AN EMPIRICAL INVESTIGATION OF MANUFACTURING FLEXIBILITY AND ORGANIZATIONAL PERFORMANCE AS MODERATED BY STRATEGIC INTEGRATION AND ORGANIZATIONAL INFRASTRUCTURE

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The purpose of this study is empirically investigating four research questions related to manufacturing flexibility. 1) What are the components of manufacturing flexibility? 2) Is there a relationship between manufacturing flexibility and organizational performance? 3) Do integrated strategies strengthen the relationship between manufacturing flexibility and organizational performance? 4) Are there organizational characteristics that strengthen the relationship between manufacturing flexibility and organizational performance? This study used a cross-sectional survey design to collect data from manufacturing organizations in multiple industries. Organizational performance was quantified using common manufacturing measures. Strategic integration and organizational infrastructure were also measured. Data were collected using a self-administered questionnaire. Factor analysis, correlation analysis, and regression were used to analyze the data. The results indicate the variables and expected relationships exist as hypothesized.

This study contributes to the manufacturing flexibility body of knowledge by identifying relationships between the manufacturing flexibility component, performance, strategic integration, and organizational infrastructure. The instrument development in this study is of particular value as there are few rigorously developed and validated instruments to measure the manufacturing flexibility components and performance. Understanding these relationships will help practitioners make better decisions in manufacturing organizations as well as enable application of the concepts in this study to other contexts such as service organizations.

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In memory of Robert Floyd Patterson
September 8, 1930 - September 26, 2005
I finally did it, Dad! Wish you were here.

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CHAPTER 1

INTRODUCTION

Modern organizations must cope with increasingly dynamic business environments wherein customers expect organizations to respond faster to changing needs. Additionally, product life cycles are becoming shorter, partially due to customer demand for more innovative products offering higher customer value (Bordoloi, Cooper, & Matsuo, 1999; Pine, 1993). In an empirical study, Qualls, Olshavsky, and Michaels (1981) used archival data to test this proposition. The results of their study indicate that product life cycles are shortening at least during the introductory and growth stages; thus, competition for resources and market share make it critical for organizations to exploit operational capabilities. Other competitive factors that increase the need for flexibility are: decreasing profit margins (Bordoloi et al.), decreasing inventory levels (Kher, Malhotra, Philipoom, & Fry, 1999), increasing global competition (Stewart, Webster, Ahmad, & Matson, 1994; Zelenović, 1982), and increasing speed of technological change (Grubbström & Olhager, 1997; Zelenović, 1982). As a result, organizations must find better ways to meet these challenges.

Manufacturing plays a critical role in an organization's ability to respond to diverse customer needs by delivering the desired products in a timely manner. It is generally accepted that developing flexibility within the manufacturing function, as well as throughout the whole organization, better prepares an organization to respond to rapidly shifting customer needs. For the whole organization to be more flexible and responsive to customers, management must ensure that the manufacturing strategies and other functional strategies are integrated with the overall organizational strategy (Skinner, 1969, 1996). This strategic integration should reflect an emphasis on flexibility and responsiveness to both internal and external customers. The organization’s infrastructure also plays a critical role in enhancing the organization’s ability to effectively use manufacturing flexibility.

Traditionally, organizations focus internally on resource productivity and on solving problems within the organization even when a problem is caused externally. Often, however, external factors – such as suppliers, distributors, and customers – affect an organization’s ability to meet or exceed customer expectations related to product performance, output variety, higher quality, availability, and faster delivery time (Egbelu, 1996; Kher et al., 1999; Slack, 1983).

Various manufacturing practices [e.g. Just-in-Time/Lean manufacturing (JIT/Lean), Total Quality Management (TQM), World Class Manufacturing (WCM), etc.] are proposed to help organizations transform the manufacturing function to improve performance. Decision-makers, however, are reluctant to invest in additional “solutions” without proof that performance will improve. For example, many organizations incorrectly implemented techniques, such as JIT/Lean, because they did not understand and implement the entire system. This resulted in a loss of the synergistic benefits. When the organization’s performance does not improve as promised, managers conclude that these techniques are inapplicable in the U.S. (Das & Narasimhan, 2001; Jaikumar, 1986).

Organizations frequently implement a fully automated flexible manufacturing system (FMS) but fail to exploit the flexible capability of that system. For example, an organization may use an FMS to produce the same number and type of products formerly produced with older, less automated technology. Thus, the organization does not use flexibility to develop the competitive factors the organization needs (Jaikumar, 1986). This results in concluding that flexibility is another failed “solution.” Japanese organizations automate operations only after they master the process, while the tendency in U.S. organizations is substituting automation for process knowledge (Carlsson, 1989). As a result, there are fewer reports of disappointing FMS implementations in Japan. Organizations need to look at production and responsiveness issues from a new perspective. Unfortunately, consultants and academics have proposed a plethora of "solutions" to identify and correct these issues.

Need for Research

Ultimately, firms have two choices in today's dynamic environment: they can decrease their need for flexibility or increase flexibility to cope with short-term and long-term uncertainty (Frazelle, 1986). For example, Japanese firms striving for greater flexibility have reduced their need for full flexibility by increasing process and part commonality (Gupta, 1993). Some organizations use modular product design to allow product design flexibility within specified limits. Additionally, situations exist in which increasing flexibility is infeasible because the required investment is larger than the potential returns. For example, oil refineries do not need to customize their output because they make a limited range of standardized products sold as price-based commodities. Changes in the narrow product line require minimal flexibility. Additional investments in flexibility in that situation are unlikely to yield returns to justify the required investment. Organizations need methods to identify when additional flexibility is needed to improve performance and when it is unnecessary (Gupta & Buzacott, 1989).

A number of options exist for organizations to implement manufacturing flexibility, but several key issues are inadequately addressed in the current literature. These include: a concise list of manufacturing flexibility components, inconsistent terminology, the benefits of increasing flexibility, and flexibility's effect on performance. Also of interest is the change in the relationship between manufacturing flexibility and performance when strategic integration and organizational infrastructure are considered. This study addresses each of these issues which are discussed below.

Since the 1980s, researchers have proposed that the lack of both a generalizable definition of, and a standardized measurement instrument for the concept of manufacturing flexibility creates difficulty in explaining flexibility to practitioners, thus reducing its application (De Toni & Tonchia, 1998; Gupta, 1993; Kumar, 1987). Although researchers agree upon the importance of flexibility, there is still no generally accepted definition (Bordoloi et al., 1999; Upton, 1994). The initial problems for organizations that strive to increase manufacturing flexibility are the proliferation of lists identifying manufacturing flexibility components, overlapping component definitions, and numerous proposed relationships among the components. The number of labels and definitions for manufacturing flexibility components continues to increase. Swamidass (1988) identified 20 different terms, Sethi and Sethi (1990) identified at least 50, and Shewchuk and Moodie (1998) found 70 in the existing literature. Many of the components have similar definitions, while some studies use the same component name but with an entirely different definition. A generalizable survey instrument is also needed, not only to measure manufacturing flexibility components, but also to allow comparisons across facilities, organizations, and industries (Upton, 1994). There remains neither a definitive list of manufacturing flexibility components applicable in multiple situations nor a complete understanding of the relationships between various components.

Not only does the current manufacturing flexibility literature contain numerous lists of components, but further confusion arises from the misuse of terminology, in particular the term flexible manufacturing systems (FMS). FMS refers to a specific manufacturing technology consisting of a computer-controlled, fully automated machine or group of machines. These systems operate with integrated material handling that requires minimal interaction with workers to produce products. Such technology, it is hoped, would allow organizations to run “lights out” facilities where production is fully automated reducing the need for a large skilled workforce. Occasionally, FMS is used to describe facilities that have implemented any form of flexibility within manufacturing. In other words, any manufacturing system that is more flexible than a rigid, traditional mass production assembly line is labeled a flexible manufacturing system. Under this definition, organizations have a flexible manufacturing system whether they have a flexible layout with highly specialized but inflexible equipment, or a layout with highly flexible machines that produce a low variety of products (Gupta, 1993). This lax use of terminology causes confusion within the literature and practical application.

Few validated instruments exist to test proposed components and relationships, so in addition to a lack of understanding about the components of manufacturing flexibility, there also remains a lack of understanding about the relationship between individual components and organizational performance. Different types of flexibility affect system performance in different ways and combinations of manufacturing flexibility components create synergy, further improving the effect on performance (Ramasesh & Jayakumar, 1991). Skinner (1996) suggests that there has been an overemphasis on the development and implementation of advanced manufacturing technologies, such as FMS, without understanding what capabilities are actually needed. Organizations that need to increase flexibility must first understand their organization’s needs and goals, as well as the potential benefits, before deciding whether to pursue increased flexibility. Expected benefits of increased flexibility include expanding product variety without reducing quality, reducing the time to design and deliver new products, improving on-time delivery, and improving market responsiveness. All of the above translate into improving organizational performance as reflected through improvements in growth indicators, better financial performance, and increased market share. One less tangible benefit is better reliability for downstream processes.

The absence of integrated manufacturing and organizational strategy is evidenced by the frequent under-representation of manufacturing strategy in overall organizational strategy (Das & Narasimhan, 2001; Skinner, 1969, 1996). Numerous researchers have proposed ways in which organizations can develop their manufacturing capabilities and strategies to support the overall organizational strategy (Ferdows & DeMeyer, 1990; Hayes & Wheelwright, 1979, 1984; Swamidass & Newell, 1987). Although some organizations have integrated manufacturing strategy into the overall organizational strategy, there is still a lack of understanding about whether integrated strategies improve the relationship between manufacturing flexibility and organizational performance. Due to resource constraints, most organizations are incapable of implementing flexibility for every process and function within the organization (Browne, Dubois, Rathmill, Sethi, & Stecke, 1984). Research indicates that, in some cases, partial flexibility may be as desirable as full flexibility. Partial flexibility generally requires lower resource investments but can yield almost the same performance improvement as full flexibility (Boyer & Leong, 1996; Jordan & Graves, 1995). Since full flexibility is infeasible for many organizations, decision-makers must be able to determine where to focus flexibility investments. Such decisions may be facilitated by developing an organizational strategy integrating specific flexibility goals. The concept of flexibility as an element of organizational strategy is poorly understood, and research is still necessary to determine the ways in which organizations develop flexibility for a reasonable investment, resulting in an acceptable performance improvement. A framework for strategically implementing flexibility is still needed (Ettlie & Penner-Hahn, 1994) as is a reliable instrument to measure the relationship between flexibility, manufacturing strategy, and performance.

