at different levels by deploying the necessary control actions to overcome such perturbations.

Thus the need for flexibility as well as stability is always present. As in a dynamic environment, the two terms seldom balance each other for any extended period of time, so in the real world systems tend to fluctuate around the states that define their steady states, rather than settle into them without further variation. So enterprise systems tend to fluctuate between stable conditions (steady state) and changing conditions (uncertainty provided by variations) which require the system to be flexible, but within certain defined guidelines and boundaries, to cope effectively with these changes. Hence in order to display its flexibilities, manufacturing systems, as do other human activity organizations, generally move from a state of higher organization (more stable state) to one of lower organization (higher entropy level), from order to disorder. As far as it is known, this process always moves in the same direction, and since entropy is a measure of the disorder in a system, a highly organized system is said to be low-entropy, while a disordered system is said to be high-entropy. Thus entropy increases as order decreases.

2. SYSTEM CONTROLLABILITY: ENGINEERING A PROPER USE OF ENTERPRISE FLEXIBILITY

While flexibility measures may be well prescribed for treating unexpected variation from outside factors, which threaten the system with disorder and disarray, the same prescription may not be used just the same and to the same extent for unexpected variations and their derived uncertainties, and then expect similar results. For instance, variations and their derived uncertainties may be dealt with effectively in terms of increasing stocks of raw materials, when there is uncertainty about the availability of the required types and quantities of materials due to external conditions such as reliable suppliers or shipment not readily available, or on the other hand, an enterprise wanting to produce for stock of finished products when there is uncertainty as to how much the demand for a certain key product may vary over a certain period, risking expected sales figures.

However, in the case of perturbations arising within the system, as for example an unexpected machine break-down, the unexpected problems with a machine's set-up or a key machine operator falling sick and not reporting for work are just a few examples of adverse situations that are quite different from outside perturbations and uncertainty in the sense that these factors, which are but a small part of a long list of factors and conditions which are part of the system itself, that is they are factors and conditions that are dependent upon the structure and organization of the manufacturing enterprise system, and as such they are built in the system, and depend essentially on the right managerial decisions, aided by an adequate operations and business strategy to structure measures to fend off such perturbations effectively.

Therefore, while perturbations and uncertainty coming from outside forces may be more readily understood and more clearly dealt with and the flexibilities measures required to deal with them and their strategic linkage more readily apparent to the trained observer, the conditions which originate perturbations and uncertainty within the system are, for the most part, factors which depend on the way the manufacturing system is structured and organized and on the resources built into the system. Thus to deal effectively with inside forces that cause perturbations and uncertainty (lack of stability) in the manufacturing system, management has to consider first and foremost such vital aspects as the manufacturing and business strategies of the enterprise, and how well the enterprise organization and structure are aligned with these strategies, and make sure that the manufacturing enterprise system as a whole is appropriately endowed with the necessary resources, both physical and human, and the management and administrative policies needed to ensure that the system is able to sort out adverse situations and conditions effectively.

Appropriate measures of flexibility at different levels of the manufacturing enterprise system are part of these resources, and it is a matter of how well and how appropriate these flexibilities measures are engineered in the enterprise system, which determines how capable is the system when it comes to responding to these adverse conditions, and how apt and effective it is at maximizing its performance despite its limitations and perturbations. Hence it is clear from this that flexibility measures ought to be built into the

system in a way that they are deeply ingrained in the organization and structure of the enterprise system, so that when the system makes use of these resources they don't come at a high extra cost to the enterprise system itself.

2.1 Enterprise's Metacontrollability and the Role of Management

The role of management is a complex one. First it has to deal with securing company profits and enterprise system overall performance, and at the same time has to always monitor the coherence of company vision and mission with its operation maneuvering to make sure that the ship is set on the right course. In this way management is responsible for controlling the organization at all levels, and it is this high level controlling which we call metacontrollability and its capacity to exert variable, localized control within the system, what will ultimately determine how able and successful the system is at dealing with perturbations and uncertainty coming from outside and within the system. Thus, the responsiveness of the enterprise manufacturing system rests upon appropriate and timely control actions engineered and built into the system by management and this in turn determines the success or failure of the manufacturing enterprise system's metacontrollability.

Hence Metacontrollability rests on the hands of management and its capability to adequately monitor the system's strategic needs and objectives and at the same time, assess the necessary system's requirements and provide the resources to fulfill these needs and objectives, which determine when, where, how much and which type of flexibility measure is to be used. Like a ship's automatic control system determines when, how and how much the ship's rudder moves at any point of its journey, the metacontrollability of the manufacturing enterprise system as a whole depends on its management and the resources and capabilities that were engineered in the system, and in turn both flexibility and stability at every level of the manufacturing enterprise system depend on the success or failure of its metacontrollability.

3. LINKING ENTERPRISE FLEXIBILITY TO SPECIFIC CONTROL ACTIONS

Companies are increasingly concentrating on flexibility as a way to achieve new forms of competitive advantage (Upton, 1995). Strategy should influence manufacturing flexibility requirements and hence the choice of production technology (Gerwin and Kolodny, 1992). As Palominos put it, when referring to the textile manufacturing industry, the enterprise production system's capacity to respond must be addressed from a broader and more general perspective (Palominos, 1996), which, in our view must necessarily account for the strategic implications of enterprise flexibility. This approach to flexibility we feel is appropriate, rather than trying to reduce flexibility to a particular subset of system and analyze it just from the operations point of view without linking it to the enterprise's strategic framework. Thus we feel that this concept of flexibility is not only more appropriate, as viewed from a wider perspective, but also more effective in terms of measuring the system's responsiveness to change and how this affects the enterprise

standing in terms of its strategic framework, whether it be at the corporate, business or operational level.

3.1 Flexibility and Stability as properties of the manufacturing enterprise system

Not only do we think that the manufacturing enterprise, as an open dynamic system, must respond adequately to changes outside its environment but also to changes that occur inside the system itself. Unlike other authors, who choose to view flexibility as the capacity to respond to outside changes that affect the manufacturing enterprise, we think that flexibility and stability are both properties of the enterprise system which are indeed of a very complex nature, and this complexity is reflected on the fact that there are multiple elements that determine the degree and extent of the flexibility measure generated by the control system of the enterprise. Thus flexibility and stability must not only be viewed as necessary properties of a firm's operations, as so many authors have done, but also as a business and corporate necessity of the enterprise as a whole, given the multidimensionality aspect of flexibility as the need for flexibility is present at every level and in every area of the enterprise, and must be administrated by management at all three levels.

Also flexibility at each level means different things, as it is associated with specific needs and objectives that are particular of the level and area/department of the enterprise at any given time. These specific needs and objectives must in our view be linked to specific strategic goals of the enterprise. For example in operational flexibility, it makes sense that the manufacturing system may have multiple routing options for any given product's manufacturing, a flexible, multidisciplinary workforce, a variety of flexible machines, that can manufacture multiple parts of a product or family of products, and that can also be reconfigured to handle other tasks such as adding finishing and other special customization characteristics to a particular product. At the business level, on the other hand, flexibility may take the form of financial flexibility, sales and marketing flexibility, flexible merchandizing or distribution flexibility. Finally, at the corporate level, the corporation must be able to tap on new markets when conditions merit so, or change to a new market when a particular market it is in is declining or becoming obsolete, and also, for example, build a new plant when particular market demand conditions so requires it. Understood this way, flexibility is not only coherent but also strategic.

