Flexibility and Performance:

A Literature Critique and Strategic Framework

Fernando F. Suarez, Michael A. Cusumano,
and Charles H. Fine

Massachusetts Institute of Technology
Sloan School WP# 3298-91-BPS
Version: November 1, 1991

I. INTRODUCTION

Much has been written about flexibility in recent years as this has become of critical concern to managers, academic researchers, and policy makers concerned with the evolution of production and design technology as well as firm and industry competitiveness. Yet there is little agreement on how to define flexibility, how to achieve flexibility, or what the costs and benefits of more or less flexibility actually are, if any. For example, some researchers have viewed flexibility primarily in terms of programmable machines and capabilities for mixing models in production (Jaikumar 1986, Fine and Pappu 1988). Others have viewed this in terms of the versatility of people and skills (Piore and Sabel 1984). Some researchers have discussed flexibility as a strategic variable that has to be consistent with the overall competitive strategy of a firm, but do not provide a conceptual framework for defining flexibility types and linking these with strategic options. Overall, the literature on the topic is fragmented and does not provide answers to basic questions that managers need to address: Under which conditions would a firm be likely to need a given type of flexibility? How can firms implement different kinds of flexibility? What is the impact of different kinds of flexibility on productivity, quality and competitive position?

This article attempts to answer these and other questions by providing a framework to analyze flexibility in terms of the strategic objectives of a firm as well as its impact on business performance. The central argument is that flexibility comes in various forms, each of which can be implemented in different ways and with different costs, but that the usefulness of flexibility depends on what a firm is trying to accomplish given its product strategy, competitors, demand, and other factors. Flexibility must therefore be viewed as a multi-dimensional concept that has more or less value to a firm not simply to support operations but to support strategic objectives. It also appears that firms position themselves, consciously or unconsciously, at a specific point within an efficiency-quality-flexibility spectrum. Consistent with other researchers in the field (Dertouzos, Lester, and Solow 1989, Senge 1990), we believe that the trade-offs among these three variables or goals have been considerably reduced in the last two decades. Still, firms have to make choices as to which goal to achieve first and at which level. Our contention is that the best performing firms in terms of measures such as market-share growth or profitability will show the best combination of efficiency, quality, and flexibility for their chosen market segment.

There are three main parts to this article. Part II provides a brief literature review and highlights the strengths and weaknesses of various branches of the literature. Part III presents a conceptual framework for analyzing in more detail the strategic value of different types of flexibility and various implementation options, with definitions of the constructs used and descriptions of the role of each within the framework. Part IV discusses several implications of the framework regarding expected interactions that have direct implications for competitive strategy and product development, and operations and technology management.

II. FLEXIBILITY LITERATURE: A CRITIQUE

Flexibility has often been defined as the ability of a system to respond effectively to changing circumstances (Piore 1989). This broad definition, used at least implicitly in some of the literature, does not contribute to the task of making the concept more operational. The rather narrow definitions used in most of the literature, where flexibility is usually associated only with the scope of the product line, do not contribute to operationalizing the concept either (Jaikumar 1986, Kulatikala 1988). A starting point to overcome these limitations is to realize that flexibility is a multi-dimensional concept. In this article, we attempt to isolate those dimensions relevant to the strategic analysis. Later, more specific definitions of the flexibility dimensions considered in this study will be presented. This section will review what has been written about the subject.

Although some foundation work related to flexibility was done several decades ago (for instance, Stigler 1939), the literature dealing specifically with flexibility is rather new. For most of this century, economies of scale and division of labor were the chief concerns of scholars and managers interested in industrial competitiveness. Some dimensions of flexibility proved to be important even early this century, as exemplified by General Motors' success with a broad product line *vis a vis* Ford's product standardization and emphasis on rigid mass-production and automation. However, most of the contributions to the flexibility literature we discuss have appeared in the past decade or two. As for our discussion here, we have chosen to leave out frameworks that deal with flexibility but not directly applied to manufacturing firms, such as the implications of "general-ism" and "specialization" strategies presented in the population ecology literature (Carroll 1988, Singh and Lumsden 1990), or discussions about "mechanistic" versus "organic" organizations found in the literature of organizational theory (Burns and Stalker 1961, Lawrence and Lorsch 1967). Many of the concepts that will be reviewed and developed in this paper parallel similar notions in these latter streams of literature. Thus, although these related frameworks form part of the general context in which our work is immersed, we do not add them to the discussion here. As it will be seen, taxonomies are already abundant in the study of flexibility.

The literature on flexibility can be divided into two major streams: empirical studies and analytical models. The empirical stream addresses issues such as why is flexibility important today, and what are the characteristics of flexible manufacturing systems and organizations as compared to more rigid ("mass-production") regimes. The analytical models literature has essentially provided a set of models that try to capture, usually in rather restrictive settings, the conditions under which flexibility may be valuable, and the relationship between flexibility and other policies such as inventory levels. In what follows, the main contributions and research focus of each stream of literature will be briefly described in order to identify the research opportunities in each.

Empirical Research

Researchers in this stream of the flexibility literature come from different fields or disciplines and have centered their respective efforts in different aspects of the problem. Indeed, empirical research may be grouped into three major concerns: (1) taxonomies of flexibility; (2) data-based studies of flexibility and performance; and (3) historical and economic analyses of flexibility.

Scholars coming mainly from the operations management field have written extensively on taxonomies of flexibility (see Table 1 for a list of the main contributions). They have pointed out that manufacturing flexibility is a multi-dimensional concept and have proposed several types. Given the background of the authors and their knowledge of production processes, an account of all proposed types of flexibility gives us a detailed map of where flexibility may arise in a production process. Browne's (1984) "routing flexibility" as the ability of a system of handling machine breakdowns, and Gerwin's (1987) "sequencing flexibility" as the ability to alter the sequence in which parts are fed into the process, are good examples of the level of detail that the authors have sought. As one might expect, there is significant overlapping among the types of flexibility proposed, and the use of different names to refer to the same type of flexibility adds some unnecessary confusion. A partial list of the types of flexibility proposed by different authors can be found in Appendix 1.

Studies that primarily review and improve on the different classifications proposed by different authors have also been classified in group one. Hyun and Ahn (1990), for instance, provide an extensive literature review on the many types of flexibility that have been proposed to date, grouped by discipline (e.g. economics, operations research). Although they attempt to go beyond the existing web of taxonomies, their "unified framework" is indeed a more elaborated taxonomy, where different types of flexibility are said to exist at the business, functional, and component level. Masri (1990) also advocates the idea that flexibility should be analyzed at different levels of the organization.

The second group of empirical research has been fed by scholars with backgrounds in both operations management and economics. The main characteristic of the research in this group is that the authors have collected and analyzed data on flexibility in order to support specific hypotheses. They have been separated as a group because data-based studies on flexibility are rather scant (see Table 1). Jaikumar's (1986) comparison between flexible manufacturing systems (FMS)[1] in the United States and Japan, or Tombak's (1988) sample of 1445 business units using PIMS data, are good examples of the few studies of this nature. Jaikumar finds that Japanese firms use more fully their FMS systems compared to their U.S. counterparts, which do not get all the flexibility that they could out of their FMS investment. Tombak relates flexibility to business unit performance, and he finds that flexibility is a statistically significant variable positively affecting performance. In a recent paper, Fiegenbaum and Karnani (1991) analyze data on 83 industries to study the

[1] This description may oversimplify reality. FMSs are usually limited to a particular family of products, thus to some extent they also represent irreversible investments.

differences between small and large firms in terms of what we will call volume flexibility (they use the term output flexibility). They conclude that small firms tend to show more volume flexibility than large firms, and that small firms are able to trade cost inefficiency with volume flexibility to increase their profits. Their data provide support for our hypothesis (see part III below) that volume flexibility tends to be important in industries with volatile demand.

The third and last group of empirical studies considered here describes the evolution of flexibility in operations as an attribute of strategic and economic importance for the competitiveness of a firm, industry, or country. Scholars in this group come basically from the social sciences, in particular economics, management, and political science (again, see Table 1 for a list of the main contributions). The common thread in these studies is the emphasis on the historical relationship between flexibility and industrial competitiveness, frequently portrayed as an evolutionary process that started long ago and has now acquired widespread recognition. There are, however, two main differences between studies in this and the second group: (a) the scope of studies in the third group is often broader than those of the second group; it is often society at large which is at stake; and (b) the third group is mainly concerned with the importance of flexibility and the development of conceptual frameworks to understand it, rather than with data collection efforts to test specific hypotheses -- the focus of the second group.

An important piece of work in the historical/economic stream of applied literature is that of Piore and Sabel (1984), who present flexibility (more specifically, a mode of industrial organization they call "flexible specialization") in contrast with mass-production, and provide a detailed account for why flexible firms are expected to dominate most markets in the future. Cusumano (1988, 1991) describes the evolution from conventional to flexible factories and elaborates on the case of software production, but using a contingency-theory framework, he proposes that mass-production (i.e. non-flexible production) is still the right strategic choice for commodity-type products that face a stable and simple competitive environment. Piore (1989) also moves in the direction of presenting a spectrum of industrial organization possibilities, with different levels of associated flexibility.