The literature on manufacturing flexibility, as well as other related research, discusses a number of organizational factors that influence flexibility's influence on organizational performance. Organizational characteristics such as culture, managerial support, and information flow, although mentioned as important to increasing flexibility, are rarely measured in manufacturing flexibility research. A few studies measure infrastructure characteristics with regard to implementing other manufacturing practices such as JIT/Lean and TQM. Some of the characteristics proposed include information management, organizational policies and procedures, organizational learning, the manufacturing environment, human resource practices, management and manufacturing practices, and supply management. In the service arena, successful organizations, such as Southwest Airlines, have developed their culture into a core competency, highlighting the importance of understanding the influence of organizational infrastructure on performance. Thus, there remains an opportunity for improving the measurement of infrastructure's effect on the relationship between manufacturing flexibility and organizational performance.

Manufacturing's importance to the economic health of the U.S. can not be ignored. Currently, for every dollar of manufactured goods produced, an additional \$1.37 of economic activity is generated. With manufactured goods comprising 61% of U.S. exports, this remains a significant part of the economy. Manufacturers invest in over 70% of all business research and development. Additionally, manufacturing jobs generate higher employee incomes than service jobs and improve national productivity, which increases the national standard of living (National Association of Manufacturers, 2008). These data reflect the continuing importance of U.S.

manufacturing in the overall economy. In the early 1900s, Shaw (1915) observed that civilization was “characterized by an increasing standard of living due to the demand on the part of the individual for more goods and more highly differentiated goods” (p. 44), which still holds true today.

Understanding Flexibility

Historical Perspective of Flexibility

Overspecialization in the natural world often leads to the extinction of a species. What is originally an advantage becomes a weakness when a species is unable to adapt, or to adapt quickly enough to a changing environment. In the natural world, these changes may take millennia or may occur within a few years. Organizations typically must adapt quickly, as they do not have millennia to evolve. Some adaptations succeed in a changing environment better than others. This implies that an adaptation should be a good “fit” to new environmental requirements, but there may be more than one successful adaptation. Often, only the most inventive and resourceful species survive. The ability to innovate allows a species to adapt and ultimately thrive in the environment in much the same way that organizations must adapt to the changing business environment in which they operate. It might be assumed that it is easier for an organization to build flexibility into the system from inception, much like Dell, Google, or Southwest Airlines. Most firms, however, do not plan for long-term flexibility from start-up. Young entrepreneurial organizations often start out very flexible and adaptable but become less flexible as the organization grows. Often, organizations refocus on increasing flexibility when a specific need arises in the industry. Unfortunately, reversing rigidity in an established system is difficult, especially for large organizations, such as General Motors or American Airlines.

What are the roots of manufacturing flexibility? Where did it start and how did the U.S. lose it along the way to becoming an industrial super power? Why and how is flexibility relevant today? All of these questions will be addressed in the following sections. This discussion includes an historical comparison of flexibility in the U.S. and Japan, followed by a review of various definitions of manufacturing flexibility components and an overview of the general research model.

Flexibility in the United States

The first flexible manufacturers in any industry are the craftsmen who have produced goods throughout the centuries. They can easily customize products and make modifications throughout the production of the product because they are involved in every phase of processing. Flexibility is often associated with project-based or non-repetitive manufacturing (job shop and batch production). While it is true that the design of these process types is relatively more flexible than either mass production or continuous flow processes, they are often perceived to be restricted to small enterprises where the owners are completely involved in the production process; however, there are many examples, such as large construction firms, airplane manufacturers, or ship builders where large organizations use these process types. Additionally, mass producers like Dell profitably manufacture a high variety of products in large volumes. Flexibility, then, is not a new concept in American industry; however, researchers did not begin earnestly studying it until the 1980s.

In the late 1800s and early 1900s, a thriving network of flexible specialty manufacturers existed throughout the United States in a variety of industries ranging from locomotive building to furniture to jewelry. The strategies of these firms focused on differentiating their products based on variety and quality. These organizations developed and thrived against a backdrop of the growing phenomenon of mass production. Flexible organizations that could meet complex customer specifications could charge higher prices for specialty goods than mass producers. William Bement, a Philadelphia machine tool builder in the late 1800s, lived by the motto, “Make good work and ask a good price for it” (Scranton, 1997, p. 33). This seems to have been the sentiment among specialty manufacturers; whose customers were willing to pay higher prices for products that represented a higher value.

In the early 1900s, however, the emerging philosophies of scientific management and professional engineering clashed with the philosophy of specialty manufacturers regarding the way manufacturing organizations should operate. Generally, there was a marked difference between the characteristics of specialty producers and mass producers, and the systems created by scientific management often ran counter to those of specialty producers. After the Civil War, flexibility was often critical to manufacturers, but as consumers became willing to accept standardized products at lower prices, the need for flexibility seemingly disappeared (Scranton, 1997).

Frederick Taylor applied scientific management to mass production with a focus on improving productivity. Mass production required a high output volume of standardized products with consistent quality. This reduced the system variability by eliminating the need to accommodate unique customer specifications. Scientific management focused on maximizing resource efficiency, improving processes to eliminate waste, and decreasing manufacturing cost. These goals were difficult to achieve in systems that allowed high output variety. There was less cooperation in these systems where managers did not trust the workers and vice-versa. Workers became specialists and did not cross-train or work outside a specific job category. They were also expendable and easily replaced. By the time Henry Ford automated his assembly line in 1913, specialty producers were being rapidly displaced by manufacturers willing to mass produce standardized products. As a result, much of the knowledge of how to operate flexibly was lost as standardization, simplification, and specialization took over U.S. manufacturing (Scranton, 1997).

Due to the tenets of scientific management, U.S. manufacturers focused internally on efficiency, process improvements, and cost. The technical core of the organization was isolated from the environment to decrease variability within the manufacturing system (Thompson, 1967). This ran counter to the post-Civil War manufacturing culture wherein flexible specialty manufacturers shared information within an industry from marketing strategies to process improvements. As a result of the dissemination and application of scientific management principles throughout U.S. industry, it became accepted that all organizations should focus on efficiency to decrease the price per unit through high volume production of standardized products. Due to various events, such as World War I and World War II and the resulting effect on global production capacity and capability, the U.S. dominated the manufacturing of consumer and industrial products until the 1970s. With rising inflation and the OPEC oil embargo in the 1970s, organizations were unable to adapt quickly to new environmental pressures and foreign manufacturers were prepared to fill the gap this created.

Flexibility in Japan

In the mid-1980s, a survey of manufacturing strategy of organizations in Japan, Europe and the United States compared the organizational concerns, competitive priorities, and the action plans for consistency (DeMeyer, Nakane, Miller, & Ferdows, 1989). Overall, the results indicated that organizations in all three regions had similar concerns: maintaining high quality, reducing overhead costs, and reducing the time for new product development.

The Japanese organizations, however, differed in their competitive priorities and action plans. The top five competitive priorities in Japan related to offering lower prices, making rapid design changes, offering consistent quality, becoming a dependable supplier, and rapidly changing production volumes. After achieving high quality and dependability, Japanese management shifted focus away from those issues to pursue cost reductions and flexibility, while maintaining an acceptable quality level. In Japanese organizations, achieving high quality was "a fundamental priority," thus enabling the reallocation of resources to improve flexibility. Japanese manufacturers' action plans primarily focused on various aspects of flexibility, while European and U.S. organizations' action plans were still limited to focusing on quality and cost. Of the top ten action plans for Japanese companies, five were directly related to increasing flexibility (implementing FMS, reducing lead times, introducing new processes for new products, reducing setup times, and giving workers broader tasks). The Japanese action plans were consistent with both their concerns and competitive priorities.

Japanese organizations did not necessarily start out trying to be flexible, but rather it was a natural progression from manufacturing systems like those created within Toyota. After WWII, the Japanese approached manufacturing much as the U.S. had in the late 1800s. They looked for ways to learn and improve systems by sharing knowledge with suppliers and leveraging this knowledge for their advantage. Expectations were high and people were treated with respect and encouraged to look for improvements and innovations.

Certain aspects of the Toyota Production System (TPS) make increasing flexibility the next logical step in the evolution of the system. A lack of large buffer inventories means that different products can be processed through the manufacturing system sooner. Workspace is limited so problems in the flow of products are easier to identify. Employees are encouraged and expected to point out process or design improvements to help processes run smoothly. Reductions in setup times automatically increase flexibility (Shingo, 1981/1989) by removing setup time as a barrier to smaller batch sizes or a batch size of one. The Japanese did not employ this approach because they are smarter than their U.S. counterparts; rather, they did it because they would not have been competitive with U.S. manufacturers if they copied U.S. organizational structures and practices. The Japanese learned from both success and failures. They studied old and new theories about the ways in which products could be produced. They were willing to experiment and think beyond traditional manufacturing practices. This did not happen overnight. They repeatedly modified the system until it worked; then they kept changing to continuously improve it. Japanese organizations used standardization to reduce the number of variations of a product, but allowed for flexibility within a set range of options. They followed the teachings of Frederick Taylor and Henry Ford, but modified the manufacturing system to work within their constraints by pushing workers to the forefront as problem-solvers.

After World War I and World War II, U.S. manufacturers were able to continue plodding along since the U.S. was the only ally that did not sustain major damage to its manufacturing capability or the national infrastructure. Every standardized good produced was easily sold in the U.S. or abroad after WWII. During that period, U.S. manufacturers did not need flexibility because consumers were satisfied with the low prices and product availability created by mass production. According to Adler (1988), the dominance of U.S. manufacturing after WWII created a situation where U.S. manufacturers were "without the challenge necessary to keep the entrepreneurial spirit sharpened" (p. 37). In the 1980s, however, the U.S. got a wakeup call from

Japan. Consumers began demanding higher quality products sending complacent American manufacturers scrambling as they attempted to meet this need. Toyota and the rest of Japan, however, were already poised to increase manufacturing flexibility allowing them to adapt and survive during uncertain times. A few U.S. organizations, such as Dell, followed the lead of the Japanese and created standardized offerings with limited modifications. Customers can, however, fully customize any Dell computer "for a price." Unfortunately, most U.S. organizations are still trying to match the innovations developed in Japan, but a systemic change is needed in the thought processes of U.S. manufacturing.