As stability is sought as a much needed property of manufacturing systems to reach a certain equilibrium state when it is required, so is flexibility an important and indispensable property in today's manufacturing enterprise as a way to face uncertainty and manage perturbations effectively, which may even nest hidden opportunities that the enterprise system must realize. The problem of uncertainty and choice risk derived from it is one which affects the enterprise at every level always. This problem was recognized formally in the literature by authors such as Stigler (Stigler, 1939) and others in which the production curve flexibility was studied with respect to uncertainty in prices of goods.

Hayes and Wheelwright (1984) point to flexibility as a basic element of a firm's competitive advantage, thus underlining the strategic character of flexibility as a desired property of manufacturing systems. Skinner (1978, 1985), on the other hand, argues that

flexibility may be considered in a strategic context, particularly in the investment process. In Figure 3.1 we show the model whereby flexibility may be achieved by means of control actions of the enterprise, and a feedback control system represented by a performance measurement linked directly to strategic needs and objectives and to the control system itself. It is important to note here that flexibility must be viewed as a necessity of the enterprise to survive, just as stability or continuity is a permanent need of the enterprise system upon reaching steady state. Therefore flexibility is not a goal in itself but means to an end. It is by being flexible and agile when conditions affecting the manufacturing enterprise so requires it that the enterprise may be able to achieve its strategic needs and objectives and not the other way around. Thus flexibility measurement is not relevant in itself but only when it is viewed in the context of the strategic needs and objectives of the enterprise that the measure of flexibility helps to achieve.

In order to illustrate our approach, we have taken the conceptual framework of flexibility proposed by Gerwin (Gerwin, 1993), which presents an interesting feedback loop approach which gives support to our systemic view of flexibility analysis, and have modified it in order to elaborate on our control system approach model to enterprise flexibility.

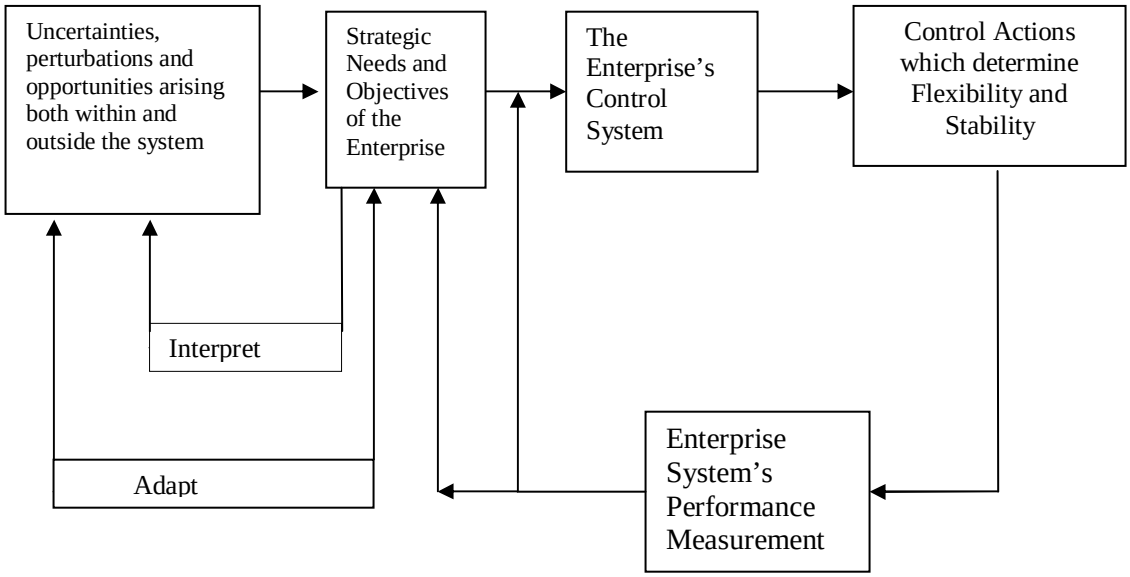


Figure 3.1 Control System Approach Model to Enterprise Flexibility

On the other hand, Jordan and Graves (1995), develop some principles of the benefits of flexibility in the production system of the automotive industry, for n plants and m products. The main principles, as resumed by Palominos (1996), are:

a) With small amounts of flexibilities, it is possible to get all the benefits of having total flexibility.

b) The way to incorporate flexibility is to create few but different products in each plant.

Finally it is important to point out that the issue of flexibility types and their incorporation at different levels of the enterprise system has been put forward by many researchers before, who present different research approaches to the flexibility problem in manufacturing systems, and lay out the basics of their postulates for future research to follow, however three fundamental problems remain (Palominos, 1996). These are:

i) The need to define, in precise terms, which type of performance measures are they making reference to when they talk about flexibility in manufacturing; so that it may be possible to establish comparisons among different factories;

ii) The metrics of Flexibility continue to be a problem that needs to be address in a more general way, since a given measure of flexibility that may be adequate for a manufacturing enterprise, may not be a representative measure of such flexibility when applied to another enterprise;

iii) The little knowledge available on the principles that rule the different types of flexibilities.

3.2 A Controlled Approach to Flexibility: The Lessons of Discipline, Simplicity and Agility

Engineers are taught early on in life the importance of simplicity and flexibility. They learn in theory and later by experience that simple but effective is better than perfect, and that too much information and too many options are usually detrimental to production systems performance. Managers have known and applied these principles for years, and we ourselves have been witnesses to this several times in our work life to know how valid they are, to the point that even top managers, of the most successful companies in the world, have signaled these principles (or properties) of enterprise systems as key to their success. Two sources of such principles and how they are applied in manufacturing are Lean Manufacturing (Womack et al., 1990) and the Rigid Flexibility model Collins et al. (1998).

In 1990 James Womack wrote a book called "The Machine That Changed the World" (Womack et al., 1990). Womack's book was a straightforward account of the history of automobile manufacturing combined with a study of Japanese, American, and European automotive assembly plants. What was new in it was a phrase-- "Lean Manufacturing" which caught the attention of the manufacturing world. As we all know, there is no cookbook for building a successful manufacturing enterprise. Each firm has its own unique environment and its own set of products, processes, people, and history behind it. While certain principles may be immutable, their application is not. Like its homologous, the Rigid Flexibility model, Lean manufacturing represents a set of tools and a stepwise strategy for achieving smooth, predictable product flow, maximum product flexibility, and

minimum system waste. Such flexibility competencies can be achieved through building simplicity and discipline in operations.

As Collins et al. (1998) show in their study, the rigid flexibility model provides evidence to link simplicity, discipline and agility to what we term controlled flexibility, in manufacturing companies from the five western European countries of Britain, Germany, Switzerland, the Netherlands and Finland. Here one can learn that a well coordinated, controlled and focalized use of flexibility measures, all part of a concrete strategic enterprise model, can really make a difference and ensure that operations choices are adequately linked to strategic options.