Analytical Models

Most of the modelling effort on flexibility comes from the operations research and operations management fields. Fine (1989) classified the streams of work into four groups[2]: (1) flexibility and life cycle theory; (2) flexibility as a hedge against uncertainty; (3) interactions between flexibility and inventory; and (4) flexibility as a strategic variable that influences competitors' actions (mainly game-theoretical models).

Many studies have a common setup: two types of production technologies are available to a firm, one dedicated and one flexible (a flexible manufacturing system).[3] An FMS can produce two (or more) products very efficiently, but it is assumed to cost more than a dedicated line. Different assumptions about demand (random, seasonal, or S-shaped, for instance), timing, and reversibility of the investment are made in order to suit the particular problem being explored by the author. Hutchinson and Holland (1982), for instance, assume that capacity can be added incrementally with an FMS, and also assume a product-life-cycle type of demand. Then they proceed to determine conditions under which one technology is preferable to the other.

---

[2] Fine (1989) is a good source for a more detailed review of theoretical studies on the topic. Fine actually presents only the last three groups, but discusses separately papers that we have classified as the first group here.

[3] A flexible manufacturing system or FMS is a computer-controlled grouping of semi-independent work stations linked by automatic material-handling systems.

In general, the goal of most studies is to improve our intuition about the costs and benefits of flexible technology, by determining conditions under which a given technology (flexible or dedicated) is superior. Although an FMS is thought to require a bigger initial investment than a single dedicated line, they have associated benefits that must be balanced against the price advantage of dedicated systems. The benefits of an FMS vary for each group of studies. For studies in group (1), FMS gives the possibility of capturing intertemporal economies of scope. In group (2), the value of an FMS stems from its ability to cope with a range of types of uncertainty. In group (3), the benefits are associated with lower inventory holding costs, given the fact that an FMS tends to reduce the need for cycle, safety, or seasonal inventories. Finally, in group (4), an FMS is a strategic weapons, i.e. they serve the purpose of disciplining competitors, for instance, through threats of entry and invasion of other firms' markets.

These models often show that there is no clear-cut answer to the question of which production technology is better. In Hutchinson (1986), for instance, the advantage of an FMS over a dedicated technology increases as the rate of new product introductions and the maximum capacity of an FMS increases, and decreases in the interest rate and the average volume per part produced. This contrasts with the apparently common belief, at least until a few years ago, that an FMS and automation in general are always superior. In fact, in many of the models the players are worse off with an FMS. In studies of group (4), for instance, and under the assumptions of a quantity game, the FMS player can be worse off because his threat of entry is not credible (Fine and Pappu 1988). A firm that invests in a dedicated line sends a clear message that it will stay in that market for a while; its investment is "irreversible" in the sense that the firm does not have the option of exiting the market to produce a different product (as an FMS player does).

In short, mathematical models on flexibility have added important insights to the problem of technology selection. There are, however, several problems with this literature, as there are with applied studies.

Shortcomings of Empirical Studies

A glance at the empirical studies listed in Table 1 reveals that most of the existing literature on flexibility has been concentrated in groups one and three (taxonomies and historical/economic analyses of flexibility), while studies with crisp hypotheses tested through intensive data collection are scarce. The lack of data-based studies highlights the practical problems that may arise when measuring flexibility, and thus points to a fruitful area for future research.

One of the first issues that stands out in an analysis of the literature is the little cross-fertilization that exists among the three streams of applied studies in terms of building upon the other groups' contributions. This may be in part due to the different backgrounds of the researchers in each group. Whatever the cause, the result is that most of the existing studies only address a specific slice of the flexibility problem. Take any of the applied studies in the first group, for instance. Although the identification of different types of flexibility is interesting and important, none of these studies has attempted to measure each flexibility type in a real case and then examine propositions with empirical data. More importantly, none of these studies (with the exception of the review papers, to some extent) has complemented the taxonomy effort with considerations about a firm's strategy (product strategy in particular), characteristics of the industry, organizational structure, demand and other environmental factors.

Data-based studies on flexibility and performance (those in the second group) have in turn largely viewed flexibility as a uni-dimensional concept, ignoring the contributions of the first group of studies. Jaikumar (1986), for instance, implicitly refers to flexibility as the ability of a system to produce a wider variety of parts. Following the taxonomy of Appendix 1, we could term this "mix flexibility," yet this is merely one of the different types of flexibility available to a firm (although it is probably the most obvious one). Fiegenbaum and Karnani (1991) only consider volume flexibility. Tombak and de Meyer (1988) move toward acknowledging the contribution of taxonomies by noticing that managers of firms planning to introduce an FMS are not only concerned with "mix flexibility," but also with flexibility to accommodate the variance in inputs to the production process (something that Mandelbaum 1978 had already termed "state flexibility" and Gerwin 1987 "material flexibility" -- see Appendix 1).

An additional weakness of empirical studies in the second group is the fact that they treat flexibility and flexible manufacturing systems as equivalent concepts when in fact they are not the same. As we will see later, an FMS is only one way to acquire flexibility. Other channels include workers with broad skills, flexible production management techniques, and the development of a network of dependable suppliers. The largely disappointing experience of General Motors Corporation with flexible automation in the 1980s, as opposed to "softer" solutions such as the NUMMI (New United Motor Manufacturing, Inc.) joint venture with Toyota, is an eloquent testimony to the importance of factors other than direct investment in FMS on the flexibility (and quality) of a firm's operations.[4] Also, studies in the second group often fail to establish connections between the level of flexibility observed in the data and considerations such as product strategy, industry life cycle, profitability, etc. As

[4] See also "The U.S. Automobile Industry in an Era of International Competition: Performance and Prospects." working paper, MIT Commission on Industrial Productivity.

a result, it is difficult to extract robust or general conclusions about the usefulness of flexibility in a production process.

Similarly, the third group of empirical studies (historical/economic analysis) shares some of the above-mentioned weaknesses. Few studies present data to back up the propositions put forward or pay attention to the different types of flexibility. In nearly all these studies, moreover, the definition of flexibility remains rather vague, although, again, they frequently view flexibility as product diversity or "mix flexibility."

A common weakness to the studies in all three groups, with the exceptions of Cusumano (1988, 1991) and Tombak (1988), is that they assume, either implicitly or explicitly, that more flexibility is always better.[5] This, as mentioned above, is in contrast to many models in the mathematical literature where flexibility may actually make the firms worse off (Gaimon 1988, Fine and Pappu 1988). Therefore, important research remains to be done in determining the conditions when flexibility, or more explicitly, each type of flexibility, can enhance a firm's competitive position.

The unit of analysis considered in the different studies varies from narrow focuses such as the individual machine, usually in studies from the first group, to the firm or plant level, in studies from the other two groups. Overall, scholars have thought of flexibility as something internal to the firm, either as strictly relevant to the shop floor (Gerwin 1987, Buzacott 1982) or as encompassing the whole firm as an organization (Hyun and Ahn 1990). While this may be a natural and intuitive conceptualization, it is also true that flexibility may arise externally, through the linkages of a firm's value chain with those of external organizations. We already mentioned suppliers as a possible locus of flexibility. Similarly, distributors may play

---

[5] Tombak does not question the assumption *a-priori*, as Cusumano does, but he addresses the issue by studying the relationship between flexibility and performance.

an important role when the goal is, say, to get products faster to customers.

Finally, a common weakness in most empirical studies on flexibility is that they consider flexibility in isolation from efficiency and quality, two other important performance parameters of an industrial firm's operations. The only exceptions to this rule are economics-based papers generally building on the flexibility notion pioneered by Stigler (1939), where firms achieve volume flexibility at the expense of efficiency (Fiegenbaum and Karnani 1991, Mills and Schumann 1985). The trade-offs among these three parameters of flexibility, quality, and efficiency are probably of crucial importance when it comes to evaluate the feasibility of acquiring flexibility, and its effect on the firm or business-unit competitiveness. We believe future studies in the area have to address these trade-offs explicitly.

Shortcomings of the Analytical Models

Despite the insights of the analytical models of flexibility, there are several weaknesses. As in the applied literature, most models make no distinction between flexibility and flexible manufacturing systems, and do not recognize that an FMS is only one possible way of achieving flexibility. Flexibility is almost invariably thought of as a box of embodied technology (an FMS) that a firm can easily buy and operate (Hutchinson and Holland 1982, Fine and Li 1988, Karmarkar and Kekre 1987).

Existing analytical models also ignore the role of worker training and skills and production-management techniques in providing flexibility to a firm, as well as the potential role of suppliers and distributors. These omissions are partly a direct result of the narrow concept of flexibility upon which most of the models are based. Moreover, in most papers flexibility is seen as a "0" or "1" variable, i.e. the firm either buys the FMS and becomes flexible, or buys (or stays with) an inflexible technology. Very few papers present richer model (among the few exceptions is

Gupta, Buzacott, and Gerchak 1988). This is clearly a major weakness because empirical or historical studies of actual firms and factories suggest they exhibit a much broader spectrum of possible flexibility levels and types, with firms choosing a desired type and level (or achieving it without an explicit strategy).