Definitions of Flexibility

In most cases, it seems like common sense that flexibility and maximizing options is preferable to rigidity. Thus, understanding flexibility and pursuing it should be fairly straightforward. Unfortunately, it is not as straightforward as one would hope because "common sense is not so common" in reality. One of the most troubling aspects of the manufacturing flexibility literature is the abundance of definitions for characteristics that could be more flexible in a manufacturing system. For example, researchers have used the terms dimensions, components, flexibilities, elements, parts, parameters, aspects, and levels to describe the components of manufacturing flexibility. In this manuscript, component is used to refer to the specific characteristics comprising manufacturing flexibility.

There is still no consensus on what manufacturing flexibility means. Some suggest it is an organizational response to a dynamic environment (Beach, Muhlemann, Price, Paterson, & Sharp, 2000; Gerwin, 1993; Hyun & Ahn, 1992). Others suggest it is a short-term and long-term adaptation (Slack, 1987) that is both an actual and a perceived manufacturing capability (Slack, 1983; Watts, Hahn, & Sohn, 1993). Some define it as the overall capability of the manufacturing system to be flexible (Adler, 1988; Buzacott, 1984; Hayes & Wheelwright, 1984; Jack & Collins, 2006; Swamidass, 1988). In much of the literature in the 1980s, it refers almost exclusively to fully automated manufacturing systems (i.e. FMS). The early writings of Buzacott (1982), Browne et al. (1984), and Sethi and Sethi (1990) studied automated FMS that could manufacture a variety of products with easy changeovers and could possibly run untended. The technology was new and organizations were trying to make investment decisions about the type of automated manufacturing technology to install to reduce labor costs. The components identified in these studies were specifically defined within that context. Unfortunately, many succeeding studies applied those components to other process types and technology without modification, regardless of their appropriateness. The early studies also tended to focus on flexibility within the technical core, ignoring that the technical core is part of a larger organizational structure.

A few studies considered manufacturing flexibility as a functional concept within a larger organizational system, but doing so made measurement more difficult. Ultimately, the whole organization needs to consider flexibility in every function. Some functions may only need to have minimal flexibility while others will lead the implementation. Further confusion arises from the terms agile manufacturing and organizational adaptability, which are often defined very similar to manufacturing flexibility or one of its components. Other researchers claim they are completely separate concepts in their own right.

Some of the manufacturing flexibility research focuses internally, ignoring external factors that influence organizational behavior and performance, such as suppliers and customers. Within that context, flexibility is often divided according to process characteristics and product characteristics. In contrast, some studies evaluate external environmental factors, such as customers, suppliers, or to the entire supply chain, without adequately defining the internal factors they influence within the organization. Only a few studies consider the influence of the organization's infrastructure characteristics relevant to manufacturing flexibility.

General Research Model of Manufacturing Flexibility

Most of the studies in the 1980s considered flexibility to be of utmost importance for the U. S. and Europe. These studies focused primarily on FMS installations and their lower than expected performance benefits. FMS referred to a specific technology rather than an overall system of manufacturing flexibility making generalizability problematic. This is where much of the confusion originates. In this study, the term manufacturing flexibility is used to prevent further confusion between the general concept and the specific technology that is defined as a flexible manufacturing system (i.e. FMS). Additionally, the terms manufacturing flexibility component or component are used to refer to the characteristics of a manufacturing system that increase the system's ability to respond to changes whether internal or external. The general research model for this study follows.

Manufacturing flexibility is comprised of the various components that an organization can use to become more responsive to customer's needs or organizational objectives. Due to the large number of proposed components within the literature, a parsimonious list of components must be derived before the relationship to performance is discussed. The purpose of increasing manufacturing flexibility is to improve some aspect of performance. The components an organization pursues are related to the performance measure they are trying to improve. Adding more flexibility does not guarantee better performance. A particular flexibility component or combination of components will not improve every possible measure of performance, thus managers must understand what they are trying to achieve in the system before randomly investing in flexible equipment, facilities, employees, or product designs. In addition to understanding a particular component's influence on organizational performance, managers must also understand that any change does not occur in isolation. Increasing flexibility in one area can have a profound impact on other functions within the organization, sometimes to their detriment. Therefore, the effect of both strategic integration and organizational infrastructure on the relationship between manufacturing flexibility and performance are also of interest in this study. A great deal of literature has been published about whether formal strategic planning has any impact on organizational performance. The results have been mixed (Shrader, Taylor, & Dalton, 1984). In this study, the issue is not whether there is a formal planning process, but rather whether the strategy is communicated and integrated across functional areas (horizontal) and planning levels of the organization (vertical). In other words, are all employees working toward a common goal of improving organizational performance and ultimately organizational survival? In many organizations, departments and functions work against each other because strategies and performance measures are incompatible. Organizational infrastructure may further improve the flexibility-performance relationship. This includes organizational characteristics that encourage and enable flexibility such as communication, coordination, management support, human resource practices, information management, and other organizational characteristics.

Figure 1 is a graphical representation of the general research model illustrating the relationships between manufacturing flexibility, organizational performance, strategic integration, and organizational infrastructure.

Summary

Prior to the 1970s, most U.S. manufacturers were not concerned with any manufacturing concepts other than those of Frederick Taylor. The focus was on eliminating waste to reduce costs. Workers' contributions were so specialized that most had no idea how they fit into the overall organizational structure. In the 1970s, high volume, standardized products of low quality were not selling. Several organizations from Japan offered products that better met customers' changing needs. This resulted in U.S. manufacturers becoming aware of the need for manufacturing flexibility.

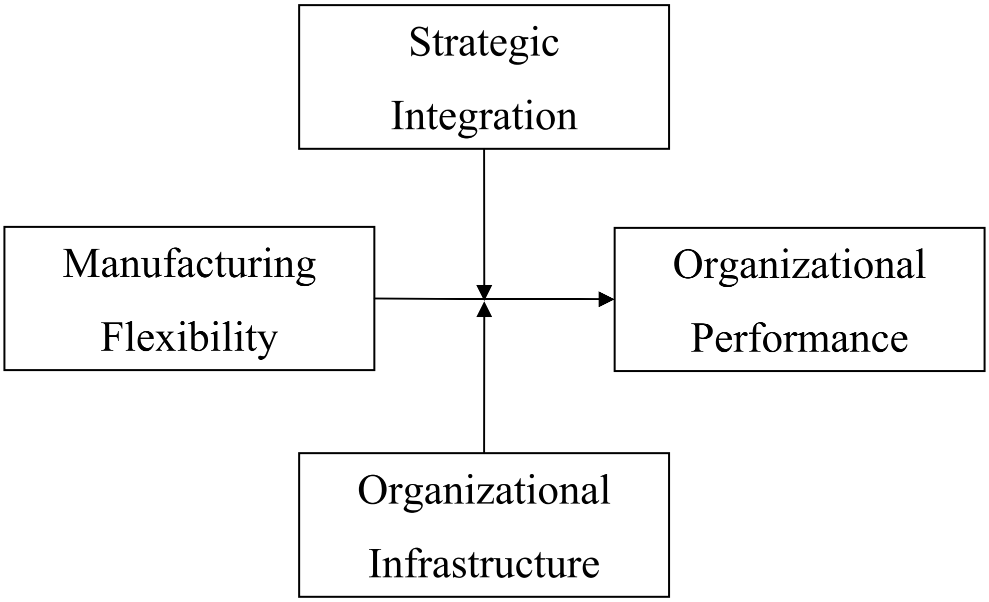


Figure 1 – General Research Model

Chapter 1 describes the origins of the concept of manufacturing flexibility and why there is a need for additional research in this area. This chapter includes an historical look at manufacturing flexibility in the U.S. and Japan. In addition, various definitions of flexibility are discussed. Lastly, a general research model for manufacturing flexibility is proposed.

The remaining sections of the dissertation are laid out as follows. Chapter 2 begins with an introduction to Thompson's (1967) theoretical framework. The concepts of reciprocal interdependence and coordination by mutual adjustment are the most flexible options for organizations. Organizations can use adaptation or demand leveling to cope with and possibly reduce environmental uncertainty. Thompson's model is integrated with information from the literature review to develop a research model for the study.

The second section of chapter 2 includes a review of literature relevant to this study. The research is divided first by the main objective of the study (component development, strategic integration, organizational infrastructure, or performance measurement) and then by the methodology used (descriptive, field study, survey, analytical model, or simulation). Descriptive literature, field studies, surveys, and other relevant research form the foundation of information related to understanding manufacturing flexibility and its components. Based on this information, six components of manufacturing flexibility are derived. This is followed by a discussion of performance measures proposed and tested in previous research. Analytical models, simulations, and surveys are the foundation for the further study of the relationship between manufacturing flexibility and organizational performance. Studies that propose and test relationships between manufacturing flexibility, strategic integration, and performance are discussed as are studies related to organizational infrastructure and its influence on the relationship between manufacturing flexibility and performance.

This research questions addressed in this study are:

1) What are the components of manufacturing flexibility?
2) Is there a relationship between manufacturing flexibility and organizational performance?
3) Do integrated strategies strengthen the relationship between manufacturing flexibility and organizational performance?

4) Are there organizational characteristics that strengthen the relationship between manufacturing flexibility and organizational performance?

Chapter 3 explains the research methodology employed in this study. A survey instrument was developed based on an extensive literature review which includes existing and new measurement items. The instrument was a self-administered questionnaire sent to U.S. manufacturing organizations. Dillman's (2000) survey methodology for instrument development and survey administration was followed as closely as possible.