Like the Rigid Flexibility model Collins et al. (1998), Lean Manufacturing is another source of what we term controlled flexibility. In this manufacturing enterprise model, flexibility types are quite focused and discrete but effective, and they respond to a controlled and measured standard which is adequately linked to a specific strategic framework, favoring particular set of strategic options, as Toyota and so many other companies which have successfully applied this model can show. As it has been appropriately put by author Giovani J.C. da Silveira "*the rigid flexibility model suggested that flexibility competence could be developed by building simplicity and discipline in manufacturing. Simplicity was about streamlining information and materials flow processes. Discipline was about carrying out procedures in dedicated and consistent fashion. Both (properties), simplicity and discipline, would result from improvements in several areas including information and process technology, labor development, product design, and process configuration*" (Da Silveira, 2005). And Da Silveira sheds more light into the model success when he adds that "*the model's premise was somewhat paradoxical, as flexibility would result not from building capacity or inventory buffers [as suggested by several studies in operations and supply chain management, e.g. Fisher, 1997; Huang et al., 2002; Jack and Raturi, 2002] or from allowing improvisation in manufacturing. Instead, flexibility would result from rigid processes that consistently and diligently pursued strategic tasks*". Thus we learn that too much leeway and too many options may in turn create confusion and disarray, letting ambiguity as to which way to go and when mark the norm. This excess and focus lacking flexibility may simply work against a proper, discrete and strategically sound use of flexibility, as it was partially hinted by Collins and Schmenner (Collins and Schmenner, 1993). Management actions that are well focused on order, agility, discipline and simplicity to pursue operations objectives, all under a strict operational strategy framework, such as the one provided by Lean Manufacturing or the Rigid Flexibility Model can prove not only effective at applying a controlled use of flexibility with very good results but also successful at linking the application of a set of well defined flexibility measures to concrete strategic objectives, rather than just reducing the number of options available to the firm.

There is ample evidence in the firms that have successfully applied either Lean Manufacturing or the Rigid Flexibility Model (see Collins et al. (1998) to suggest that streamlined manufacturing processes, order, focus and discipline make quite a difference in operations. Japanese manufacturing is a very good example of these traits. Also the concepts of simplicity and discipline in manufacturing are clearly defined in the empirical

study by Collins et al. (1998). Simplicity in the manufacturing environment takes the form of streamlining processes, procedures, information and material flow. Special work and labor arrangements and greater visibility of stocks and material flows are other forms of simplicity, which may include product modularization, cellular layout, reduction of waste including wasted motion, inventory reduction at all levels, zero defect, improved information exchange and processing both with suppliers and customers, and the importance of internal customers within the system and the responsibility of work force with one another in order to respond effectively the first time.

Discipline has to be embedded in the organization's culture and makes up for important practices such as process control, effectiveness and efficiency metrics, process focus, process automation, and an ever ending quest for a reduction in operations complexity and variation have made many companies that have applied these manufacturing models successful. Discipline is best illustrated by the 5-S strategy which is one of the best and most effective tools of Japanese manufacturing, and part of Lean Manufacturing. It refers to making sure that the manufacturing system and everything in it is reliable and effective. Everything, from work methods, procedures, and process performance to information processing, machine utilization, organization in materials flow and stock obey certain rules and constraints.

Much of this manufacturing philosophy has to do with best practices and effectiveness at no extra cost to the system. As Kaoru Ishikawa (Ishikawa, 1985) and Shigeo Shingo (Shingo, 1995) taught, it involves quickly identifying and solving problems, improving work methods, and carrying out procedures in a dedicated and consistent fashion to secure the system response upon sudden requirements. Discipline initiatives included preventive maintenance, workplace development, housekeeping, continuous improvements, and operator checking of quality in general. These practices coupled with the way in which management actions account for their unique and effective types of flexibility, provide convincing evidence that in these manufacturing companies a controlled, well disciplined form of flexibility is a key part of the equation, making it possible for manufacturing systems and processes to reconfigure themselves when needed and adapt to changing requirements at no significant cost or chaos to the enterprise. But it is metacontrollability the one which is ultimately in charge, and it is its responsibility to exert measured, controlled flexibility in the system but keeping certain constraints like those easily observed in Lean Manufacturing for example, where simplicity, discipline, and a well balanced form of flexibility. Similar conditions and principles govern is the case of the rigid flexibility, where management, rather than stiffening procedures and processes, promote company best practices at every level and push both efficient and effective work methods that enabled the firm to respond quickly to market changes as well as being agile and responsive to changes inside the system.

4. LINKING ENTERPRISE FLEXIBILITY TO STRATEGIC OPTIONS

In order to carry out an immense number of complex operations and tasks, which in turn demand a multiplicity of complex decision making processes, all of this in very dynamic

environments, manufacturing enterprise systems must decide, upon uncertainties and unpredictability arising both from outside and within the systems, when and how to plan and when to act, how to detect and recover from errors, how to handle conflicting goals and decisions, etc. In short, management at every level of the manufacturing enterprise must effectively plan, coordinate, and control their limited physical and human resources, trying to optimize the systems' outcomes as a result of transformation of their given inputs and outputs at any given time.

As the tasks and decision making environments become increasingly complex, explicit constraints and boundaries are needed to impose a certain structure on the control of planning, perception and action of the systems to improve system performance and to ensure that they are able to operate effectively within a specific operational framework which delimits their flexibility in operations and ensures that their decision making options are mapped to specific strategy options and not the other way around. This we feel is essential in making sure that the systems will achieve their goals while strategic options remain secured. In our view, this approach handles uncertainty and unpredictable changes better, since it reduces the amount of entropy and complexity being produced within and outside the manufacturing enterprise system. However it is unclear how systems can maintain their balance between flexibility and stability requirements and at the same time keep their strategic coherence as tasks and environments increase in diversity. The problem is that, as manufacturing systems grow bigger and more versatile, complexity increases and so does entropy, hence complex interactions among decisions and actions within the system increase as well, to the point where it becomes difficult to predict the system's overall outcome, measure its flexibility-linked effectiveness and much less secure the link between this effectiveness and the enterprise strategic options.

One way in which we can try to limit the amount of flexibility in the enterprise system to a level and scope that is adequate and manageable based on system's requirements and objectives, is to limit the options available in operations (too many options and too much leeway in operations is just as bad as not having options at all), thus preventing it from spanning out of control. This may be achieved by adding top-down constraints upon the system's available actions and allow it to take advantage of regularities in its domain to coordinate actions in a more recursive fashion, thus reducing entropy and complexity at different levels of the system and, in this way, preventing or at least attenuating these adverse conditions from happening. Good examples of this can be found in Lean Manufacturing and the Rigid Flexibility Model, both cited previously as examples of what we call a controlled approach to manufacturing enterprise flexibility.

The approach advocated here, which we term metacontrollability of the manufacturing enterprise system, is basically one in which, like Lean Manufacturing (Womack, 1990) and the Rigid Flexibility Model Collins et al. (1998), strategic options are closely linked to and secured by their operational and business strategic framework by means of adequate control actions of the system. System reliability and effectiveness is increased by using an operation model whose pillars are adaptability, simplicity and agility, maintaining specific operational constraints and system's boundaries to secure its quick, agile and effective response and incrementally layering on additional options in operations behavior to handle exceptions and extreme, unbounded situations. Thus, the separation of regular/nominal and

exceptional behaviors of the enterprise system increases system understandability and controllability by isolating different concerns: the manufacturing enterprise system's behavior during normal, regular operations and conditions is readily apparent, and its efficiency and responsiveness are maximized, while strategies for handling exceptions can be developed as needed. Furthermore, complex interactions are minimized by constraining the applicability of behaviors to specific situations, so that only manageable, predictable subsets will be active at any one time.