Some of the analytical models literature on flexibility focus on common concerns in the field of operations management, addressing issues such as inventory levels and scheduling (Graves 1988, Porteus 1985, Caulkins and Fine 1990). They have tended to neglect strategic or competitive as well as organizational issues, no doubt reflecting the background of researchers contributing to this literature (almost all of them have operations management or operations research training). Thus there appears to be much room for theoretical papers addressing the strategic and organizational components of flexibility, along the lines of Tombak (1988) or Fine and Pappu (1988). As pointed out in Fine (1989), it is likely that analytical models in future years will address these concerns more frequently.

Finally, there are at least a couple of issues regarding the concept of flexibility used in the models. Authors of analytical models have tended to think of flexibility as the ability to produce a variety of products -- what has also been referred to as mix flexibility (Hutchinson 1986, Fine and Li 1988). Few attempts have been made to consider other types of flexibility, which would add new dimensions to the theoretical analysis. A good exception to this later statement is Gaimon (1988), who considers the benefit or liability of what this article will later describe as "volume flexibility," i.e. the ability to contract or expand production under the assumptions of open-loop or closed-loop dynamics.

A related point, although mostly valid for models in the fourth group, is that most models tend to consider the ability to jump into and out of markets as the major (or unique) consequence of flexibility (see, for instance, Fine and Pappu 1988).

Flexible manufacturing systems are thought to produce very different products, which helps authors of analytical models justify their assumptions about the advantages of dedicated technologies over an FMS in terms of the "threat credibility" and "irreversibility" of the investment. However, an FMS can usually produce only parts or products within a particular family, which means that the products or parts are still likely to be in the same industry and market. To some extent, investment in FMS is also irreversible. Modelers thus need to become more careful in their treatment of flexibility.

Summary

The discussion of weaknesses in recent literature on flexibility suggests several ways to improve how researchers address flexibility theoretically and study flexibility in practice. In particular, any new framework needs to incorporate at least four notions: (1) different types of flexibility; (2) the strategic positioning and goals of the firm (or specific company divisions or factories); (3) distinctions between flexibility in general as opposed to flexible automation, as well as other means by which a firm might achieve different types of flexibility; and (4) the trade-offs or interconnections among flexibility, efficiency, and quality. Applied research faces the challenge of gathering data to test specific hypotheses derived from a richer framework than previous researchers have proposed.

III. A STRATEGIC FRAMEWORK

This section builds on existing literature to propose a framework that considers three interrelated sets of variables, each of which generates several hypotheses that should be empirically testable: (1) the different types of flexibility, as suggested by variety of researchers; (2) factors that affect a firm's need for each type of flexibility; and (3) factors that affect the implementation of each type of flexibility at the firm level.

An issue that needs to be discussed before reviewing the details of the framework is the unit of analysis. There is no difficulty in the simplest case, a single-industry, single-plant firm, because the plant, business-unit, and firm levels are the same. With large, multi-plants firms, however, determining the unit of analysis becomes more difficult. For example, mix flexibility may be achieved at the firm or business-unit levels through either a multi-product plant or a collection of single-product plants. Thus, although individual plants may have low mix flexibility, they may indeed be part of a larger strategy and structure to achieve mix flexibility at the business-unit or firm level. For simplicity, this article and much of the theoretical literature frequently refer to the unit of analysis as "the firm," although in many cases the relevant unit of analysis will be a business unit or a factory, and perhaps even a particular manufacturing line within a factory.

Different Types of Flexibility

Four types of flexibility (for mix, volume, new products, and delivery time) have been chosen from the many types discussed in the literature (see Appendix 1). These appear to include other kinds of flexibility, both of a general nature and those related to specific manufacturing or operations problems. For example, routing flexibility, defined in Appendix 1 as the ability to reroute the production flow should a breakdown occur in one of the production stages, can be considered within the concepts of volume flexibility and delivery time flexibility. A system's ability to handle uncontrollable variations in a production process or the composition and quality of inputs will necessarily be reflected in the system's ability to handle volume fluctuations and speed up delivery. Since these four general types also appear to affect business performance more directly than more specific kinds of flexibility, they have special relevance for linking operational capabilities with managerial strategy. Table 2 presents a more detailed working definition of the four basic types of flexibility.

Need for Flexibility

An important area for any strategic framework considering flexibility are the factors determining when a business unit might need different types of flexibility. Gerwin (1987) proposes that different types are useful to respond to uncertainty of various kinds, although his flexibility types tend to suffer from the weaknesses described in the previous section, namely, they often are difficult to relate directly to strategic or competitive concerns since they focus primarily on engineering problems such as sequencing or rerouting flexibility. Fiegenbaum and Karnani (1991) stress the importance of the demand characteristics (i.e. volatility) on the requirements for volume flexibility, although, like other authors, they tend to employ no more than a vague notion of "environmental volatility" to explain the need for flexibility. The literature reviews suggests that a more careful description of the factors affecting the need for each flexibility type is a prerequisite for better understanding the strategic importance of flexibility for the firm in general. Table 3 outlines the five factors affecting the need for flexibility proposed in this paper.

The specific <u>product strategy</u> followed by a firm clearly affects its need for flexibility. We may expect firms competing in the high-end of markets to need more mix flexibility (ability to produce many products -- at the limit, perfectly customized products) than firms competing in the low-end, where product standardization is greater. Furthermore, firms whose strategy is to compete in several related industries may need more mix flexibility than single-industry competitors. Along the same lines, firms competing in a market with highly unpredictable consumer demand may need to be more flexible. They will have to be able to react quickly to meet customer preferences, which implies both volume and mix flexibility.

An important issue that is seldom addressed in the literature is the fact that flexibility is a relative measure -- relative to that of competitors (and to the market demand). This means that there are not "flexible" firms or factories as such, but only organizations that are more flexible than others. That is why competitor behavior is one of the determinants of how much flexibility a firm needs. If competitors are constantly introducing many new improved products embracing a wide variety of features, then "new product flexibility" is likely to be important for the firm or business unit, unless it competes in a specific segment or niche of the marketplace where other characteristics (such as high product performance) are more important.[6] If competitors offer fast delivery to customers that are sensitive to delivery times, then "delivery time flexibility" may be more important.

It is also useful to consider the location of the industry or its products in terms of the product life cycle,[7] which can be thought of as a proxy for the type of demand and competition that firms are most likely to encounter. In general, young industries may expect volatile demand and competition centered around new products, making new-product flexibility (as well as mix flexibility, to some extent) highly desirable. Mature industries tend to face stable demand for a well defined product, which tends to reduce the need for flexibility. It is true, however, that these "pure"

---

[6] In Appendix 1, new-product flexibility may be found as "changeover flexibility" (Gerwin) or "product flexibility" (Browne).

[7] The importance of the industry life cycle has been championed by scholars such as Abernathy and Utterback (see their 1975 joint paper, for instance). More recent contributions using and extending the A-U model are those of Anderson and Tushman (1986, 1990), Utterback and Suarez (1990), and Suarez and Utterback (1991).

configurations may differ in reality. In particular, some mature industries have been invaded by new entrants with innovative products, making it important for incumbents to remain or become flexible and react quickly. The role of these "discontinuities" has to be taken into account to achieve a more realistic description of industry or product life cycles. Even in mature, rather stable industries without the threat of technological discontinuities, fast delivery may still be a source of competitive advantage, prompting firms to remain flexible in that dimension.

The last factor identified here as having a major effect on the need for flexibility, <u>end-product characteristics</u>, applies primarily to intermediate industries, i.e. industries whose output is an input for another downstream industry.[8] The characteristics of the end product affect the required configuration of flexibility of the intermediate producer in several ways. For instance, technology-intensive end products, where the pace of progress is rapid, will require more new-product flexibility from the intermediate industry. Similarly, non-standardized and complex end products (such as very small electronic products) might require greater mix flexibility from intermediate producers such as PCB assemblers or particular processing operations. Also, end producers using "just-in-time" production systems may impose greater delivery time requirements on their intermediate suppliers.

Implementation of Flexibility

In addition to knowing which types of flexibility to monitor and how each may be useful, management also needs to understand that there are different ways to implement each type of flexibility. Very little work, however, has been done so far

[8] We could consider this factor as part of "consumer demand" to the extent that the downstream industry represents the demand of the intermediate industry. We prefer, however, to separate the case of intermediate industries because of several peculiarities they present.

on this issue of flexibility implementation. As pointed out earlier, most studies have assumed or implied that flexibility can only be acquired through capital investment in new machinery. But, in practice, firms employ various mechanisms to improve their levels and types of flexibility. After considering the literature, especially on manufacturing flexibility, it appears that there are seven flexibility source factors that make it possible for a firm to implement the types of flexibility considered to be most fundamental. Table 4 outlines these flexibility source factors. Our contention is that these seven factors affect each flexibility type in a different way. Thus, firms that want to stress different kinds of flexibility because of, for example, different demand patterns, can concentrate on a different set of source factors.