The analysis of the results is presented in chapter 4. Correlation analysis and factor analysis were used to determine the manufacturing flexibility components. Regression analysis was used to evaluate the proposed relationships in the research model. The data were also analyzed to determine whether having integrated manufacturing and organizational strategies and specific organizational infrastructure characteristics further improved performance. The findings confirm that a relationship exists between manufacturing flexibility and organizational performance. The results also indicate how strategic integration and organizational infrastructure alter this relationship.

Chapter 5 contains a discussion of the consistencies and inconsistencies in the research findings and the study's limitations, as well as the theoretical and managerial implications of the study. The chapter concludes with a discussion of future research.

This research contributes to the knowledge of manufacturing flexibility by identifying relationships between manufacturing flexibility components and organizational performance. The integration of knowledge from various research areas and management theories is of particular value to developing integrated manufacturing strategies. For academicians, the confirmation of relationships between the manufacturing flexibility components and performance provide additional avenues to consider when designing production models and theories. The development of an instrument to identify the manufacturing flexibility components organizations may choose to increase flexibility aids practitioners in selecting those components that should be most beneficial to their organization.

CHAPTER 2

LITERATURE REVIEW

Introduction

Since the 1980s, there has been a proliferation of both qualitative and quantitative research related to manufacturing flexibility, yet it remains poorly understood. Scranton's (1997) historical research of industrial development in the United States from the end of the Civil War through World War I (1865-1925) illustrates how manufacturers in various industries used flexibility competitively. He finds that in some industries it was a conscious strategic choice, while for others it was simply a survival mechanism in response to highly dynamic markets.

Although manufacturing flexibility terminology is routinely discussed in the operations management literature, several unresolved issues remain. Some of these issues include a lack of a definitive component list, inconsistent terminology, overlapping component definitions and measures, a lack of well-defined relationships between components, and a lack of empirical evidence that flexibility improves performance. Additional confusion arises when researchers take proposed manufacturing components and apply them in other contexts (i.e. service organizations or the entire supply chain) without considering whether the components are valid. The manufacturing flexibility components should be applicable in other contexts once a validated component list exists. Additionally, much of the literature related to manufacturing flexibility does not consider the effect of other variables, such as strategic integration or organizational infrastructure on manufacturing flexibility or the relationship between manufacturing flexibility and performance (Vokurka & O'Leary-Kelly, 2000). Beach, Muhlemann, Price, Paterson, and Sharp (2000) suggest that until there is agreement on the components of flexibility and an understanding of the relationships between the components and performance, as well as the role of strategic integration and organizational infrastructure, research related to flexibility at the system level will remain difficult.

The manufacturing flexibility phenomenon became the object of interest during studies of the Toyota Productions System (TPS) and JIT/Lean (Schonberger, 1982). The majority of studies that primarily focused on manufacturing flexibility, however, were not published until the 1990s. Although flexibility has been studied for over two decades, there remains a lack of complete understanding about what constitutes manufacturing flexibility. The term manufacturing flexibility is used to refer to any manufacturing system that is flexible, regardless of the process type or technology, but more frequently it is used when referring to an FMS.

This chapter includes a theoretical model for studying manufacturing flexibility and a synthesis of literature related to: the manufacturing flexibility components, the relationships among the components, the relationship of the components to organizational performance, and the concepts of strategic integration and organizational infrastructure. In reviewing the relevant literature, previous studies were selected that were seminal to studying manufacturing flexibility such as Browne et al. (1984) as well as later studies that were more thorough and/or rigorous in their methodology such as Sethi and Sethi (1990). Studies were then classified according to the main objective of the study and by research methodology where appropriate.

The first section contains a discussion of Thompson’s (1967) theoretical framework of interdependence and coordination as the theoretical foundation for the model developed in this study. The second section includes a chronological discussion of studies related to defining the manufacturing flexibility components. The primary studies are specifically written about manufacturing flexibility; however, other relevant studies from the operations management literature are included to further support the components developed in this study. These studies typically use either a descriptive/field research or survey methodology. In addition, the other relevant literature expands on the concept of organizational infrastructure and its influence on the relationship between flexibility and organizational performance, as well as the influence of supplier flexibility. This is followed in the third section by a definition for each proposed manufacturing flexibility component.

The fourth section includes studies that primarily investigate relationships between various components and organizational performance. These studies are primarily analytical models and simulations that prove relationships as well as surveys that measure flexibility and its relationship to performance. The fifth section contains a discussion of literature related to strategic integration and hierarchical planning. This is followed by a synthesis of literature related to organizational infrastructure in section six.

The final section contains a detailed research model illustrating the relationship between manufacturing flexibility, organizational performance, strategic integration, and organizational infrastructure based on the synthesis of the literature and Thompson’s (1967) theoretical framework discussed below.

Theoretical Framework

To investigate the variables and relationships proposed in this study, a theoretical framework is needed for understanding organizational systems. Manufacturing systems generally reside within the context of a larger organizational entity. Thompson’s (1967) model includes input activities (upstream processes), the transformation process (internal processes), and output activities (downstream processes). In a closed system, the organization remains completely isolated from external environmental influence. In very stable business environments, organizations can be successful using this approach. In Thompson's model (Figure 2), the input and output activities interact directly with the environment and, to some extent, are part of the environment (e.g. buyers/suppliers, distributors/customers, etc.); however, they also act as buffers for the isolated technical core. This buffering reduces the variability the technical core must cope with while converting inputs into outputs, thus maximizing efficiency. Unfortunately, most business environments are increasingly dynamic and buffering with inventory is less successful. Open systems theory assumes that the parts of the organization are highly interdependent and interact with the environment, as opposed to a closed system (Von Bertalanffy, 1956). When organizational functions are isolated from each other, it creates a situation where communication occurs through a multi-level hierarchy with multiple layers of approval for decisions. As a result, Thompson expanded his model to include characteristics and ways of organizing functions to better understand interdependence, coordination, and technology that enable an organization to cope with a dynamic environment.

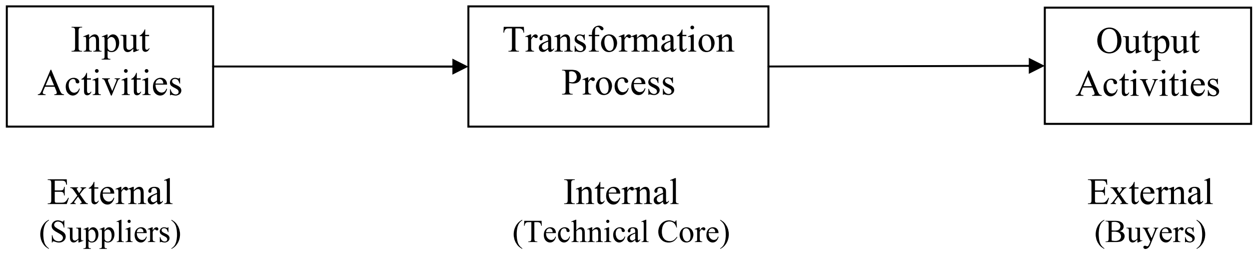
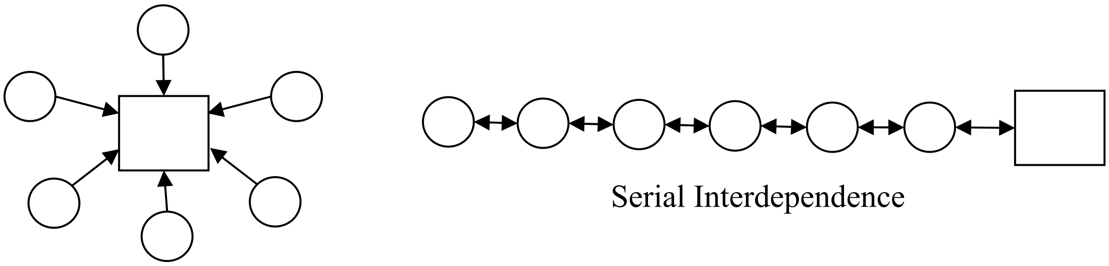


Figure 2 – Thompson's Model

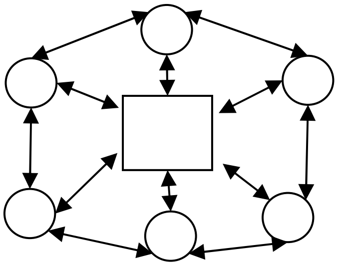
Interdependence, Coordination, and Technology

Thompson (1967) proposes three forms of interdependence within and between organizations – pooled, serial, and reciprocal (Figure 3). In pooled interdependence, each unit of the organization makes a distinct contribution to the output and works in relative isolation, thus reducing the effect on one another. Actions are coordinated through standardized routines and rules constraining the actions of each unit. Coordination is relatively easy and inexpensive as routinization results in infrequent decision-making usually with one-way communication. Functional groups further reduce coordination costs because everyone performs similar or related tasks within a group and rules apply the same way to everyone in the group. Although each unit operates independently, within the overall organizational context, the units are still interdependent. The rules are stable, repetitive, and minimal, so they work in different situations and are consistent throughout the organization. Mediating technology is used to operate in standardized ways with different units or clients.



Serial Interdependence

Pooled Interdependence



Reciprocal Interdependence

Figure 3 – Interdependence and Coordination

Serial interdependence exists when two units have direct interdependence and the sequence of interdependence is clearly specified. Coordination is achieved through the development of a plan. Schedules constrain the actions of each unit and there is less routinization and stability than with pooled interdependence. Coordination is more difficult than with pooled interdependence, thus the frequency and cost of coordination increase. Feedback between units that are directly interdependent improves coordination. Organizations often employ vertical integration to reduce the uncertainty in a preceding task (e.g. buying sources of supply). Serial interdependence uses long-linked technology where a task is performed only after the successful completion of a preceding task.

Reciprocal interdependence occurs when outputs from one unit become inputs for multiple other units within the organization. The interdependence is considered reciprocal since each unit's output becomes a contingency for one or more other units. To coordinate the actions of the various units, mutual adjustment is used to coordinate and transmit information between units during task performance. Decision-making is faster as authority is given to those who are interdependent, rather than those in the top tiers of the organizational hierarchy possessing all decision-making authority. Processes are performed simultaneously, thus reducing the time required to complete a task. Since employees interact directly, they get immediate feedback if any adjustment is needed. Therefore, among the three forms of interdependence, coordination is the most difficult with reciprocal interdependence requiring more frequent communication resulting in the highest coordination cost. As a result, intensive technology is employed whereby the selection, combination, and order of application is determined by feedback during the process. This interdependence and the intensive technology allow some output customization based on the existing process conditions and customer needs. This increases the flexibility within an organizational system to cope with a dynamic environment.