Finally, this control problem approach acknowledges the fact that creating agile, operationally flexible and strategically sound manufacturing enterprises is indeed, in itself, a very complex and formidable challenge which must be treated as an incremental process: one in which managers and engineers should be able to treat singularities with caution. They should think twice before adding more behavioral options and variety to the system (thus incrementing the system's complexity and entropy), but adding new behaviors only when it is extremely necessary to do so, and with little or no modification to existing systems and operations, thus limiting the cost and operational compromise as consequences of these additions. There are many successful examples of companies in the manufacturing world which have accomplished a sound, controlled and cost effective use of flexibility in a variety of forms at all levels of the enterprise system. Lean Manufacturing and the Rigid Flexibility model already mentioned here are both good examples of manufacturing enterprise strategies which apply this rational, control system approach to the use of flexibility, and with excellent results. Examples of this are companies like Honda and Toyota, which combine the best practices of Lean Manufacturing with Japanese manufacturing principles. Such is the case of Nissan's Smyrna plant recently named North America's most productive auto plant by Harbour and Associates. Employing more than 5900 persons, with a production capacity of 450,000 vehicles per year, Nissan knows the importance of synchronizing flow, JIT manufacturing and optimizing production processes.

Another forerunner, which combines the best of Lean Manufacturing with Japanese manufacturing principles and philosophy is Honda, which like Toyota, has developed a built-in flexibility with clearly defined boundaries, achieving high quality, cost efficiency and productivity with appropriate measures of flexibility. Toyota Motor Company for example, like its competitor Honda, developed a highly-disciplined and process-focused production system, with the sole objective of minimizing the consumption of resources that do not have any added value to the product. Just-in-time and 5-S programs are also good examples of this particular form of achieving a controlled form of enterprise flexibility. 5S refers to the five structured programs using the Japanese principles of seiri, seiton, seison, seiketsu, and shitsuke —or commonly referred to as sort, set, shine, standardize and sustain, respectively. The Japanese words are shorthand expressions for principles of maintaining an efficient and effective workplace and office. In essence Japanese manufacturing is much more concerned with having the least many options to run the system properly. Only the truly necessary options, which prove to make the manufacturing and the company's operations in general most efficient and productive, are left. Nothing is wasted and everything is strictly for a reason, otherwise it should not be there. Therefore excess flexibility in the system, far from being beneficial or desirable, is seen by Japanese managers as a waste.

4.1 Metacontrollability of the enterprise system: tying the knot between flexibility metrics and strategic objectives

Organizations in general, and particularly manufacturing enterprises, fluctuate between periods of stability and change in the course of their operations almost permanently. The degree of stability and change in the enterprise system also fluctuates, depending on a myriad of factors. This becomes even more so as production transits from low season sales to high season during the course of a regular year, and it is more evident toward the end of the month, as work orders pile up disputing scarce manufacturing resources such as equipment and machinery, labor, materials and time for processing.

As work orders are run thru the manufacturing system and products are fabricated, customers' purchase orders strive hard for the chance of being served on time, in order to meet dead lines and deliver the products to the customer on the date agreed upon with the sales agent. All of this imposes different levels of stress on the system, which in turn reflect various degrees of uncertainty affecting the enterprise system's operations, which must be dealt with. Thus every successful organization, in order to deal with this ongoing reality in an effective manner, ought to combine flexibility and stability judiciously by triggering the appropriate actions in the system when and where they are needed, to adequately monitor and control its requirements for more or less flexibility or stability as operations unfold.

Although the latter is rather evident, especially for those with vast manufacturing and operations management experience, it is by no means evident how this delicate balance between stability and flexibility of varying degrees is being achieved. For the outside observer, who witnesses the enterprise control system in action, amid all the frenzy of change and uncertainty being brought upon the system by both outside and inside forces acting differently upon the enterprise and therefore triggering different system responses, things seem to work fine and for the successful manufacturing enterprise, its control system appears to respond. But if we look closer and more attentively, we will notice that this clockwork coordination at every level of the enterprise system is not random, much less mechanical. There must be a higher control layer, or what we term metacontrollability, a supra control system operating around the clock in order to ensure the system capacity to respond to the various exigencies being brought upon it.

This higher or supra control, which can be understood as the control of the enterprise control system, is what we have termed metacontrollability. Metacontrollability is in the hands of enterprise management and it is no other than management the one which is ultimately responsible for its success or failure. Metacontrollability is in charge of applying and adjusting the degree of stability and flexibility at every level of the manufacturing enterprise system as needed. The amount of flexibility needed depends on the degree of both, environmental disturbances (changes outside the organization) and perturbations inside the organization as well, and how these forces affect specific strategic needs and objectives. Both flexibility and stability are generated and controlled by the

metacontrollability of the organization. This metacontrollability is the very central nervous system of the enterprise, meaning that it is over all the other forms of control which operate at every level of an enterprise, being each organization a unique system.

The control system of the enterprise, which we have termed metacontrollability, is in turn comprised of five basic elements. These elements of the enterprise must be strategically interconnected and operate closely intertwined in order to correctly determine the enterprise requirements for flexibility (or stability) at any given time, and what control action is needed to generate such flexibility. Fig. 4.1 shows this construct and its relations with one another. The five basic elements which determine the controllability of the enterprise system are:

1. Enterprise management
2. Strategic goals and management policies at all levels;
3. Organizational structure and culture;
4. Enterprise infrastructure
5. Technology.

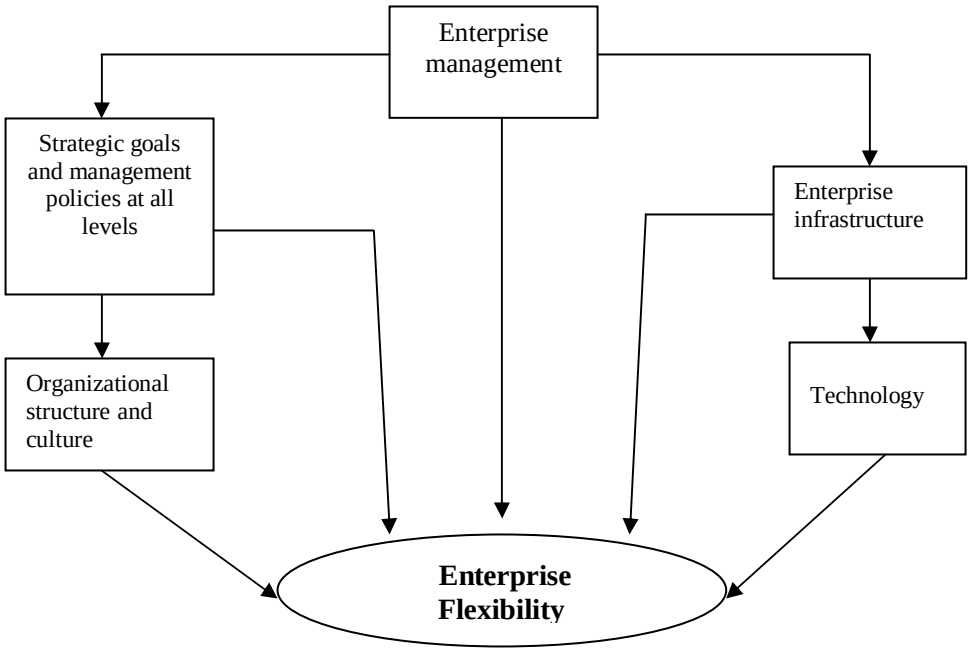


Fig. 4.1 The 5 basic elements which comprise the control system of the enterprise. However differently, they all impact both enterprise flexibility and stability capabilities and determine the enterprise system's viability in terms of its capacity to adequately manage both.

The above fundamental elements, which comprise the control system of every organization, particularly manufacturing enterprises, and how these elements are ensemble

and coordinated, will ultimately determine the type of organization, its control capability and operational characteristics, and most importantly, its capacity to effectively manage and satisfy the enterprise system's needs for flexibility and stability. The most important of all five is of course the enterprise management, as it is management indeed the main articulator, and as we said earlier, it is upon management shoulders that the metacontrollability of the entire enterprise system rests. Hence at the heart of the system there is always management which is responsible for the right and timely interplay between flexibility and stability at every level and in every unit of the company.