More specifically, production technology refers to the capital intensity of the production process and the characteristics of that capital. We are concerned with two basic points here: how capital-intensive and automated the production process is (as opposed to labor-intensive and manual), and the extent to which capital is flexible (for example, adaptable manually or computer-programmable) or dedicated (not adaptable and non-programmable).

Production-management techniques refer to the extent to which particular kinds of production methods that enhance flexibility, especially those associated with Japanese management, are used. These have been labelled "fragile" or "lean" production-management techniques in a study on the automobile industry conducted at the Massachusetts Institute of Technology (see Shimada and MacDuffie 1987, Krafcik 1988, Womack et al. 1990). Our usage is similar but contacts a slightly different emphasis.[9] We also consider specific techniques such as total quality

[9] The use of the terms "fragile" and "lean" here differ somewhat from the cited authors, who used the concepts to describe a whole production system, focusing on the interdependence between hardware and human resources (a system is said to be fragile and lean when it depends heavily on human resources and does not contain many buffers, such as extra in-process stocks of parts). Our framework separates

management, just-in-time production, quality circles, personnel rotation, reduced hierarchical levels, teamwork approaches as opposed to functional division, and similar measures as contributing to flexibility.

Product development process refers to the extent to which the principles of "design for manufacturability" have been applied (reduced number of components, components modularization and standardization for reusability in different products or models, simpler designs). During the last few years there has been an increasing interest in these types of design techniques and processes (see, for instance, Kenichi Imai et. al. 1985; Clark, Chew, and Fujimoto 1987; Whitney 1988). This literature has not had flexibility as its focal point, although the implications of product design for flexibility are easily traceable. For example, product design has direct effects on the unit-cost of production and on the ability of a firm to produce new products in a short period of time. Production lead times are related to new-product flexibility, while unit costs affect the trade-offs between process flexibility and efficiency. Modular design concepts have the potential to enhance both mix flexibility and new-product flexibility, in addition to affecting manufacturing and product-development costs.

In the area of worker skills and training, we are primarily interested in differences that may arise in terms of the types of skills that workers possess (e.g. specialized versus broad skills) for operations that are not totally automated. In general, firms pursuing high divisions of labor, and therefore fostering specialized skills in their workers, will tend to be less flexible than firms relying on a more broadly-trained worker that can adapt more quickly to new products or product changes, or to new technologies.

---

hardware (production technology) from the human-resource component of the production system (production-management techniques, work force skills and training) since such a breakdown appears more useful for analyzing the sources of flexibility and their respective contributions.

Labor policies are mainly associated with two issues: flexibility in firing and hiring, and in changing the workforce wage level and structure. In the labor-relations literature, these issues fall under the rubric of employment security and compensation policies. Policies such as secured permanent employment or localized and contingent pay procedures will substantially affect volume flexibility in plants that are not fully automated, as discussed in more detail below.

Suppliers & distributors relationship tries to capture the degree of cooperation or integration that a firm achieves with its suppliers or distributors in cases where all materials, parts, and operations are not produced or done in-house. This integration includes not only formal outside contracting but also joint staffing and cooperation in product development or quality and productivity improvement. This area is important because a firm can achieve or enhance different types of flexibility by relying on dependable and effective suppliers and distributors. For example, when faced with time-sensitive orders, a firm can subcontract parts that it would otherwise manufacture internally, and thus be able to cope with changes in the volume demanded. Similarly, in many industries it would be possible for a firm to shorten the "time-to-customer" period through coordination and better use of the distribution network. Thus, flexibility is not limited to the boundaries of the firm, and in fact can arise in any segment of the supplier-manufacturer-distributor value chain.

Finally, accounting and information systems also affect the implementation of flexibility by a firm. For instance, an effective information system in place can lead to dramatic improvements in the time it takes to process a customer order, thus enhancing the delivery time flexibility of the firm. The impact of accounting systems on flexibility is somehow more indirect, but no less significant; the accounting system in use will have important policy implications. It will influence, for instance, capital investment decisions such as the purchase of an FMS of other product-flexible production technology (thus affecting mix flexibility). Moreover, the use of an effective accounting system such as an activity-based cost system (ABC), will uncover areas of the operations where improvement is possible (e.g reduction in set-up costs). This in turn may lead to improvements in productivity, flexibility, and quality (Kaplan 1989). Overall, accounting and information systems have the potential to affect the four types of flexibility we have identified in this paper.

Schematic Representation of the Framework

The central contention of the framework proposed in this article is that, assuming comparable levels of product or service quality and overall efficiency in operations, firms that consistently perform better than competitors in its markets should exhibit a closer match between the need for flexibility, as determined by strategy, competition, demand, and other factors discussed above, and the different types of flexibility that exist. Other historical or empirical studies, beginning with Chandler (1962), have sought evidence of such a "fit" among strategy and structure, and the effect on performance. Not all have found precise matches, especially given the complexity of strategic, environmental, and organizational variables, as well as the difficulty of specifying precise measures and collecting appropriate statistical data (Venkatraman 1989). Nonetheless, if the framework in Figure 1 illustrates crucial interrelationships, as we believe it does, then there should be some measurable correspondence between needs for flexibility and how well firms respond to these needs as well as some impact on performance.

To represent some of the complexity involved in these issues, we have divided Figure 1 vertically into two realms (the firm and the environment) and horizontally into three stages (need for flexibility, implementation of flexibility, and the match between the two). Out of the five factors that affect the need for flexibility, only product strategy is within the internal realm -- ultimately, a firm decides where to compete. The other four factors are external to the firm, i.e. part of the environment, and thus are depicted on the left side. Together, these four factors comprise an "optimal configuration" of flexibility types and levels needed. Firms that attempt to implement a particular optimal configuration should achieve the desired configuration so that there is an "observed configuration" of flexibility types and levels. This implementation of flexibility, defined in the framework as Stage II, is represented in the lower part of Figure 1.

Out of the seven factors listed as affecting the implementation of flexibility, four fall within the control of the firm: production technology, production-management techniques, product design, and accounting and information systems. The other three factors are only partially controlled by a firm, that is, for them the environment also plays some role. These latter three factors are depicted in Figure 1 as being mostly, but not completely, within the realm of the firm. The environmental characteristics that affect these factors are listed on the left of Figure 1 (the external realm). For example, the relationship with suppliers not only depends on a firm's policy regarding supplier relations, but also on the policies of the suppliers themselves. Similarly, the employment security and compensation policies applied by a firm are not only shaped by its own labor policies, but also by existing government regulations. Nonetheless, since firms still have a great deal of influence over these three factors.

Finally, Stage III at the center of Figure 1 illustrates the importance of the fit between flexibility requirements and flexibility implementation, i.e. between the required and observed configurations of flexibility. To generate specific hypotheses for empirical research, as discussed in the next section of this article, three sets of relationships appear to be particularly important: (1) The match between the types of flexibility shown by each firm in the industry and the different factors affecting the need for flexibility. In general, high-performers in each industry should tend to be those which match more closely the levels and types of flexibility required by their product strategy and environment. (2) The relationship between flexibility type and the seven factors affecting the implementation of flexibility. Of special interest here is the relative influence of each source factor in achieving a given flexibility type; specific relationships of this kind should guide firms in the implementation of their flexibility goals. (3) The relationship of different types of flexibility with productivity and quality. There is conflicting evidence from other research regarding whether increases in flexibility (such as product mix) detracts from productivity and quality or has no specific impact in a well-managed production environment.

IV. IMPLICATIONS OF THE FRAMEWORK

The three distinct parts of the framework presented above lead to several implications regarding the conditions under which a firm should need different types of flexibility as well as the relative importance of each source factor in the implementation of each flexibility type. These implications, particularly those related to the implementation of flexibility types, should be explored further with empirical data before making any definite conclusions about relationships or specific strategic recommendations. A framework is useful, however, to provide general guidelines for managers as well as to set an agenda for future research. Such guidelines are summarized in Tables 5 and 6. Table 5 describes how the different need factors identified should affect the need for each flexibility type. Table 6 illustrate some expected relationships between the seven flexibility source factors identified and each flexibility type.

Flexibility Need Factors

Mix flexibility is likely to be an asset when a firm follows a customization strategy or when it follows a full-line approach, i.e. to serve most segments of the market. Competitor behavior may also imply the need for mix flexibility; the latter is valuable when competitors are themselves full-line producers or when competition stems from the presence of several close substitutes. Mix flexibility may also be important when demand is heterogeneous or volatile, and when complementarities among different products are highly valued by consumers (competitors may even exploit these complementarities by cross-subsidy prices). The latter implies that having a wider product line becomes a strategic weapon.