Thompson (1967) proposes that complex organizations can utilize all three types of interdependence. Therefore, an organization may have some units organized in a pooled structure while others are serial or reciprocal. Groups reduce the cost of coordination, but do not have to be grouped by function. For example, an organization can group reciprocally interdependent units into cross-functional teams or manufacturing cells. This allows easier coordination within the small group due to less frequent decision-making as routines and rules are created. This requires increased horizontal communications and horizontal information systems in addition to vertical communication systems. Using only reciprocal interdependence with mutual adjustment to coordinate the actions of a large multi-national organization with divisions in different product categories for different countries would likely fail, due to the complexity of the coordination.

Organizations are assumed to act rationally, but any uncertainty in the environment creates uncertainty for the organization, thus challenging its ability to respond rationally. Organizations, however, are not always rational as they are limited by their ability to gather and process information; thus, most organizations satisfice in decision-making, rather than making optimal decisions. Due to unavoidable interaction with the environment, organizations compromise between rationality and coping with environmental changes. Organizations have multiple options for responding to environmental challenges that allow them to remain competitive. In terms of flexibility, this implies that an organization does not automatically need every type of flexibility; but rather, factors such as the organization's environment, goals, and process type determine which specific areas within the organization need to be more flexible, and those where increased flexibility adds little or no value. By using Thompson's different interdependencies, an organization can increase manufacturing flexibility and improve performance without sacrificing basic efficiency.

Coping Mechanisms

Thompson (1967) proposes three mechanisms for coping with environmental uncertainty:

buffering, leveling demand, and anticipating changes to adapt proactively. All of these are ways to increase an organization’s ability to function in a dynamic environment.

Thompson proposes buffering with raw material (inputs) and finished good (outputs) inventories to absorb environmental fluctuations, but this is no longer a rational choice for most organizations to cope with dynamic environments. Inventory buffers cost money to hold and reduce the organization’s ability to respond to environmental fluctuations. Thus, inventory buffering generally reduces flexibility. Creating unnecessary slack or redundant resources contradicts many of the currently accepted management practices such as JIT/Lean and TQM which focus on ways to eliminate waste in the system. Slack resources do, however, increase flexibility. A certain degree of slack or redundancy is implied within the general concept of flexibility. For example, workers, who are cross-trained both for production and routine maintenance or to operate multiple machines that perform similar processes, are redundant resources. This is not necessarily a negative characteristic, as it allows workers time to assess whether machines need maintenance and to perform that maintenance without creating a bottleneck; they can temporarily shift production to another machine that can perform the same process, instead of postponing maintenance until a machine breakdown causes a larger disruption in the system. The challenge is determining the cost/flexibility tradeoff, or breakeven point, where the increased cost of redundant resources does not justify the additional flexibility. Flexibility is a non-inventory buffer against environmental uncertainty, as it provides a way for organizations to develop the ability to respond to or create changes in the business environment.

Leveling demand by smoothing input and output transactions is another option to cope with uncertainty. This traditionally involved using buffer inventories to maintain a level output volume. Organizations can level demand through various techniques, such as maintaining a level production schedule, having continuous replenishment from suppliers, or having cross-trained workers that can shift between tasks. By leveling demand, it is more likely the organization can cope with a change, such as accommodating a special order. Manufacturing flexibility levels demand by increasing an organization's ability to quickly switch between existing products when demand changes, customize existing product lines, or make frequent new product introductions.

The third coping mechanism is to anticipate changes in the environment and adapt proactively. By adapting to the environment and understanding the target population, an organization can meet customer needs with a better output than competitors. In other words, organizations should strategically plan to anticipate and reduce the influence of environmental changes. Increasing manufacturing flexibility allows organizations to perform better in a dynamic environment. Anticipating environmental changes allows a company to be proactive and flexible, rather than reactive and defensive when a change occurs in the environment. The ability to profitably design new products and customize existing products may create opportunities for the organization to seek niche markets and create environmental uncertainty for competitors. Through innovation the organization may influence what the environment demands, again creating unexpected environmental pressure and change for competitors.

Open Systems

A system is a combination of interdependent parts that form a whole (Von Bertalanffy, 1956). In systems theory, the output of one part of a system is the input for another part of the system, similar to Thomson's reciprocal interdependence. When tasks are divided, the organization must coordinate those tasks, reduce duplication of effort where possible, and minimize costs. Thompson (1967) suggests that vertical two-way communication across organizational levels is critical to improving performance. Tasks coordinated by mutual adjustment require more management coordination. One option to reduce management cost is using cross-functional teams that increase flexibility while maintaining efficiency. This requires two-way horizontal communication and horizontal information systems in addition to vertical communication. This concept can be expanded to include communication between business units and across organizational boundaries. Cross-functional communication, however, is often discouraged by the organizational culture and resource buffering.

Open systems allow both tight and loose relationships between system parts. By increasing the relationships horizontally across functional areas, these interdependencies become stronger and workers begin to better understand how the parts of the organizational system fit together. Thus, to increase flexibility, an organization should adopt an open systems perspective. Within the organization, a structure using reciprocal interdependence increases flexibility, which requires building an organizational infrastructure to support this interdependence. Although this requires more coordination effort, the resulting flexibility allows employees to fully exploit the resources of the organization. Using cross-functional teams comprised of workers who have complementary knowledge, skills, and abilities reduces some of the coordination costs, while intensive technology allows workers to make adjustments during the process if operating parameters change.

Although rational at the time, Thompson's (1967) proposed isolation of the technical core is no longer feasible. Organizational boundaries are becoming more blurred, and it is often difficult to define where one organization ends and another begins. Pooled interdependence works best in very stable environments, but most modern organizations are coping with increasing environmental complexity and dynamism. To reap the full benefits of flexibility, the technical core must interact with upstream and downstream supply chain members, in addition to using cross-functional coordination efforts that require an open system design.

Summary

Thompson's theoretical model and open systems theory form the foundation for studying manufacturing flexibility. Organizations can use the three types of interdependence with the coping mechanisms to increase flexibility. With regard to the interdependencies, reciprocal is the most flexible by design. The high degree of communication and interaction between the units provide an opportunity to make adjustments based on real-time information. Cross-functional new product development teams are an application of reciprocal interdependence. These teams include representatives from marketing, R&D, accounting, engineering, and production. They may also involve suppliers and customers. Everyone provides input to the product design which includes considering manufacturing capabilities, direct and indirect costs, new technologies, and customer needs. Both the product and the process to manufacture it are designed simultaneously to insure product manufacturability. Traditional product design uses either a pooled or sequential interdependence process. The time to introduce new products has been dramatically reduced using cross-functional teams. Coordination is more complicated as more functions are involved simultaneously; however, problems can be solved much earlier in the process before costly, irreversible decisions are made. In this example, knowledge is a non-inventory buffer as team members will have some overlapping knowledge. By having team members with overlapping knowledge, they can move between tasks as needed. These teams can exploit their knowledge to develop the best product to meet customer needs. Proactively seeking input from multiple stakeholders may enable the organization to innovate and create an environmental change for which competitors are unprepared. Organizations needing less flexibility can use the other interdependencies with the coping mechanisms. For example, a serial manufacturing process can use cross-trained workers or flexible equipment as non-inventory buffers against bottlenecks or to create environmental uncertainty for competitors by developing shorter serial processes that can be quickly switched over to make a different product.

Thompson's (1967) theoretical framework and the manufacturing flexibility literature are combined to create the manufacturing flexibility model presented at the end of this chapter.

Flexibility Component Research

In reviewing the relevant literature for this section, studies are classified according to the objective of the study (i.e. component development) and the methodology employed. The early literature in manufacturing flexibility is primarily descriptive with authors describing flexibility, the environments in which it is found, and trying to understand the effects of flexibility on performance. Flexibility is acknowledged as a desirable organizational characteristic and researchers have documented the flexible characteristics of manufacturing organizations by observing and interviewing with those who use and implement manufacturing flexibility. This knowledge is used to further refine the manufacturing flexibility components. Tentative measures of the components and organizational performance are proposed in both descriptive and field studies. Some measures are based on the researcher's understanding of the concept while others are actual measurements used within organizations. Although there are differences between the proposed components in each study, commonalities exist across the proposed lists of manufacturing flexibility components. Overlapping construct definitions and lax terminology usage (i.e. same component name with multiple definitions) create confusion as evidenced in the study by Shewchuk and Moodie (1998) who found over 70 component definitions and measures in a review of the literature.

Further understanding of the manufacturing flexibility components is the result of developing measurement instruments through survey research. These studies investigate how well flexibility is understood and used within organizations. Literature related to supply chain management is also reviewed to develop supply management flexibility as a component. In addition, several survey studies are reviewed that investigate flexibility and its relationship to organizational performance. Other relevant areas of research such as JIT/Lean, time-based competition, and mass customization are analyzed to develop the concepts of strategic integration and organizational infrastructure, as well as their relevance to manufacturing flexibility and performance. The manufacturing flexibility components are discussed in the next three sections followed by the definitions for the components in this study. Summaries of the studies reviewed are contained at the end of each section in Table 1, Table 2, and Table 3, respectively. Table 3 also contains an overall summary of the studies reviewed in these three sections.

Descriptive and Field Research

Early descriptive literature in manufacturing flexibility focuses on describing the concept and its components (Adler, 1988; Browne et al., 1984; Sethi & Sethi, 1990; Slack, 1983; Swamidass, 1988), while the early field research focuses on observing the components in actual production environments and assessing manufacturing flexibility to determine what characteristics make manufacturing systems flexible (Cox, 1989; Slack, 1987). Sethi and Sethi's study is discussed in detail because their descriptions and proposed measures are the foundation for much of the subsequent research related to manufacturing flexibility. One drawback to these early studies is that flexibility is often defined within the context of automated flexible manufacturing systems (FMS) and the components related to FMS installations. This requires consideration when assessing the proposed components and definitions for applicability in other environments.