The degree and extent to which flexibility and stability are to be used in the enterprise system, as well as the lack of either one, at any one time, depends on enterprise management capacity and skills to articulate all these elements correctly at every level of the enterprise, and on the other four elements being adequately designed and implemented to sustain the enterprise control system capabilities. But management alone is not enough. It is fundamentally important to distinguish how the different elements are assembled in the organization and the logic and coordination behind this assemblage. In the 1990's and still today, many business reengineering efforts are aimed chiefly at securing this very point.

The degree of responsiveness of the enterprise control system will depend ultimately on how well this objective is reached. The supra control of the enterprise — the metacontrollability of the system— will depend on the management's capacity to act upon the other four elements in an effective and timely manner, and will also depend on how well aligned and coordinated are they with one another. This is a key measure of strategic coherence. Each one of these elements has to be a logical part of the whole, but finally it is management which is responsible for the whole and every move of its parts. Hence effectiveness of the enterprise system as a whole relies on its management.

4.2 Describing the different types of enterprise flexibility

The different elements which comprise the control system of the enterprise give birth to different types of enterprise flexibility as each element's flexibility contribute to the enterprise flexibility differently although they all complement one another, and although each occupies its unique place and ranks differently in the contribution hierarchy to enterprise flexibility, with management flexibility at the top, they all contribute their share to accomplish enterprise objectives. We describe now each one of the five types of enterprise flexibility.

1. Management flexibility. Management is by far the most important of all elements, ranking at the top of the contribution hierarchy to enterprise flexibility, as it is management the one responsible for the metacontrollability of the enterprise system, with the other elements' decisions being dependent upon management. We can define management flexibility as the capacity of management to respond to change, and to be able to adjust its policies and management style in order to create the necessary conditions within the enterprise system for the enterprise to become effectively responsive, agile and recursive in its actions toward the need to adapt to changes, whether they present themselves in the form of perturbations or opportunities coming from inside or outside the enterprise system.

Management style and policies, its capacity to act on every other element of the enterprise control system, and its influence in the organizational structure and culture, directly determine the degree of flexibility available. Rigid, hierarchical management styles and policies are a basic hindrance to enterprise flexibility. Enterprise management actions which determine flexibility include making the right decisions in a timely and consistent manner and taking a proactive approach to problem solving, promptly bringing about the necessary changes as needed without having hierarchical or structural factors hinder their actions. Also the enterprise management capacity to act quickly in making the right changes in any of the other elements or in a combination of them, whether it may be a problem with a particular technology being used, an inadequate equipment choice or a production or storage facility layout that is affecting infrastructure flexibility, or a problem with the culture of the company that might affect flexibility as well as stability of the enterprise, will ultimately make the difference between an enterprise control system being highly responsive and effective and one that it is not .

Management style is a major determinant of enterprise flexibility, most noticeably in horizontal, almost flat corporations, where management is always available and access to decision making information regarding enterprise operations flows freely and effectively, without fear of sharing responsibility and accountability for decisions being made at every level. Hence a good measure of management flexibility is the ease and effectiveness of the decision making process and the degree of accessibility and responsiveness that enterprise personnel gets from management at every level. The strategic options being served are obvious in this case and need not be explained.

2. Flexibility of strategic goals and management policies at all levels. Strategic goals and management policies of the enterprise at all levels, on the one hand ought to be flexible enough so that they may change and adapt to ever changing conditions and unforeseeable situations which may affect the enterprise. Rigid, inflexible strategic goals may ultimately turn against the enterprise viability by not allowing it to shift gears when the circumstances call for it. Management policies on the other hand have to be such that they may not hamper the changes that are to be implemented as a result of the control actions generated to deal with perturbations and uncertainty. Strategic goals and management policies are both strong determinants of enterprise flexibility. Clear, concise and enterprise's mission-driven goals are important in maintaining alignment and focus, however they must also be flexible enough to adapt to changing conditions and situations, whether internal or external, which may affect the manufacturing enterprise. Management policies must not be rigid either, but adaptable and operate as means-to-an-end, not an end in themselves as unfortunately still occurs in so many companies. The strategic option of enterprises which follow these principles is clear, preserving the organizations viability and effectiveness over other considerations.

3. Flexibility of organizational structure and culture: Organizational structure and culture are both determined by the enterprise management and its influence is gravitating at all levels. Therefore it is crucial to build a highly flexible organizational structure and an enterprise culture which supports and enhances this property, this way engineering flexibility in the enterprise's spinal cord. Organizational structure is, as it was pointed out before, a major determinant of enterprise flexibility. With the advent of the horizontal

corporation and the reengineering movement in the 90's, companies were seeking to become much more productive, substantially reducing cost and time in operations, plus becoming more customer responsive, and create an agile, empowered and result-driven culture. The result of applying such innovations in the enterprise organizational structure and culture paid off and thus provoked a major shift towards greater flexibility and agility in organizations throughout the world. On the other end, companies which still employ tall, rigid and highly hierarchical organizational structures and foster submissive, don't-ask type of culture find it extremely difficult to articulate changes by generating the necessary control actions quickly and productively. Therefore, the measure of flexibility associated to organizational structure and culture and the strategic option thereafter are obvious. The ease and speed with which the organization's structure can modify itself in order to meet the organization's needs and objectives when being faced with conditions and situations which make these changes necessary on the one hand, and the measure of proactive and responsive behavior of its culture on the other are both vital to determine enterprise success in accomplishing its objectives.

4. Enterprise infrastructure flexibility. The types of infrastructure being used in an enterprise system are in themselves a major determinant of flexibility. Being subordinated to management's decision, infrastructure accounts not only for manufacturing plants, storage facilities and office buildings but for all types of workspace arrangement within the enterprise, including energy, power systems, and other systems which make possible to operate the enterprise at all levels. The infrastructure is in itself a key player in the flexibility issue. There are abundant examples in the literature of this type of flexibility, from reconfigurable work spaces, manufacturing cells, modularity, and even reconfigurable factories which can modify themselves to accommodate new products manufacturing, new machinery and multimodal work stations. The measure of flexibility associated to enterprise infrastructure is the ease, the cost and the speed with which infrastructure can change and adapt to new operations requirements without hampering or jeopardizing the manufacturing enterprise standards and business obligations. The strategic option is clear, to be operationally viable as much as possible without compromising cost, quality and productivity.

5. Technology flexibility. Technology is a key architect of flexibility and thus it must be chosen correctly. From advanced manufacturing technologies to modern information and communications technologies, they all impact flexibility in the enterprise at different levels and in different ways, but undoubtly they play a major role in the enterprise control system. Technology in all its forms is a key determinant of enterprise flexibility anywhere, particularly in manufacturing. Advanced manufacturing technologies of various kinds have emerged over the last fifteen years, particularly with the rapid advent of advanced manufacturing automation solutions and the advancements in industrial robotics.

On the other hand, advanced integrated information technologies and communication systems have made possible to have the right information anywhere it is needed at anytime. Thus flexibility associated to I.T. and communications solutions plus advanced manufacturing technologies have made a big difference in today's manufacturing enterprise. The measure of flexibility is simple: it is given by what the technology allows operations to do at every level. From the executive offices to the manufacturing floor,

whether it is an ERP system that provides multiples advantages and enterprise-wide flexibility in terms of information access and processing to advanced, state-of-the-art manufacturing systems, which are capable of quickly and easily reconfigure themselves to be used in a variety of product customization options or in new product lines altogether. The strategic option is unmistakable. It is simply to enable and/or enhance the enterprise operations capabilities as much as it is economically possible to do so for the company to achieve its full potential in terms of its mission and business objectives.