In the case of intermediate products, mix flexibility will be needed when the end application itself comprises a large number of products trying to satisfy a heterogeneous final demand. A heterogeneous end-product line will probably imply a greater need for mix flexibility from the intermediate producer. Finally, mix flexibility may be important in the early or transitional stages of an industry or product life cycle, where demand is large but not too standardized, and firms compete by introducing multiple products. Even in relatively mature markets, competition may switch from low-cost production to product differentiation (as in the auto industry during the 1920s or 1980s), making mix flexibility an important strategic variable.

New-product flexibility should be needed when a firm decides to compete in technology-intensive markets, where the pace of innovation or product differentiation is rapid. It should also be useful in the case of markets subject to changing fashions or trends. In turn, competitors that are innovative and come out with new products and ideas frequently should be able to charge a premium for their greater new-product flexibility. This type of flexibility should also be important when demand is not well defined, either because consumer tastes are changing or because consumers do not have enough information about where the technology or market preferences are going to make sound decisions. In such situations, rapid introduction of new products should give a firm a better chance of capturing a significant share of the unstable demand. Demand in a state of flux often corresponds to the early or fluid stage of the industry life cycle, before the emergence of a dominant design. But new-product flexibility may also be needed in later stages of the industry life cycle, particularly when a mature industry is experiencing a technological discontinuity.[10] For an intermediate producer, new product flexibility should be needed when the pace of technological progress in the end product market is rapid. New, more technologically sophisticated end products should require rapid technological advances and rapid product introductions from the intermediate producers.[11]

Volume flexibility should be useful when demand volume (not the specific product) is difficult to predict for a given firm. In terms of strategy, this reflects the selection of an industry or market segment where demand traditionally presents high uncertainty. Volatile demand volume is, obviously, a factor that makes volume flexibility very important. In turn, situations where the production capabilities of competitors are difficult to predict should put a premium on volume flexibility, because a firm that can react quickly to fill the demand gaps left by competitors (in the

[10] Indeed, a technological discontinuity may represent the highest need for new product flexibility on a firm, because a firm (often the incumbent) is forced to develop new products based on a radically different technology. The new products sometimes have little resemblance with the old ones, other than the fact they address the same market need.

[11] In economics, the demand for the intermediate output is known as a "derived" demand, i.e. derived from that of the end product. Thus, the intermediate demand will tend to mirror the changes and requirements experienced by the end-product demand.

case of competitors' unexpected underproduction) should have an advantage.

Volume flexibility should also be more valuable in the transitional stage of an industry or product life cycle, where demand growth is highest and therefore the ability to quickly change production volume is an asset. However, the presence of technological discontinuities, often late in the industry cycle, may also require volume flexibility. Technological discontinuities (and other crises) often imply a major restructuring effort on the part of the incumbents or firms with the old technology. Significant layoffs and a shrinkage in production usually accompany restructuring (the experience of Chrysler in the late 1970s or that of British Leyland in the mid 1970s are examples of this). Volume flexibility may help weather such storms by making possible profitable operations at lower volume. Volume flexibility may also be an asset in the presence of "network externalities," as discussed below. For intermediate industries, volume flexibility should be important when the end product demand is volatile or difficult to predict.

<u>Delivery-time flexibility</u> should be important when demand is sensitive to time, for example when consumers cannot wait too long; possible exceptions are the very high-end, high-quality market segments, where firms may have products with such a strong brand name and sufficient differentiation from the competition that they can afford to deliver products later than other producers, or in commodity markets, where products and demand are certain, and orders are stable and placed well in advance. Delivery-time flexibility should also be associated with a later stage of the industry or product life cycle, when competition, especially for commodity products, centers on variables such as price, delivery time, and service.

Delivery time flexibility may be important in other stages of the industry cycle, however, such as when positive network externalities exist.[12] If positive network externalities arise, it is in the interest of a firm to reach customers as quickly as possible so that its product has a higher market share and is more likely to become the industry standard. Sectors such as computers, semiconductors, and integrated circuits have at times exhibited this pattern, although standardization in mass consumer markets usually requires years and may not be only affected by this variable (Cusumano, Mylonadis, and Rosenbloom 1991). On the other hand, intermediate producers will most likely need delivery time flexibility when the end- product firms that buy their products embrace production management techniques such as just-in-time systems, which require frequent delivery of small lots of components "just-in-time" for assembly.

While the above discussion assumes that some flexibility types will be more valuable than others, depending on the specifics of the situation for a given firm or unit of the firm, it must be recognized that flexibility is not the only variable that explains performance. Some combination of efficiency and/or quality in goods and services are at least two other aspects of performance that a successful firm operating in a competitive market should exhibit. An empirical study of flexibility should, however, be able to measure the impact different flexibility types have on various measures of performance and total quality, including customer satisfaction.

Flexibility Source Factors

The flexibility literature, especially from the field of production and operations management, also makes it possible to suggest how firms might use one or more of the

[12] Positive network externalities are said to exist in an industry when a good is more valuable to a user the more users adopt the same good or compatible ones. For examples of literature dealing with network externalities see Farrel and Saloner (1985, 1986), and Katz and Shapiro (1985, 1986).

various flexibility source factors to achieve different types and degrees of flexibility in manufacturing. Although these relationships are contingent upon various factors, making precise theoretical linkages difficult to draw, we have attempted to capture the most important ones in Table 6. An empirical study, nonetheless, should find relationships in the directions summarized in Table 6 and described in the text below, given particular conditions, as well as establish how well different source factors perform in achieving a particular kind of flexibility, in terms of relative costs, quality, customer satisfaction, contribution to a firm's market-share growth, or other areas.

For example, in non-automated and even some automated operations, the implementation of mix flexibility should be strongly influenced by production technology (i.e. capital investment and the degree as well as type of automation), production-management techniques, product design, and worker skills and training. Theoretically, a firm could obtain full-line mix flexibility with separate dedicated production lines or a series of focused factories. In practice, that strategy may be more costly than obtaining mix flexibility through investing in an FMS or similar technologies based on programmable automation, since separate lines or factories may result in higher minimum-efficient scales of operation and higher average unit costs.

As seen in discussions of conventional mass production versus Japanese approaches, various production techniques can also enhance the ability of a factory to handle a wide mix of products easily. Similarly, product design affects mix flexibility directly to the extent that a firm follows principles of design for mix flexibility or components reuse. In particular, a reduced number of standard components used in multiple products creates the possibility of producing different products (made out partly or totally of different combinations of those components) without a significant increase in total costs. The workforce also has a direct effect on mix flexibility to the extent that workers with broad skills, particularly in production settings with limited automation, should be better able to make a wide variety of products than workers with narrow, specialized training. Suppliers can have a major impact on mix flexibility as well if a firm subcontracts a large number of critical components or assembly operations.

Similar concerns apply to other kinds of flexibility. For example, with regard to new-product flexibility, fixed automation is usually detrimental, while easily programmable automation can often handle new products as well as a wide product mix with little cost in terms of production efficiency and quality (down time, errors, etc.). The degree of newness in the product design, workforce training, and the degree of dependence of suppliers (or distributors) on fixed routines also affects how quickly or easily a firm can introduce new products. The type of information system used by the firm also affects new-product flexibility by making it easier (or more difficult) for different teams within the organization to communicate and exchange information.

On the other hand, volume flexibility may be most strongly influenced by the labor policies of a firm or by its commitments to suppliers and distributors (assuming full plant utilization. Companies that are committed to workers and suppliers cannot easily reduce their level of operations during demand downturns. Similarly, a firm that sets wages by bargaining and wage formulas (as in the "traditional union model" described by Kochan et. al. 1986), will also have more difficulties with low volume production than another firm whose wage system is localized and contingent on the firm's performance in the marketplace. A close and cooperative relationship with suppliers can also result in a greatly enhanced volume flexibility, if suppliers are willing and able to respond quickly to unscheduled changes in production levels.

Delivery-time flexibility should be strongly affected by production-management techniques, such as the Japanese just-in-time systems, as well as by relationships with suppliers (to provide components on short notice), with distributors (to deliver goods quickly on short notice), and by the information system in place (the speed of the information flow within the firm). Labor policies may play a role if a firm needs to add people quickly within the firm to fill special orders. Production technology may also be important if, for example, set ups require long preparations.

V. CONCLUSIONS

As stated at the outset of this paper, the literature on flexibility to date has been weak in terms of establishing probable connections between flexibility in operations and a firm's strategy, competitive environment, and business performance. Much of the literature also focuses on how flexible automation is. This article attempted to overcome some of these limitations by providing a framework to conceptualize the need for various kinds of product and process flexibility as well as how firms might implement these flexibility types in a variety of ways. We have also suggested several implications of the framework that can be developed further into empirically testable hypotheses.