Many flexibility studies investigate the characteristics of one flexibility component in a manufacturing system, such as labor flexibility (Dahlen, Ericsson, & Fujii, 1995) or material handling flexibility (Witt, 1996). Other researchers, such as Upton (1994, 1995, 1997), expand the scope of their studies beyond manufacturing flexibility to include issues related to organizational infrastructure and whether it enables successful implementation of manufacturing flexibility.

More recent flexibility research refines component definitions and extends the flexibility concept from manufacturing to the entire organization and beyond (Koste & Malhotra, 1999; Parker & Wirth, 1999; Vokurka & O'Leary-Kelly, 2000). In addition, these studies further develop quantifiable measures for each component and in some cases aggregate measures for manufacturing flexibility. Although later descriptive studies focus less on measuring flexibility in an automated FMS, they often continue to include components, such as program flexibility that are defined specifically for FMS. Descriptive and field studies, however, did lay the groundwork for later studies of manufacturing flexibility and are discussed in chronological order to aid in understanding how the concept developed.

Buzacott, 1982

Buzacott (1982) is one of the first studies to describe manufacturing flexibility and its potential effect on productivity and efficiency. Buzacott presents an analytical model, his descriptions of flexibility components, however, are of primary interest to the current study. He defines two components – job and machine – that are implemented at the machine and system levels of the organization. Job flexibility is the ability to cope with changes in the jobs processed in the production system and is measured as the set of all jobs that need processing. At the machine level, job flexibility relates to expanding machine capabilities, such as adding new tooling, numerical control, or group technology. At the system level, job flexibility involves creating workstations specializing in certain tasks (i.e. FMS or cellular layout). This implies a flexible material handling system that moves materials to the appropriate workstations and machines. Machine flexibility is defined as the ability to cope with changes and disturbances on the production floor and is measured by the expected loss in production due to a disturbance. There is some overlap between these component definitions, thus further refinement is necessary.

Slack, 1983

Slack (1983) defines five types of flexibility (new product, product-mix, volume, delivery, quality) describing the range of feasible system change, the cost of such changes, and the time required to make changes. New product flexibility is the range of products a system can produce, which implies not only new, but also modified products. This flexibility is limited by the product development process, available technology, labor skills, job design, and materials management. Coordination between these activities is critical for developing products and manufacturing them. Slack defines product-mix flexibility as the range of product mixes the system can process. Product-mix flexibility is increased by reducing differences between product designs, but is limited by available technology, production scheduling, and on-time, accurate material delivery. Volume flexibility is the range of short-term output change, which links this flexibility to capacity management, production planning, and human resource practices. Delivery flexibility is the ability to adjust the production schedule, which is limited by production planning, material handling, and the manufacturing system's ability to adjust to a new schedule. Quality flexibility is the ability to increase or decrease output quality and is influenced by available technology, labor skills, and human resource practices. This component, however, does not appear in subsequent research. Several descriptions imply that material handling flexibility is an additional component. Slack also implies a form of supplier flexibility within his definition of quality flexibility. It is defined, however, as the buyer being flexible by using incorrect inputs, rather than the supplier accommodating the buyer. Slack suggests that developing a single measure for manufacturing flexibility is problematic because it combines multiple objectives, and managers often perceive it as a potential rather than an actual ability. He suggests that implementation of manufacturing flexibility is enabled or limited by organizational infrastructure and strategic integration.

Browne, Dubois, Rathmill, Sethi, and Stecke, 1984

An early study by Browne et al. (1984) defines additional components with more comprehensive descriptions than those of Buzacott (1982) and Slack (1983). The authors describe eight components (machine, product, process, operation, routing, volume, expansion, production) in the context of an FMS, as well as potential measures of each. These components are often used in subsequent research for component development and measurement.

The authors propose that an ideal FMS has all eight components; however, they realize this is not economically feasible for many organizations. They present a model showing relationships between components, implying that the components build upon each other. Thus, organizations must determine the appropriate flexibility components during system design, elevating manufacturing flexibility into the strategic planning process. The components are discussed below with regard to proposed relationships.

Browne et al. (1984) define machine flexibility as the ability to make changes and produce a set of parts, which is achieved by increasing tool loading efficiency, job sequencing efficiency, and the simultaneous delivery of materials and tools. Product flexibility is the ability to change from one product mix to another, requiring machine flexibility and efficient production planning and control. Process flexibility is the ability to produce a given product mix in different ways and requires machine flexibility and adaptable computer numerically controlled (CNC) manufacturing cells. Operation flexibility is the ability to change the order of operations or processes for a particular part, which requires machine flexibility.

Routing flexibility is the ability to reroute a part due to system disturbances and requires a flexible material handling system. Volume flexibility is the ability to run a system profitably at different output quantities, which is increased using automation to lower setup times and variable manufacturing costs. Volume flexibility requires not only routing flexibility, but also multipurpose machines, a flexible material handling system, and a non-dedicated product layout. Expansion flexibility is the ability to expand the production system as needed and requires a flexible material handling system, a non-dedicated product layout, flexible manufacturing cells, and routing flexibility. Material handling flexibility is an implied component not specifically defined by Browne et al. (1984) but discussed throughout their definitions of routing, volume, and expansion flexibility. Infrastructure which includes characteristics such as job sequencing, shop floor layout, and production planning and control systems is an important aspect of flexibility.

Slack, 1987

Slack (1987) uses unstructured interviews with managers from ten organizations and finds ten common perceptions related to manufacturing flexibility. These are: managers focus on individual resource flexibility; different processes have different flexibility objectives; there are four system components (product, mix, volume, delivery); managers tend to focus on product and mix flexibility, while volume and delivery are emphasized more in mass production and job shop/batch, respectively; managers try to reduce the need for flexibility; flexibility is the range of possible changes and ease of response in terms of cost and/or time; flexibility needs are easier to describe when the distinction between range and ease of response is clear; ease of response relates to short-term flexibility, while range relates to long-term flexibility; managers envision flexibility as a means to improving product availability, delivery reliability, and productivity; and the flexibility emphasized varies with the variety of products and processes, as well as forecast accuracy.

Slack (1987) develops a two-dimensional continuum for managers to evaluate what type of flexibility is needed based on both short-term and long-term uncertainty. Slack also develops a framework for assessing flexibility needs at different organizational planning levels, facilitating the development of manufacturing flexibility capabilities across the organization to meet organizational goals. Organizational characteristics, such as process type, are an implied component that is important to determining which components are needed.

Adler, 1988

Adler (1988) suggests much of the confusion related to manufacturing flexibility is traceable to overlapping component definitions, making differences between components indistinguishable. Consequently, he proposes two broad components of flexibility: product and process. He describes product flexibility as having ever-broader boundaries expanding from product mix changes to design modifications, then to new product development within current product families, and lastly, the creation of new product families. Process flexibility is described as a three-level hierarchy comprised of machine (machine), system (routing, process, operation), and plant (volume, expansion, program).

In addition, Adler (1988) addresses complementary issues related to implementing flexibility, such as the increasing need for individual and organizational learning, a clear and more integrated strategic plan, closer relationships with suppliers, a flexible organizational infrastructure, procedures emphasizing flexibility, organizational culture encouraging cooperation, and new technologies for design, administration, control, and manufacturing automation. Adler states that flexible systems are more knowledge-intensive than traditional mass production, especially for shop floor employees; thus, organizations must carefully consider manufacturing strategy to justify flexible technology investments. Adler also observes organizations that implement manufacturing flexibility without an adequate understanding of the link between their products and processes, have systems that are underutilized because the system is more flexible than needed. Lastly, Adler discusses that ongoing employee training is necessary to instill workers with new attitudes about responsibility for process integrity and performance results. This requires training, not only in technical skills, but also in problem-solving, functional interdependence, and cross-functional cooperation.

Swamidass, 1988

Swamidass (1988) expands the overall concept of manufacturing flexibility to include three broad categories (process, product design, and infrastructure). These categories collectively comprise aggregate manufacturing flexibility, which helps firms cope with uncertainty, and influences organizational performance. Process flexibility relates to those system characteristics that are primarily contained within the system's hardware, such as machines, robots, automated material handling, computer integrated manufacturing (CIM), computer-aided process planning (CAPP), computer aided manufacturing (CAM), and group technology. Product design flexibility relates to the ability to design and modify products using the bill of material, computer-aided design (CAD), computer-aided engineering (CAE), process plans, and coding systems. Swamidass defines the third category as infrastructure flexibility that supports manufacturing flexibility and includes organizational attributes such as policies and procedures; manufacturing practices; planning, scheduling, and control systems; data collection, storage, and retrieval; and human resource practices. Additionally, this study is one of the first to formally link manufacturing flexibility to organizational performance.

Cox, 1989

In interviews with managers, Cox (1989) finds that although managers perceive flexibility as important to long-term competitiveness, none prioritized flexibility as an important organizational goal. Cox defines flexibility as a measure of efficient process change, in terms of both time and cost. He proposes two components – product-mix and volume flexibility.

The following system characteristics have a negative relationship with product-mix flexibility: supplier lead times, number of job classifications, setup time, cycle time, use of special-purpose equipment, lot sizing, and work-in-process (WIP) inventory. System characteristics with positive relationships to product-mix flexibility are cross-training, switching workers between jobs, using programmable equipment, and using “pull” production.

Cox (1989) also finds that supplier lead times and cycle time had a negative relationship with volume flexibility. System characteristics with positive relationships to volume flexibility are: the extent orders can increase without increasing lead time, manufacturing capacity slack, and scheduling slack. Excess inventory also affects volume flexibility, but no further explanation is provided. Some of these components potentially work against each other. For example, resource slack increases short-term volume flexibility, but runs counter to streamlining the system, which is often a goal of increasing product-mix flexibility.

Cox (1989) proposes measures for the two components, The diversity and sheer quantity of measures, however, imply that more than two components comprise manufacturing flexibility. In his discussion, he proposes that suppliers, labor, facilities, equipment, and production control processes affect product-mix and volume flexibility. Thus, labor, infrastructure, and supplier flexibility are implied within Cox’s discussion.