4.3 Linking Flexibility Types and Measures to Strategic Options of the Manufacturing Enterprise.

The effective control of the manufacturing system's uncertainties and variations at all levels of the manufacturing enterprise requires management to opt for different ways of handling uncertainty by using different flexibilities (Correa, 1994). However, not enough research has been directed towards understanding the nature of the different flexibility types, which flexibility type suits which specific manufacturing enterprise need, how the appropriate flexibility type is achieved, and which strategic option is being served by applying this or that flexibility type. Moreover, it is vital in our view, to map flexibility types and metrics to specific strategic options, this way ensuring that specific strategic needs and objectives are well served by a specific set of manufacturing enterprise flexibilities appropriately measured. These in turn are part of a global strategic model to which different flexibilities contribute with different metrics. That way each flexibility type can be linked to a specific strategic option within the firm, whether it is at the operational, business or corporate level.

As an example of flexibilities that may be linked to business strategy options, there are internal and external factors cited by the literature. As an example of market-related factors, from the marketing perspective, Chen et al. (1992) define three different sources of flexibility need:
(1) increased product diversity;
(2) short product life cycle; and
(3) an increase in buyer concentration (resulting in variations in demand).

In turn, De Toni and Tonchia (1998) offer an extended list of market-related requests for flexibility:
. the variability of the demand (random or seasonal);
. shorter life cycles of the products and technologies;
. wider range of products;
. increased customization; and
. shorter delivery times.

Another example, although restricted entirely to the manufacturing function, is provided by Correa (1994) and Gerwin (1993) both of whom have also indicated a number of internal factors requiring the need for flexibility:

1. uncertainty with respect to machine downtime;

2. uncertainty of whether the material input meets the standards of the process;
3. changes with regard to delivery times of raw materials; and
4. Variations in workforce.

Now that we know the five elements and their interaction in the enterprise system, as determinants of enterprise flexibility at different levels, we will attempt to link concrete examples of flexibility measures, triggered by control actions of the system, to specific strategic options, thus closing the loop on enterprise flexibility performance measurement.

Likewise, there are several types of manufacturing flexibility addressed in the literature. In order to illustrate our point, we will use the 11 types of flexibility proposed by Sethi and Sethi (1990) plus others that we have added to complement these in order to illustrate our basic construct shown below in Figure 4.2

As we saw earlier, the five basic elements which determine the controllability of the enterprise system are namely:

1. Enterprise management
2. Strategic goals and management policies at all levels;
3. Organizational structure and culture;
4. Enterprise infrastructure
5. Technology.

Hence, the flexibility types we have added to complement those offered by Sethi & Sethi at the manufacturing system level are: Labor Flexibility (Chang, A.Y. , 2004); Delivery Flexibility; Supply Flexibility (Elcio Mendonça Tachizawa et al, 2005 and Caniato et al, 2004); and Maintenance Flexibility. Now, in order to clearly differentiate our approach which aims to analyze flexibility with a feedback loop control system approach at the enterprise system level, and with a systemic view of the problem, we will proceed to add the 5 types of enterprise flexibility we explained earlier to clearly illustrate our control system approach to enterprise flexibility, namely: Management Flexibility (Harwood, 2004); Flexibility of Strategic Goals and Management Policies; Flexibility of Organizational Structure and Culture; Enterprise Infrastructure Flexibility, and Technology flexibility which account for the five

Our control system approach to enterprise flexibility is supported by our vision of how the different flexibility types being present in the enterprise system, and which derived from each one of the five basic categories we have termed the fundamental elements of the control system itself; determine the controllability of the enterprise system as a whole.

Requirement type	Source	Flexibility type	Control Action to generate the flexibility	Measure of flexibility	Strategic need and/or objective being served
operational	internal	Machine flexibility	technology enhancement	Variety of operations that a machine can perform without incurring in major or lengthy set up changes and significant extra cost	Operations capacity and capabilities
business	external	Market flexibility	market development	the ease with which a manufacturing system can adapt to changing market conditions.	Market share and penetration
operational	internal	Production flexibility	production versatility and enhancement	the set of products that a manufacturing system can produce without adding major equipment or capacity.	Operations capacity and capabilities
operational	internal	Material-handling flexibility	operational enhancement	the ability of a material-handling system to move different part types through the manufacturing system	Operations capacity and capabilities
operational	internal	Operational flexibility	operational enhancement	the ability of a product to be produced in different ways without major changes and significant extra cost to the enterprise	Operations capacity and capabilities
operational	internal	Process flexibility	operational enhancement	the ability of a manufacturing system to produce different products without major setups.	Operations capabilities
operational	internal	Product flexibility	manufacturing enhancement	the ability of a manufacturing system to produce different products or various product mixes.	Operations capabilities
operational	internal	Routing flexibility	operational enhancement	the ability of a manufacturing system to produce a product by alternative routes through the system	Operations capabilities
operational	internal	Expansion flexibility	manufacturing enhancement	the amount of overall effort needed to increase the capacity and capability of the manufacturing system when required	Operations capacity and capability
operational	internal	Volume flexibility	manufacturing enhancement	the ability of a manufacturing system to be profitable within a wide range of product output levels.	Operations capacity
operational	internal	Program flexibility	manufacturing enhancement	the ability of a manufacturing system to run virtually unattended for a long period of time.	Operations capabilities
operational	internal	Labor flexibility	operational enhancement	abilities and skills that are common to most of the work force of a manufacturing system allowing quick replacement or interchange of labor as needed	Multidisciplinary and polyvalent work force
operational	internal external	Delivery flexibility	logistics enhancement	the capacity of an enterprise to have multiple delivery options and schedules	Customer Satisfaction
operational	external	Supply flexibility	logistics enhancement	the capacity of a manufacturing firm to have multiple suppliers and flexible delivery conditions	Reliable suppliers' network
operational	internal	Maintenance flexibility	operational enhancement	the ability to perform quick maintenance and repairs to machines and equipment, including infrastructure without substantially disrupting production processes	Equipment and machinnery up time maximization