Future research needs to explore these propositions through research done not merely at the level of manufacturing machinery or production lines, as in many previous applied studies, but at multiple levels. These need to consider the potential contribution or constraints of production techniques, suppliers and distributions, worker skills, labor policies, and product design, as well as production technology.[13]

Finally, we think that integrative approaches to operations strategy and performance, like the one proposed in this paper, are needed. Much has been written in the last decade or two about particular aspects of product development and manufacturing operations (e.g. design process, quality control, manufacturing-engineering communications). The task ahead for researchers is to develop frameworks that can adequately integrate what has been learned in the more focussed studies. Ultimately, all aspects of a firm's operations will affect one or more of three basic parameters: efficiency, quality, and flexibility. Any positive effect on performance can be seen as coming through improvements in these areas. We have moved in this direction here, trying to integrate existing literature and concepts, but there is much room for further improvement.

[13] The next stage in this research, which is already underway, involves the formulation of a questionnaire to test this framework with empirical data collected from manufacturers of assembled printed circuit boards in the United States, Japan, and Europe.

Table 1. Literature on Flexibility - Partial List

(1) Empirical Studies of Flexibility

Taxonomies of Flexibility	Gerwin (1987) Adler (1985) Piore (1989) Buzacot (1982) Kumar (1987) Hyun & Ahn (1990)	Mandelbaum (1978) Zelanovic (1982) Browne (1984) Slack (1983) Gupta & Goyal (1989)
Flexibility & Performance (data-based studies)	Jaikumar (1986) Tombak (1988) Tombak & de Meyer (1988) Fiegenbaum & Karnani (1991)	de Meyer et al. (1988)
Historical and Economic Analyses of Flexibility	Piore/Sabel (1984) Cusumano (1988) Jaikumar (1988) Storper (1986) Piore (1989)	Boyer (1988) Adler (1988) Harrigan (1984) Womack et al. (1990)

(2) Analytical Models of Flexibility

Flexibility & Life Cycle Theory	Fine and Li (1988) Hutchinson (1986) Hutchinson and Holland (1982)
Flexibility & Uncertainty	Kulatikala (1988) Fine and Freund (1986, 1988) Gupta, Buzacott, and Gerchak (1988) He and Pindyck (1989)
Flexibility and Inventory Levels	Porteus (1985, 1986) Karmarkar and Kekre (1987) Vander Veen & Jordan (1988) Graves (1988) Caulkins & Fine (1990)
Flexibility and Competitive Dynamics	Gaimon (1988) Tombak (1988) Fine and Pappu (1988)

Table 2: Types of Flexibility

Mix:	*Ability of a system to produce a number of different products at the same time*
Volume:	*Ability of a system to change significantly both the total production level and the composition of the product mix in a relatively short time span, in order to respond quickly to unexpected demand changes*
New-Product:	*Ability of a system to deal with additions to and subtractions from the product mix over time*
Delivery Time:	*Ability of a system to reduce the time span between order placement by a customer and order delivery to that customer*

Table 3: Flexibility Need Factors

Product Strategy:	*Full line production versus niche production.*
Competitor Behavior:	*Focus of competition: price, new products, timely delivery, etc.*
Consumer Demand:	*Stable versus dynamic demand; rate of change in customers' preferences.*
Product Life Cycle:	*New versus mature product; absence or existence of a "dominant design."*
End-Product Characteristics:	*Size; level of relative sophistication; rate of change in end-product characteristics; stage in end-product life cycle.*

Table 4: Flexibility Source Factors

Production Technology:	*Level of automation; nature of automation: dedicated or flexible.*
Production Management Techniques:	*Extent to which new techniques are used: just-in-time production; total quality control; flat organizational hierarchy, etc.*
Relationship with Suppliers and Distributors:	*Degree of closeness and cooperation: subcontracting, technical assistance projects, cross staffing, etc.*
Worker Training/Skills:	*Educational background; nature of skills: broad versus specialized.*
Labor Policies:	*Ease of firing and hiring; use of localized and contingent pay procedures.*
Product Development Process:	*Extent to which principles of design for manufacturability have been applied.*
Accounting and Information Systems:	*Extent to which the accounting and information systems are part of an integral strategy to provide relevant and timely information for decision making (e.g. activity-based cost systems).*

Figure 1. Flexibility Requirements, Implementation, and Business Performance

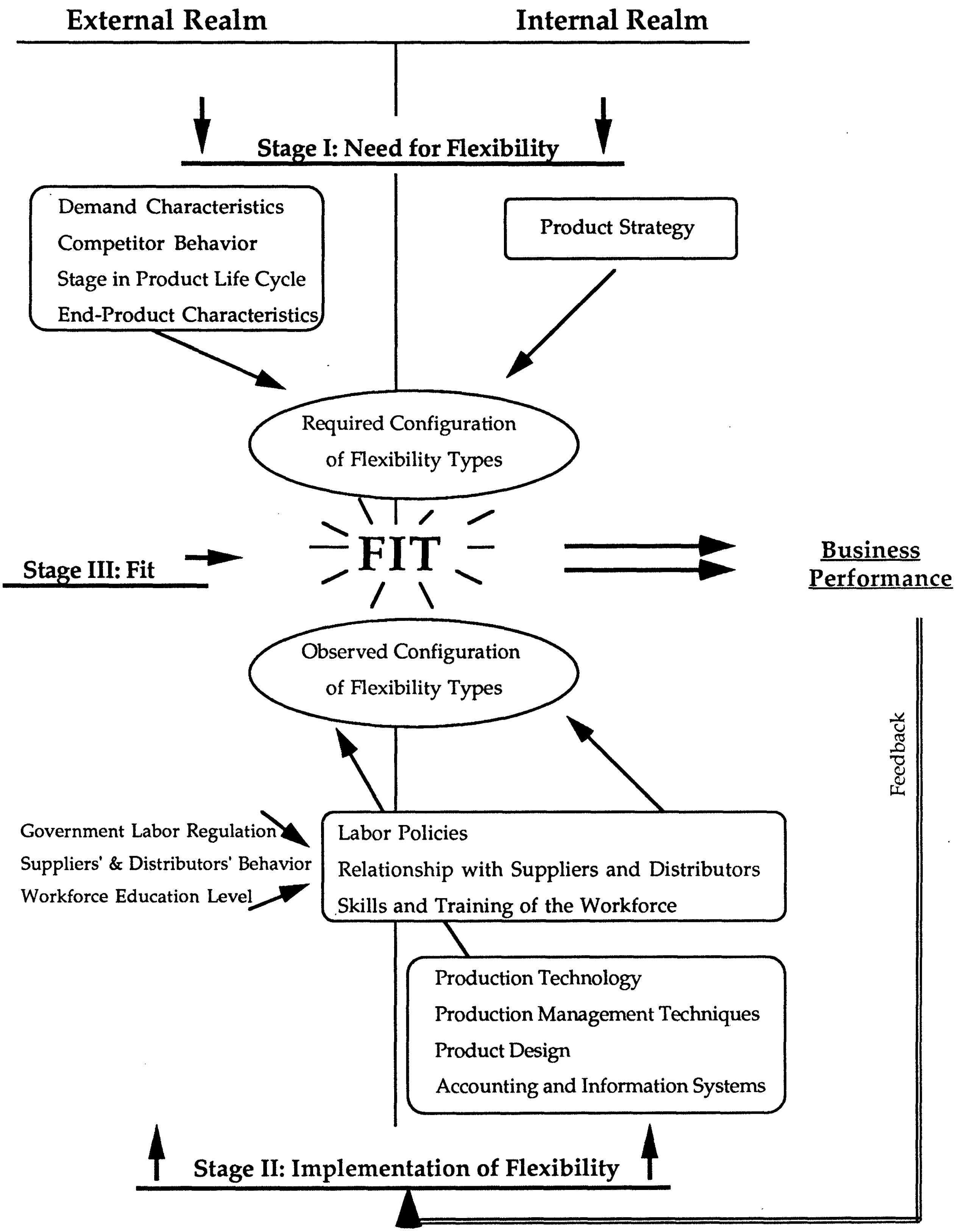

Table 5. Hypothesized Influence of Need Factors on each Flexibility Type

	Product Strategy	Competitor Behavior	Demand Characteristics	Product Life Cycle	End-Product Characteristics*
Mix Flexibility	• for custom markets • full-line strategy	• full line competitors • competitors with close substitutes	• differentiated customers • product complementarities highly valued	• early-to-transitional stage • later periods where competition shifts to product differentiation	• Non-standardized end-products • Complex, multi-parts end products
New Product Flexibility	• technology-intensive markets • fashion markets	• innovative competitors	• demand ill-defined, i.e. required product features always evolving • fast-changing demand patterns	• early or fluid stage, pre- dominant design • period of discontinuity (often late in a cycle) • other periods where competition shifts to product differentiation	• Technology intensive end prod. • Higlhly competitive end product market
Volume Flexibility	• industry characterized for high volume fluctuations	• competitors' production difficult to predict	• volatile volume demand	• transitional stage, where demand growth is highest • period of discontinuity, where major reestructuring is needed	• End-product market with high fluctuations in demand volume
Delivery Time Flexibility	• likely to be important in most cases, except for the high-end of markets.	• fast-to-market competitors with strong sales support	• time-sensitive consumers	• stages where differentiation by mix, features or cost (volume) are insufficient	•End customers use JIT techniques