Sethi and Sethi, 1990

Sethi and Sethi (1990) review research in economics, organizational theory, and manufacturing theory; they state that manufacturing flexibility is not, in fact, a new concept and has been studied in various disciplines. Although this study defines the components within the application and measurement of an FMS, the authors develop the most comprehensive definitions, relationships among components, and potential measures for the manufacturing flexibility components to date. The study uses the components of Browne et al. (1984) as a foundation for their eleven components: machine, material handling, operation, process, product, routing, volume, expansion, program, production, and market.

Sethi and Sethi (1990) propose specific interrelationships between the components. Basic flexibilities are machine, material handling, and operation. These components support five system flexibilities: process, routing, product, volume, and expansion. At the aggregate flexibility level, program flexibility requires process and routing flexibility; production flexibility requires process, routing, and product flexibility; and market flexibility requires product, volume, and expansion flexibility. From an organizational perspective, strategy determines the need for flexibility, thus dictating the requisite components. Organizational structure and technology enable manufacturing flexibility implementation, but there are costs to implement any component. Sethi and Sethi's definitions are discussed below in detail as they are frequently used in subsequent manufacturing flexibility research studies.

Machine flexibility is defined as the variety of processes a machine could perform with minimal setup (Sethi & Sethi, 1990). They suggest that machine flexibility is achieved using programmable machines, having easy tool changes, integrating processes with CAD/CAM, designing CNC workstations, and using group technology. Workers must be cross-trained not only in production skills, but also in machine programming, maintenance, and problem solving. Proposed measures are the number of different processes a machine efficiently performs, ratio of the total output to the machine's idle cost, number of tools/programs a machine uses efficiently, input variations a machine can process, or rate of machine obsolescence. Sethi and Sethi also propose that as setup time decreases smaller batches can be processed further increasing flexibility. Increasing machine flexibility improves performance related to inventory cost, new product introduction lead-time, machine utilization, product complexity, and product quality.

Sethi and Sethi (1990) define material handling flexibility as the ability to move parts efficiently between machines or workstations including loading/unloading parts, storing parts, and using alternate routes. Proposed measures are the ratio of actual paths to total possible paths, type of material handling system, and a measure of material handling system characteristics. By increasing material handling flexibility, machine availability increases improving utilization and throughput. Automated material handling improves part tracking and information flow.

Operation flexibility is the ability to manufacture a product with multiple process plans using either alternate process sequences or interchangeable processes (Sethi & Sethi, 1990). This flexibility is implemented through product design and facilitated by using standardized parts/modules, group technology, CAD/CAM, and CAPP. Proposed measures are the number of process plans for each product, number of products using standard parts, and number of products designed modularly. Sethi and Sethi suggest that as operation flexibility increases scheduling options and machine availability also increase, which improves utilization and throughput.

Sethi and Sethi (1990) define process flexibility as the number of part types that can be produced without extensive setups. Cross-trained workers improve process flexibility. Proposed measures are the number of parts produced without major setups, number of part families, number of parts per family, range of sizes, shapes, etc. of parts in a family, changeover cost between tasks, average changeover time, and average changeover time compared to average cycle time. Sethi and Sethi propose that process flexibility reduces batch size and inventory cost, thus improving response time to short-term demand changes.

Routing flexibility is the ability to produce parts using alternate routes and the ability to reroute parts during a system disturbance (Sethi & Sethi, 1990). This includes using different machines, different processes, or different processing sequences. Parts that do not have alternate process plans can be processed using an alternate route to an identical machine, however, multiple process plans further increase routing flexibility. Any part has many potential routes but is limited by the material handling system's ability to transport parts along a route. Sethi and Sethi suggest that routing flexibility is achieved through overlapping machine capabilities, multi-purpose machines, and grouping similar machines. Workers must identify problems, thus job design should encourage worker cooperation to reroute parts. Proposed measures are the average number of routes, ratio of existing routes to all possible routes, decrease in throughput time due to machine breakdowns, and cost associated with lost production due to expediting. This component improves scheduling efficiency, machine loading, and on-time delivery.

Sethi and Sethi (1990) define product flexibility as the ability to add new parts into the product mix inexpensively, allowing organizations to bring new or modified products more rapidly to market. They state that this component is more important during a product's growth phase, as well as for organizations with nonstandard products or products with short life cycles. This component requires CAD/CAM, CAPP, group technology, similar part routines, rapid exchange of tool and dies, and multi-purpose equipment. Designing products using standardized parts, modular design, or delayed differentiation, in addition to employing cross-trained workers, increase product flexibility. Proposed measures are the time and/or cost to switch between part mixes, ratio of cost to switch between part mixes to total manufacturing cost, ratio of total output to total setup cost, number of new parts introduced in one year, and total incremental value of new parts that can be processed given new fixtures, tools, and software.

Volume flexibility is the ability to operate profitably within a set range of output quantities and the ability to rapidly change planned delivery dates (Sethi & Sethi, 1990). Volume flexibility includes the speed of response (short-term) and the range of output variation (long-term). Cross-trained workers create workforce stability when output for one product decreases. Excess machine capacity, temporary workers, and outsourcing increase volume flexibility when demand is highly variable. Proposed measures are the lowest profitable output volume for all products, range of profitable output volume, and ratio of average volume fluctuations to total system capacity.

Expansion flexibility is the ability to increase system capacity and capability as needed (Sethi & Sethi, 1990). Capacity is the output rate for a given time period while capability refers to characteristics such as quality or technology. In comparison to volume flexibility, expansion flexibility increases the maximum feasible output quantity by adding manufacturing capacity, not just changing output within a specific range. This component allows for growth strategies, since a system can be designed for incremental expansion. Expansion flexibility is implemented through manufacturing cells, group technology, multi-purpose equipment, automated systems, and an infrastructure supporting growth. Proposed measures are the overall time and/or cost to add a unit of capacity, ratio of the cost of doubling the system output to the original FMS cost, the maximum size of an FMS, and whether long-term profit approaches an optimal level. Sethi and Sethi suggest that expansion flexibility helps reduce the time and cost to introduce new and/or modified products by increasing manufacturing capacity and/or capability. Although this component is defined in the context of an FMS, with modification it may be applicable to other processes.

Sethi and Sethi (1990) define program flexibility as the ability of an FMS to run untended for an extended period of time, which requires sensors and controls that detect and manage unanticipated problems. They suggest that program flexibility is enhanced through information and knowledge management by implementing a system that allows controlled experimentation, modification of accumulated knowledge, and knowledge transfer between similar products and processes. A proposed measure is the percentage of time the system runs untended on the second and third shifts. Program flexibility improves throughput via reduced setup times, better inspection, and better fixtures or tools facilitating the tightening of tolerances to improve output quality.

Production flexibility is all potential and existing part types that a system can produce without major capital investments (Sethi & Sethi, 1990). To differentiate this component from the process and product flexibility components, Sethi and Sethi suggest that additional resources are purchased, such as new tooling, and setups may be significantly longer. Production flexibility is increased by logistics systems, transparent information systems, production control systems, standardized communication protocols, and cross-trained workers. Explicit measures are not given, as this component is described as long-range product flexibility. Sethi and Sethi do suggest, however, that a measure similar to those for product flexibility be used. Like process flexibility, this component reduces the time required to introduce new and/or modified products, thus increasing product variety.

Sethi and Sethi (1990) define market flexibility as the ability of the system to adapt to a dynamic market environment requiring cross-functional cooperation between manufacturing and marketing. They suggest market flexibility allows organizations to implement integrated manufacturing and marketing strategies emphasizing frequent product introductions and product customization. Product, process, and volume flexibility are market-related components that allow minor product design modifications, innovative technology applications, and supply uncertainty reduction. Cooperation among production planning, inventory control, forecasting, product development, customer relations, supply management, and distribution channels increases market flexibility. Proposed measures are the time/cost to introduce a new product, time to increase/decrease output volume, time/cost to increase production capacity, lost sales due to shortages, and cost of late deliveries.

Although Sethi and Sethi (1990) acknowledge that cross-trained workers are necessary for manufacturing flexibility, labor flexibility is not included in their model. Throughout their discussion, however, worker attributes related to flexibility are mentioned such as: autonomous teams, direct access to materials, and employee planning and control of work. Through teams, workers test, inspect, and repair products in addition to assembly while automated systems perform routine processes. Designing a facility layout for teams also improves ergonomics, health, and safety. With new product introductions and frequent product mix changes, workers need on-going training to cope with disturbances, schedule changes, and volume changes, as well as learning new skills. Flexible information technology and other relevant infrastructure characteristics are described within their discussion.

<u>Olhager, 1993</u>

Olhager (1993) considers two primary flexibility components – volume and product-mix – and ways to implement them, as well as the expected effect on profitability in terms of sales, assets, investment cost, and operating cost. Olhager suggests these two components meet short-term and long-term flexibility needs. Short-term flexibility related to the manufacturing system is measured by production lead time with performance improvement measured by setup time reduction. Short-term product-related flexibility relates to using modular product design to increase variety and customization. Short-term customer-related flexibility is reflected in shorter delivery times and product specification changes through modular product design. Long-term flexibility for the manufacturing system relates to the system's life cycle and integration of new equipment via flexible production floor layouts (e.g. cells, group technology, FMS). Long-term product-related flexibility requires continuous product development and improvements through modular design and standardization to meet customer requirements. Long-term flexibility related to customers includes product upgrades and availability of replacement parts. Although only two components are proposed, the discussion includes descriptions of equipment, supplier, labor, new product design, and design modification flexibility.

Watts, Hahn, and Sohn, 1993

Watts et al. (1993) suggest that flexibility is either a strategic response to environmental uncertainty or a supporting element of corporate strategy to improve performance. Flexibility components are categorized as primary (volume, mix, variety, and delivery) or secondary (process/machine, setup, capacity/expansion, routing, scheduling, worker, and design). Primary components directly relate to organizational strategy, while secondary components support the primary components. Their classification attempts to integrate manufacturing strategy and capabilities with organizational strategy. The authors emphasize the difficulty of measuring flexibility, as it is often a potential, rather than an actual capability. They posit that flexibility measures should consider not only time and cost, but also organizational infrastructure. There is overlap between several component descriptions, thus variety, design, setup and scheduling flexibility are included under more common terminology in Table 1 (i.e. new product, modified product, process/mix, delivery).