*F.F. Yanine, 2007

Requirement type	Source	Flexibility type	Control Action to generate the flexibility	Measure of flexibility	Strategic need and/or objective being served
managerial	internal	Management flexibility	Managers actively review and evaluate their practice and policies to ensure workforce responsiveness	Managers are responsive to the organization's needs and to enterprise requirements, adjusting their actions and adapting their management style and company policy.	Managerial responsiveness & leadership
managerial	internal	Management flexibility	Managers flexibilize command & control in the organization	The effectiveness of management actions and style in dealing with organizational needs and enterprise objectives	Managerial effectiveness
strategic	internal	Strategic goals & Management Policies flexibility	Managers strive to align enterprise objectives & management policies	The degree of coherence & effectiveness of strategic goals in aligning with company policies and managerial style to meet enterprise objectives is a measure of flexibility.	Operations & business strategy congruence
strategic	internal	Strategic goals & Management Policies flexibility	Reformulate business plans and adapt operations to deal with changing scenarios	The ease and effectiveness with which an enterprise can change its business and operations practices to adapt to changing business environments.	Enterprise adaptability to changing conditions
organization & culture	internal	Organizational Structure & Culture flexibility	Create a horizontal, business process driven organization.	The speed and effectiveness with which work flows thru the organization and the responsiveness and dilligence of workforce in dealing with everyday operations.	Organizational performance and effectiveness
organization & culture	internal	Organizational Structure & Culture Flexibility	Culture actively reflects company values and goals	The degree and extent to which enterprise culture and structure support enterprise needs and objectives.	Structure & culture strategic alignment
infrastructure	internal	Enterprise Infrastructure Flexibility	Easy reconfigurable production and storage facilities	Work places and storage facilities can easily be changed and adapted to meet unexpected requirements.	Operations flexibility
infrastructure	internal	Enterprise Infrastructure Flexibility	Infrastructure can easily change to accomodate new processes	New processes and production lines can be implemented without substantially disrupting production processes.	Operations flexibility
infrastructure	internal	Enterprise Infrastructure Flexibility	Create versatile work spaces & production arrangements that easily accomodate new lines	Work spaces and plant floor can easily adapt to accomodate new equipment and/or relocate existing equipment to serve various production and operations requirements	Operations capacity and flexibility
organization & culture	internal	Organizational Structure & Culture Flexibility	Create multifunctional teams and interdepartamental roles	Employees are grouped in task forces, including workers work crosses departamental boundaries and hierarchies	Organization culture & structure flexibility
strategic	internal	Strategic goals & Management Policies Flexibility	Align company objectives with business & operations practices	Enterprise needs and objectives and company policies easily adapt to clearly reflect strategic alignment and coherence.	Strategic alignment & max performance
operational	internal	Technology Flexibility	New production technologies and automated manufacturing systems that allow large mass customization	The high volume mass cutomization of products to meet ever changing customer needs and styles, plus the capacity of processes to reconfigure themselves is a measure of flexibility	Technology flexibility and adaptability
operational	internal	Technology Flexibility	Technological versatility and enhancement	New and flexible technologies that provide flexibility and adaptability to new and changing processes, business needs.	Technology flexibility
operational	internal	Management Flexibility	Managers actively seek feedback, value diversity and foster change to enhance organizational flexibility	Management's capacity to value and foster heterogeneity, learning and proactiveness within the organization to enhance the workforce capacity and skills to handle change.	Organizational diversity and flexibility
managerial	internal	Management Flexibility	Managers are quick to adapt to change and provide support, leniency & guidance to workforce	Management's capacity to be supportive, offer feedback and guidance throughout the organization in order to create an atmosphere of trust, commitment and loyalty to the firm	Organizational commitment, satisfaction and loyalty

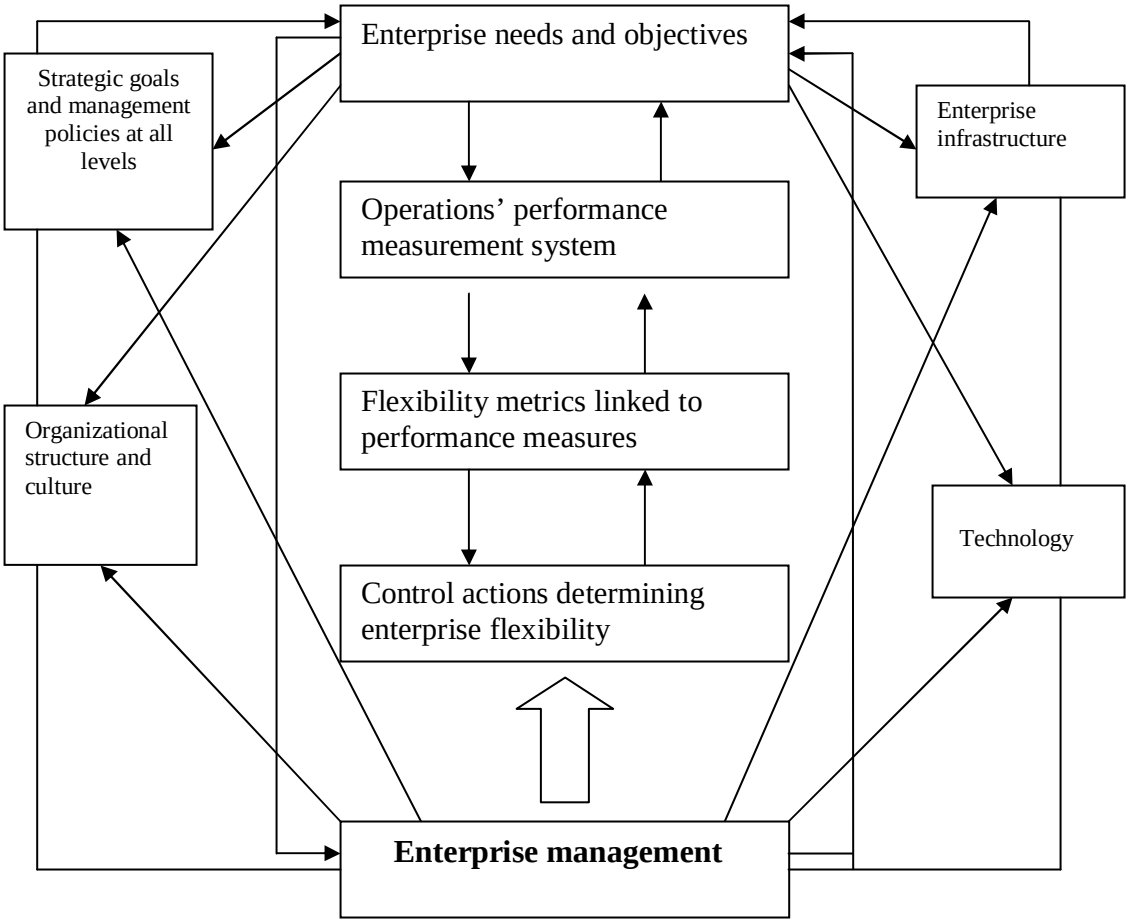
*F.F. Yanine, 2007

Fig. 4.2 Concrete examples of our control system approach to enterprise flexibility and the strategic needs and objectives being served.

In Figure 4.3 below we show the metacontrollability of the manufacturing enterprise system, represented by management and its actions upon the rest of the enterprise control system elements. The model shows the elements' interconnectedness and the flexibility metrics linked to performance measurement compatibility. It is evident, by looking at the sketch, that management is the key player in the controllability of the enterprise system, and as we said earlier it is at the very top of the hierarchy within the five elements which make up the control system of the manufacturing enterprise.

Management is itself the metacontrollability of the enterprise system, and as such it is responsible for the other four elements. It is management's responsibility to choose them correctly and to elaborate on them in order to adequately support the enterprise needs and objectives.

The strategic options chosen by management, on the other hand, must clearly reflect the needs and objectives of the company and if misalignments were to occur as identified by the enterprise performance measurement system, appropriate actions ought to be taken, in the form of control actions, in order to correct the problem and thus allow the enterprise system to thrive.



*F.F. Yanine, 2007

Fig. 4.3 The metacontrollability of the manufacturing enterprise system, its interconnectedness and the flexibility metrics linked to performance measurement compatibility.

As the figure shows, enterprise needs and objectives, placed at the top of the hierarchy, constitute the basic beacon which must guide the management's efforts to engineer enterprise flexibility at every level. Enterprise needs and objectives are clearly impacted by all the elements in the control system, which in turn are controlled by management. Thus we have termed management the metacontrollability of the enterprise.