* For intermediate producers only

Table 6. Hypothesized Influence of Source Factors on each Flexibility Type

	Production Technology	Production Management Techniques	Product Development Process	Workforce Skills & Training*	Labor Policies*	Suppliers & Distributors Relationship**	Accounting & Information Systems
Mix Flexibility	↑ Flexible automation ↓ Fixed automation (and no multi-plant strategy)	↑ Lean management techniques ↓ Mass production management techniques	↑ Component reuse ↑ Design for manu-facturability ↓ "Throw design over the wall" practices.	↑ Broad Skills ↓ High division of labor, narrow skills			↑ Timely and effective information system ↑ Activity-based accounting system
New Product Flexibility	↑ Flexible automation ↓ Fixed automation		↑ Component reuse ↑ Design for manu-facturability ↓ "Throw design over the wall" practices.	↑ Broad Skills ↓ High division of labor, narrow skills		↑ Firm subcontracts new parts or prototype production	↑ Timely and effective information system ↑ Activity-based accounting system
Volume Flexibility	↑ Flexible automation w/ excess capacity ↓ Labor-intensive with lifetime employment	↑ Lean management techniques ↓ Mass production management techniques			↑ Localized and contingent wage system ↓ Committment to permanent employment	↑ Firm subcontracts production	↑ Timely and effective information system ↑ Activity-based accounting system
Delivery Time Flexibility		↑ Lean management techniques (JIT)			↑ Overtime can be arranged easily ↑ More workers can be added rapidly	On short notice: ↑ Suppliers can provide components ↑ Distributors can deliver quickly	↑ Timely and effective information system ↑ Activity-based accounting system

* For non-automated operations or operations requiring manual intervention or set-ups.

** For processes where all production or operations are not done in-house.

Appendix 1. Partial List of the Types and Definitions of Flexibility Proposed in the Literature

AUTHOR TYPE OF FLEXIBILITY	DESCRIPTION
Mandelbaum (1978)	
Action Flexibility	Leaving options open so that it is possible to respond to change by taking appropriate action.
State Flexibility	The ability of the system to process a wide variety of parts of assemblies without intervention from outside to change the system
Buzacott (1982)	
State Flexibility	same Mandelbaum
Job Flexibility	The ability of the system to cope with changes in the jobs to be processed.
Machine Flexibility	The ability of the system to cope with changes and disturbances at the machines and work stations.
Zelanovic (1982)	
Design Adequacy	The probability that the system will adapt itself to environmental conditions and to the process requirements within the limits of the given design parameters.
Adaptation Flexib.	The value of time needed for system transformation/ adaptation from one to another job task.
Browne (1984)	
Machine Flexibility	Easy of making changes to a given set of parts.
Process Flexibility	Ability to produce a given set of parts types, each possibly using different materials, in several ways.
Product Flexibility	Ability to change over to produce a new set of products very economically.
Routing Flexibility	Ability to handle breakdowns and to continue producing a given set of parts.
Volume Flexibility	Ability to operate profitably at different production volumes.
Expansion Flexib.	Capacity of the system to expand as needed, easily and modularly.
Operation Flexibility	Ability to interchange the ordering of several operations for each part type.
Production Flexib.	Ability to produce a large universe of part types.

Jaikumar (1986)		
	Process Flexibility	Ability to reroute a part when a machine is down.
	Program Flexibility	Ability to run the system unattended.
	Product Flexibility	The total incremental value of new products that can be fabricated within the system for a defined cost of new fixtures, tools, and parts programming.
Gerwin (1987)		
	Mix Flexibility	Ability to produce a number of different products at the same point in time.
	Changeover Flexib.	Ability of a process to deal with additions to and substractions from the product mix over time.
	Modification Flexib.	Ability to make functional changes in the product.
	Rerouting Flexibility	Degree to which the operating sequence through which the parts flow can be changed.
	Volume Flexibility	Ease with which changes in the aggregate amount of production can be achieved.
	Material Flexibility	Ability to handle uncontrollable variations in the composition and dimensions of the parts being processed.
	Sequencing Flexib.	Ability to rearrange the order in which different kinds of parts are fed into the manufacturing process.

Bibliography

Adler, Paul S., "Managing Flexibility: A Selective Review of the Challenges of Managing the New Production Technologies's Potential for Flexibility," Report to the Organization for Economic Cooperation and Development, Stanford University, 1985.

Amsden, Alice, *Asia's Next Giant: The Properties of Late Industrialization,* Oxford University Press, 1989.

Anderson, Philip, and Michael Tushman, "Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change," *Administrative Science Quarterly*, 1990, December.

Boyer, Robert (ed), *The Search for Labor Market Flexibility: The European Economies in Transition,* Oxford Clarendon Press, 1988.

Browne, J., D. Dubois, K. Kathmill, S. Sethi, and K. Stecke, "Classification of Flexible Manufacturing Systems," *The FMS Magazine*, 1984, April.

Burns, Tom, and G.M. Stalker, *The Management of Innovation,* Tavistock, London, 1961.

Buzacott, J. A., "The Fundamental Principles of Flexibility in Manufacturing Systems," Proceedings for the 1st International Conference on Flexible Manufacturing Systems, Brighton, U.K., 1982.

Cainarca, Gian Carlo, Massimo Colombo, and Sergio Mariotti, "An Evolutionary Pattern of Innovation Diffusion. The Case of Flexible Automation," *Research Policy*, 18, 59-86, 1989.

Carroll, Glenn R. (ed.), *Ecological Models of Organizations,* Ballinger Publishing Company, 1988.

Caulkins, J. P., and Charles Fine, "Seasonal Inventories and the Use of Product-Flexible Manufacturing Technology," *Annals of Operations Research*, 26, 351-375, 1990.

Chandler, Alfred, *Strategy and Structure,* MIT Press, 1962.

Clark, Kim B., "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development," *Management Science*, 35, Nº10, 1247-1263, 1989.

Clark, Kim B., Bruce Chew, and Takahiro Fujimoto, "Product Development in the World Auto Industry," *Brookings Papers on Economic Activity*, 3, 729-771, 1987.

Cusumano, Michael, *The Japanese Automobile Industry,* Harvard University Press, Cambridge, MA, 1985.

Cusumano, Michael, "Shifting Economies: Craft Production to the Flexible Factory," working paper #2012-88, Sloan School of Management, M.I.T., 1988.

Cusumano, Michael, Yiorgos Mylonadis, and Richard Rosenbloom, "Strategic Maneuvering and Mass-Market Dynamics: The Triumph of VHS Over Beta," Working Paper #40-91, International Center for the Management of Technology, MIT, 1991.

De Meyer, A., J. Nakane, J. G. Miller, and K. Ferdows, "Flexibility: The Next Competitive Battle," *Strategic Management Journal,* 10:2, 135-144, 1989.

Dertouzos, M., et al., *Made in America,* The MIT Press, 1989.

Farrel, J, and G. Saloner, "Standardization, Compatibility, and Innovation," *Rand Journal of Economics,* 16, 70-83, 1985.

Farrel, J., and G. Saloner, "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation," *American Economic Review,* 76, 940-955, 1986.

Fiegenbaum, Avi, and Aneel Karkani, "Output Flexibility: A Competitive Advantage for Small Firms," *Strategic Management Journal,* 12, 101-114, 1991.

Fine, Charles, "Developments in Manufacturing Technology and Economic Evaluation Models," prepared for Logistics of Production and Inventory, S.C. Graves, A. Rinnooy Kan, and P. Zipkin (eds), in the North Holland Series of Handbooks in Operations Research and Management Science., 1989.

Fine, Charles, and R. M. Freund, "Optimal Investment in Product-Flexible Manufacturing Capacity," *Management Science,* vol. 36, 449-466, 1990.

Fine, Charles, and L. Li, "Technology Choice, Product Life Cycles, and Flexible Automation," *Journal of Manufacturing and Operations Management,* 1, No. 4, 1988.

Fine, Charles, and S. Pappu, "Flexible Manufacturing Technology and Product-Market Competition," Working Paper, Operations Research Center, MIT, 1988.

Gaimon, C., "Closed Versus Open Loop Dynamic Game Results on the Acquisition of New Technology," Working Paper, Academic Faculty of Management Sciences, The Ohio State University, 1988.

Garvin, David A., *Managing Quality,* Free Press, New York, 1987.

Gerwin, Donald, "An Agenda for Research on the Flexibility of Manufacturing Process," *International Journal of Operations and Production Management*, 7, No. 1, 38-49, 1987.

Gerwin, Donald, "Manufacturing Flexibility: A Strategic Perspective," mimeo, School of Business, Carleton University, Ontario, Canada, 1991.

Graves, Steven, "Safety Stocks in Manufacturing Systems," *Journal of Manufacturing and Operations Management*, 1, No. 1, 67-101, 1988.

Gupta, D., J. A. Buzacott, and Y. Gerchak, "Economic Analysis of Investment Decisions in Flexible Manufacturing Systems," Working Paper, Dept. of Management Sciences, University of Waterloo, Ontario, Canada, and , 1988.

Gupta, Y. P., and S. Goyal, "Flexibility of Manufacturing Systems: Concepts and Measurements," *European Journal of Operations Research*, 43, 119-135, 1989.

Harrigan, K. R., *Strategic Flexibility: A Management Guide for Changing Times*, Lexington Books, Lexington, MA, 1984.

Hayes, R. H., and S. C. Wheelwright, *Restoring Our Competitive Edge: Competing Through Manufacturing*, John Wiley and Sons, 1984.

Hayes, Richard H., Stephan C. Wheelwright, and Kim B. Clark, *Dynamic Manufacturing: Creating the Learning Organization*, The Free Press, 1988.

He, H., and R.S. Pindyck, "Investments in Flexible Production Capacity," Working Paper MIT-EL 89-001WP, Center for Energy Policy Research, M.I.T., 1989.

Hutchinson, G. K., "Production Capacity: CAM vs. Transfer Line," *IIE*, 30-35, September 1986.

Hutchinson, G. K., and J. R. Holland, "The Economic Value of Flexible Automation," *Journal of Manufacturing Systems*, 1 No. 2, 215-228, 1982.

Hyun, Jae-Ho, and Byong-Hun Ahn, "Flexibility Revisited: Review, Unifying Frameworks, and Strategic Implications," Mimeo, Korean Advanced Institute of Science and Technology, 1990.

Imai, Kenichi et al., *Managing the New Product Development Process: How Japanese Companies Learn and Unlearn*, in Clark, Kim et. al., The Uneasy Alliance: Managing the Productivity-Technology Dilemma, Harvard Business School Press, 1985.

Jaikumar, R., "Postindustrial Manufacturing," *Harvard Business Review*, 64, No. 6, 69-76, 1986.

Jaikumar, R., "From Fitting to Flexible Manufacturing: A Study in the Evolution of Process Control," working paper, Harvard Business School, 1988.

Kaplan, Robert S., and , "New Approaches to Measurement and Control," Chapter 5 for Bower (ed.), Battling Back, forthcoming.

Kaplan, Robert S. (ed), et al., *Measures for Manufacturing Excellence,* Harvard Business School Press, Boston, Massachusetts, 1990.

Karmarkar, U. S., and S. Kekre, "Manufacturing Configuration, Capacity and Mix Decisions Considering Operational Costs," *Journal of Manufacturing Sytems*, 6, 315-324, 1987.

Katz, M., and C. Shapiro, "Network Externalities, Competition, and Compatibility," *American Economic Review*, 75, 424-440, 1985.

Katz, M., and C. Shapiro, "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy*, 94, 822-841, 1986.

Kekre, Sunder, and Kannan Srinivasan, "Broader Product Line: A Necessity to Achieve Success?," *Management Science*, 36, No. 10, 1216-1231, 1990.

Kochan, Thomas, Harry Katz, and Robert McKersie, *The Transformation of American Industrial Relations,* Basic Books, New York, 1986.

Krafcik, John F., "Triumph of the Lean Production System," *Sloan Management Review*, Fall issue, 41-52, 1988.

Kulatilaka, N., "Financial, Economic and Strategic Issues Concerning the Decision to Invest in Advanced Automation," *International Journal of Production Research*, 22, No. 6, 949-968, 1984.

Kulatilaka, N., "Valuing the Flexibility in Flexible Manufacturing Systems," *IEEE Transactions on Engineering Management*, 35 No.4, 250-257, 1988.

Kumar V., and Kumar U., "Entropic Measures of Manufacturing Flexibility," *International Journal of Production Research*, 25, No. 7, 957-966, 1987.

Lane, W., "Product Differentiation in a Market with Endogenous Sequential Entry," *Bell Journal of Economics*, 11, 237-260, 1980.

Lawrence, Paul, and Jay Lorsch, *Organization and Environment: Managing Differentiation and Integration,* Harvard Business School, Division of Research, 1967.

MacDuffie, John Paul, and John Krafcik, "Flexible Production Systems and Manufacturing Performance: The Role of Human Resources and Technology," presented at the Academy of Management, August 1989.

Mandelbaum, M., "Flexibility in Decision Making," Ph.D. Thesis, Department of Industrial Engineering, University of Toronto, 1978.

Mills, D. E., and L. Schumann, "Industry Structure with Fluctuating Demand," *American Economic Review*, 75, No. 4, 758-767, 1985.

Piore, Michael, "Corporate Reform in American Manufacturing and the Challenge to Economic Theory," Mimeo, Massachusetts Institute of Technology, 1989.

Piore, Michel, and Charles Sabel, *The Second Industrial Divide,* Basic Books, New York, 1984.

Porteus, E. L., "Investing in Reduced Setups in the EOQ Model," *Management Science*, 31, 998-1010, 1985.

Porteus, E. L., "Optimal Lot Sizing, Process Quality Improvement, and Setup Cost Reduction," *Operations Research*, 34, 137-144, 1986.

Robinson, William T., "Sources of Market Pioneer Advantages: The Case of Industrial Goods Industries," *Journal of Marketing Research*, 25, 87-94, 1988.

Schmalensee, Richard, "Product Differentiation Advantages of Pioneering Brands," *American Economic Review*, 72, 349-365, 1982.

Shimada, Haruo, and John Paul MacDuffie, "Industrial Relations and Humanware: Japanese Investments in Automobile Manufacturing in the United States," working paper, Sloan School of Management, M.I.T., 1987.

Singh, Jitendra, and Charles Lumsden, "Theory and Research in Organizational Ecology," *Annual Review of Sociology*, 16, 161-195, 1990.

Slack, N., "Flexibility as a Manufacturing Objective," *International Journal of Production Management*, 3, No. 3, 4-13, 1983.

Smith, Adam, *The Wealth of Nations,* Random House, New York, 1937.

Spence, Michael, "Product Selection, Fixed Cost and Monopolistic Competition," *Review of Economic Studies*, 43, 217-235, 1976.

Stigler, G., "Production and Distribution in the Short Run," *Journal of Political Economy*, 47:3, 305-327, 1939.

Storper, Michael, and Susan Christopherson, "Flexible Specialization: A Critique and Case Study," mimeo, University of California, Los Angeles, Institute of Industrial Relations, 1986.

Suárez, Fernando F., and James M. Utterback, "Dominant Designs and the Survival of Firms," MIT International Center for Research on the Management of Technology, working paper #42-91, 1991.

Swamidass, Paul M., "Empirical Science: New Frontier in Operations Management Research," *Academy of Management Review*, 16:4, 793-814, 1991.

Taylor, Frederick, *Principles of Scientific Management*, Harper, New York, 1911.

Teece, David, "Economies of Scale and the Scope of the Enterprise," *Journal of Economic Behavior and Organization*, 7, 21-45, 1980.

Teece, David J., Gary Pisano, and Amy Shuen, "Dynamic Capabilities and Strategic Management," University of California at Berkeley, mimeo, 1991 (November).

Tirole, Jean, *The Theory of Industrial Organization*, MIT Press, 1988.

Tombak, Michael, "A Strategic Analysis of Investment in Flexible Manufacturing Systems," Insead Working Paper No. 88/35, Fontainbleau, France, 1988.

Tombak, Michael, "The Importance of Flexibility in Manufacturing," Insead Working Paper N0.88/33, Fontainbleau, France, 1988.

Tombak, Michael, and A. De Meyer, "Flexibility and FMS: An Empirical Analysis," *IEEE Transactions on Engineering Management*, 35, No.2, 101-107, 1988.

Tushman, Michael, and Philip Anderson, "Technological Discontinuities and Organizational Environments," *Administrative Science Quarterly*, 31, 439-465, 1986.

Utterback, James M., and William Abernathy, "A Dynamic Model of Process and Product Innovation," *Omega*, 33, 639-656, 1975.

Utterback, James M., and Fernando F. Suárez, "Innovation, Competition, and Industry Structure," *Research Policy*, forthcoming, December 1992.

Vander Veen, D.J., and W.C. Jordan, "Analyzing Trade-offs Bewteen Machine Investment and Utilization," Operating Sciences Department, General Motors Research Department, Warren, MI., 1988.

Venkatraman, N., "Masurement of Business Economic Performance: An Examination of Method Convergence," *Journal of Management*, 13:1, 109-122, 1987.

Venkatraman, N., "The Concept of Fit in Strategy Research: Toward Verbal and Statistical Correspondence," *Academy of Management Review*, 14, Nº3, 423-444, 1989.

Whitney, Daniel, "Manufacturing by Design," *Harvard Business Review*, July-August, 83-91, 1988.

Womack, James P., *The Machine that Changed the World,* Rawson Associates, New York, 1990.

Zelanovic, D.M., "Flexibility: A Condition for Effective Production Systems," *International Journal of Production Reseach*, 20, No. 3, 319-337, 1982.