Management is at the bottom of the top down model symbolizing the foundation (at the base) of the model. Thus everything rests upon management shoulders and although the other four elements are clearly linked within the enterprise and their action is systemic, influencing enterprise flexibility in terms of their scope of operation and particular role in the enterprise system, it is management which ultimately determines the other four and their successful interaction as well as the dynamics taking place in the ladder comprised of control actions determining flexibility; flexibility metrics linked to performance measures; operations' performance measurement system and finally the top of the ladder, enterprise

needs and objectives. Therefore we can say that enterprise flexibility, being a desired property of the enterprise system, whose action is indeed systemic in nature, is strongly leveraged by enterprise management and the success with which they can manage the different elements which comprise the control system of the enterprise, including management itself.

The success of failure of the dynamics shown in ladder going up to enterprise needs and objectives in the figure 4.3 is also management responsibility, therefore we may justly say that management is after all the nervous system of the enterprise, and thus it is in charge of the metacontrollability of the enterprise as a whole. This of course accounts for all the different types of flexibility that we saw earlier and also for stability, all being desired properties of the manufacturing enterprise.

Management determines and controls the control actions determining enterprise flexibility at every level of the enterprise system. These in turn are used to elaborate the flexibility metrics which are linked to performance measures and these metrics also provide feedback to management in order to adjust and correct misalignments which may affect strategic options.

Flexibility metrics in turn are responsible for adequately supporting the Operations' performance measurement system without which the control system would collapse and management would become blind to enterprise strategic performance. Thus there must be feedback between the two as in every other case in order for the system to learn and adjust itself until it finds its right setting. Finally it is the Operations performance measurement system which is closest to enterprise needs and objectives in the model, as it is clear that the information being gathered through this performance measurement system will in turn determine the management actions that are necessary, in terms of its role and hierarchy in the enterprise control system as the metacontrollability of the enterprise, to guarantee alignment and performance.

Although it is obvious that the remaining four elements of the enterprise control system impact the satisfaction of the enterprise needs and objectives differently, they all contribute to its sustainability and the degree of cohesion, integration and coherence in their operation will make a difference between poor performance and overall rigidity of operations and high performance, agile and highly flexible organizations which can easily and quickly adapt to changing scenarios and perturbations.

4.4 Implementing flexibility metrics in terms of enterprise performance measures

Determining what to measure can take considerable effort when the right focus is not in place. In order to build an efficient and effective enterprise control system, a measurement system equally efficient and effective must be in place since as everyone knows, we can not control what we can not measure. Data collection and processing systems for all enterprise operations that are tied to flexibility metrics will have to be implemented to produce the measures; everyone involved will have to be trained in using the systems and

measures at every level; and as the measures are used, some problems are sure to be identified that will require changes to the system.

Certainly developing the appropriate measures to have the ability to determine if sales and profit problems are caused by strategic options, operations, or both and how much of a factor it is the flexibility factor in the equation is not an easy task. Perhaps the greatest challenge faced when implementing flexibility metrics, in terms of enterprise performance measurement systems, is changing an organization's culture. We must not forget that culture is one of the key elements of the control system itself, and therefore its adequate disposition toward work flexibility and change must also be measured as well as measuring how proactive and effective the work force is in terms of accomplishing enterprise objectives that are closely linked to culture flexibility. This is of course a task that must be realized by enterprise management which, as we saw earlier, is at the top of the hierarchy in the enterprise control system, the control over the control if you will, and thus it is responsible for the metacontrollability of the whole enterprise system.

Using performance measures requires managers and employees to change the way they think and act. For most people, this is relatively easy, but for some, changing old beliefs and habits is very difficult. Overcoming such problems requires strong leadership to provide appropriate direction and support. The best measurement system in the world will yield few benefits if the right knowledge, skills, abilities, and values are not developed in a company. We must understand that an organization doesn't just interface with a measurement system; it must be part of the system itself. Therefore, we propose elaborating concrete flexibility measures that are linked to the five fundamental elements which comprise the enterprise controllability.

In order to have a good assessment of our enterprise control system performance in terms of being able to act quickly and effectively to provide the appropriate measures of flexibility and stability being required (control actions) by the enterprise, we have to develop an adequate measurement system. If we are to measure flexibility in the manufacturing enterprise, we have to make sure that appropriate flexibility metrics are developed that are adequately linked to the strategic needs and objectives of the enterprise. Hence we first have to make sure that we know what to measure in order to measure it well. Developing and implementing effective measurement systems requires leadership, commitment and hard work and we have to make sure that this effort will not go to waste.

Every company is different but one can start by looking at the core processes of the company and how these processes performance which span throughout the enterprise, may be affected (hindered) by flexibility problems ingrained in the organization, which can be linked to factors belonging to the five basic elements which comprise the controllability of the enterprise system, namely Management Flexibility (Harwood, 2004); Flexibility of Strategic Goals and Management Policies; Flexibility of Organizational Structure and Culture; Enterprise Infrastructure Flexibility, and Technology flexibility. A good example of what we are proposing has already been done to some extent in the large business reengineering wave that hit the United States in the 1990's in an unrelenting quest to achieve operational and business superiority over Japanese fierce competition, and which is present still today although to a lesser degree and often times not targeting enterprise flexibility directly as a goal in itself.

Hence, it is all too important for manufacturing enterprises to realize that enterprise flexibility is a key catalyst of enterprise performance at the organizational, operational and business level and that flexibility in itself is a goal that must be sought. It is also important to understand that flexibility can not be added or installed as if it were an addition to enterprise infrastructure. Flexibility must be engineered in the enterprise system by developing and integrating the appropriate control capabilities in the control system itself, the five basic elements which comprise the controllability of the enterprise. At the same time, enterprise flexibility must clearly reflect the company's strategic options since it is in how well these are served that the degree and success of enterprise flexibility may ultimately be measured. We believe that the benefits that may be obtained by achieving the latter can be in part summarized as follows:

- The ability to know what to enhance and what to prioritize in terms of the organization, operations and business needs in order to align with enterprise strategic options, making sure that these indeed represent the enterprise needs and objectives.
- Early identification of problems with the elements which comprise the enterprise control system and opportunities to correct them; the ability to reach the right balance between stability and flexibility in the manufacturing enterprise: that which allows for maximum enterprise performance without jeopardizing the system viability.
- Increased productivity, quality, and customer service at no extra cost to the enterprise system. When there is perfect alignment of operations and strategic options which effectively meet company objectives, the likelihood of having excess flexibility or not enough of it is little.
- A cohesive organization and a supporting culture working toward common goals.

Conclusions

Flexibility and stability are both desired properties of the enterprise system. They are both determined by the enterprise control system, which in turn is comprised of the five fundamental elements which, although acting differently, have an impact on enterprise flexibility, as we explained earlier. Flexibility as well as stability is systemic, and thus cannot be explained by isolated actions or relegated to a phenomenon that can be explained by entropy, or worse to try to increase flexibility by resorting to additions in just one part or another of the enterprise system alone without considering the dynamics and interconnectedness of the enterprise system elements as a whole.

Management is responsible for handling the controllability of the system and therefore it is the control over the control, which we have termed the metacontrollability of the enterprise. Management is both, at the top of the hierarchy of the control system of the enterprise and also at the bottom, representing its foundation. It is management which determines and controls the actions determining enterprise flexibility or the lack of it at

every level of the enterprise system. These in turn will be used to elaborate the flexibility metrics which are linked to performance measures of the enterprise and these metrics also will provide feedback to management in order to adjust and correct misalignments which may affect strategic options. Flexibility metrics are useful for adequately supporting the Operations' performance measurement system, without which the control system would collapse and management would become blind to enterprise strategic performance. Thus there must be feedback between the two as in every other case in order for the system to learn and adjust itself until it finds its right setting.

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