Upton, 1994

Upton (1994) develops a framework to assess manufacturing flexibility and applies the framework to organizations in three different industries. The first step identifies what needs to change. Each organization likely needs to change different characteristics, thus managers must prioritize the type of flexibility needed to achieve organizational goals and improve performance. Next, the time period over which changes need to occur is determined (operational, tactical, or strategic). Lastly, the flexibility capabilities that are most critical for the organization to manage are determined.

Range is defined as the number of feasible options possible and includes the difference between the two extremes of the range. Mobility is defined as how fast a change within the component's range can occur measured by the time, cost, or effort to change. Uniformity of performance measures whether a change affects performance with no difference in performance implying greater flexibility (Upton, 1994).

A firm focusing on operational flexibility develops a strategy based on product customization, quick response, or a broad product offering. Each competitive initiative requires developing different capabilities. To offer customized products, an organization develops the range capability supported by mobility and uniformity. A focus on quick response requires improving mobility supported by range and uniformity. A broad product line requires uniformity and range capabilities, supported by mobility (Upton, 1994). Upton uses this framework for two studies discussed below.

Upton, 1995, 1997

Upton (1995, 1997) develops a model of the determinants of operational (short-term) process flexibility, using data from over 50 plants owned by 11 U.S. paper manufacturers. Upton (1995) investigates process mobility flexibility (speed of changing product mix) while Upton (1997) investigates process range flexibility (product mix depth/breadth). He proposes that overall organizational structure helps organizations cope with long-range issues, internal infrastructure helps organizations cope with mid-range issues, and management helps organizations cope with short-range issues.

Using observations, unstructured interviews, and structured questionnaires with senior managers, plant managers, plant superintendents, and machine operators, data are collected on changeover times, range of products, frequency of changeovers, size of the plant, employee experience, age of production technology, use of general computer integration, use of computer integration specifically for mobility, managerial emphasis, and process stability (Upton, 1995, 1997).

In looking at process mobility, Upton (1995) finds no significant relationship between neither mobility and scale, nor between mobility and computer integration. There is a significant negative relationship between mobility and worker experience. Several possible explanations are provided, such as physical limitations of more experienced workers or whether training occurred when shorter changeover times were not critical. Managerial emphasis is also negatively related to mobility which may imply a lack of strategic integration.

In the second study, Upton (1997) found plant size and computer integration are negatively related to process range, as is the age of the plant and its technology. The experience of the workers is positively related to process range flexibility, while cross-training is negatively related. One explanation for this is that workers are less likely to experiment when less familiar with a different task. Managerial emphasis on producing a broad range of products is positively related to range. Facilities with more process range flexibility are capable of producing 20 times the number of products, implying they have higher process flexibility because they can accommodate larger process variation. Upton states that managers need quickly calculated measurements using easily accessible data. One of the main difficulties, however, is that process range and mobility may be negatively related to each other. Thus, managers must be sure which type of flexibility they need before investing in manufacturing flexibility.

Koste and Malhotra, 1999

Koste and Malhotra (1999) review literature related to flexibility components as well as studies proposing hierarchical relationships between components. They define ten flexibility components (machine, labor, material handling, operation, routing, expansion, volume, mix, new product, modification) and potential measures. For each component, four parameters (range-number, range-heterogeneity, mobility, uniformity) are proposed. Range-number measures the number of possible options for a given component. Range-heterogeneity measures the relative difference between possible options. The definitions for mobility and uniformity are similar to those proposed by Upton (1994, 1995, 1997).

Koste and Malhotra (1999) develop a five-level hierarchical structure of relationships among the components. At the individual resource level, the components are labor, machine, and material handling. The shop floor level includes routing and operation flexibility which support the plant level components of expansion, volume, mix, new product, and modification. At the functional level are R&D, marketing, manufacturing, and organizational flexibility. Lastly, strategic flexibility is defined at the strategic business unit level. The top two levels of the hierarchy and their components are not discussed in-depth. Koste and Malhotra's (1999) component definitions are similar to those of Sethi and Sethi (1990) for machine, material handling, routing, volume, operation, expansion and mix (process); thus, only proposed measures for these components are listed below. Koste and Malhotra define three components (new product, modification, and labor) not defined by Sethi and Sethi. Each is discussed in detail below.

Koste and Malhotra (1999) propose various measures for the seven components in common with Sethi and Sethi (1990). Machine flexibility is measured by changeover time, setup cost, lost production time, scrap produced, changes in output quality, processing times, productivity, and efficiency. Material handling flexibility is measured by material transfer times, cost to transfer materials, the time/cost to add/remove a path, and the number of parts moved by the system. Routing flexibility is measured by average number of alternate routes per part, average number of machines to which parts are routed, time to change a route, and differences in processing time. Volume flexibility is measured by the range of profitable output volumes, time to change the output volume, and changes related to quality, cost, or profitability. Operation flexibility is measured by the number of parts having alternate process plans, relative difference between those plans, time/cost to switch between process plans, and changes in quality or cost. Expansion flexibility is measured by the number of expansions a system can accommodate, time to add new resources and restart the process, and changes in quality, product cost, and productivity. Mix flexibility is measured by the number of end items, variety of products, time and cost to change the product mix, and changes in productivity or quality.

Many previous studies imply that product flexibility includes both design modification and new product design. Koste and Malhotra (1999) consider these separate components. Modification flexibility is the ability to change current products without changing basic functionality to better meet customer requirements. Measures are the number of modified products, extent designs can be modified, time/cost to make modifications, and changes in productivity or quality when modified products are added to the product mix. New product flexibility emphasizes product development and innovation. This is measured by the number of products introduced with measurably different functionality, diversity of new products, time/cost to develop new products, and changes in productivity or quality when new products are added to the product mix. Additionally, Koste and Malhotra (1999) define labor flexibility as not only vital to most processes but also affecting performance. Labor flexibility is the result of cross-training workers and the diversity of tasks trained. Measures include lost production time to move workers between jobs and whether workers perform tasks consistently. Process design and organizational policies improve labor flexibility.

Vokurka and O'Leary-Kelly, 2000

Vokurka and O'Leary-Kelly (2000) propose fifteen manufacturing flexibility components, which are implemented through manufacturing practices (e.g. JIT/Lean, mass customization, time-based competition, agile manufacturing) that address shortened product life cycles, changed customer needs, and unanticipated environmental changes. This study adds four additional components to the eleven proposed by Sethi and Sethi (1990) which are automation, labor, new design, and delivery. It also includes an analysis of other variables influencing flexibility.

Vokurka and O'Leary-Kelly's (2000) definitions for these four additional components follow. Automation flexibility is defined as the extent to which a system's flexibility is contained within automated manufacturing technology. Labor flexibility is the range of tasks a worker can perform. New design flexibility is how quickly products are designed and introduced into the production system, which overlaps with Sethi and Sethi’s (1990) definitions for process/mix flexibility and product flexibility. Delivery flexibility is how well the system responds to delivery change requests.

Based on previous studies Vokurka and O’Leary-Kelly (2000) propose four variables (strategy, environmental factors, organizational attributes, and technology) that either directly affect manufacturing flexibility or moderate the relationship between manufacturing flexibility and performance. Manufacturing flexibility is proposed as an aggregate construct but they do not mention either the relationships among the fifteen flexibility components or a way to measure it.

Vokurka and O’Leary-Kelly (2000) review empirical studies to determine which component relationships have been studied, whether flexibility is measured as an independent or dependent variable, whether other variables are studied, and how performance is measured. Vokurka and O’Leary-Kelly find that, although previous empirical research exists, there are several limitations. Only two studies include environmental factors, three include strategy, seven examine relationships between organizational infrastructure and flexibility, and five examine the relationship between technology and flexibility. They find no single study examines all of the relationships they propose with most studies addressing a limited number of flexibility components. Additionally, the level of analysis is an issue due to the difficulty of accurately attributing performance contributions by individual facilities within large organizations. In the area of methodology and design, Vokurka and O’Leary-Kelly emphasize operationalizing the flexibility components through the development of valid and reliable measures remains a priority. They suggest that research in the field of manufacturing flexibility needs to be generalizable with data gathered from multiple sources in each organization and with less emphasis on studying FMS. As with the other descriptive studies, Vokurka and O'Leary-Kelly provide additional information for developing better measurement instruments for manufacturing flexibility components. Additionally, they emphasize that empirical research needs to include other variables that affect implementing manufacturing flexibility.

Other Studies

Other descriptive studies include further literature reviews related to classifying the different flexibility perspectives (De Toni & Tonchia, 1998; Hyun & Ahn, 1992) and providing additional support for the various manufacturing flexibility components (Dahlen et al., 1995; Gupta & Goyal, 1989; Parker & Wirth, 1999; Slack, 1989; Witt, 1996). Gupta and Goyal add support for the components proposed by Browne et al. (1984) as did Parker and Wirth, who summarize measures developed in the literature following Browne et al.'s publication. In addition, Parker and Wirth add measures for volume and expansion flexibility, as well as discussing relationships among components. Slack (1989) revises his earlier definitions and adds the concepts of labor, infrastructure, and technology/automation flexibility as well as discussing the role of suppliers.

Gerwin (1993) studies flexibility components as mechanisms by which organizations cope with different environmental uncertainties allowing them to achieve various strategic objectives. He proposes four product-oriented components (mix, changeover, modification, volume) and three process-oriented components (routing, material, responsiveness) that can be used with generic strategies proactively or defensively.

Dahlen et al. (1995) use questionnaires, interviews, and observations to investigate variables influencing labor flexibility and stability in Japan and Sweden. Variables include the effect of multi-skilled workers, unions, seniority, wages, benefits, absenteeism, flexible hours, work pace, subordination of tasks, and employee participation in planning and problem-solving. Results indicate a more stable and flexible labor situation in Japan versus Sweden.

Witt (1996) observes four organizations with new material handling systems. The results indicate: material handling systems should be expandable; material handling flexibility solves more problems than it creates; an organization's problems should be understood relative to material handling needs; and training and education are critical to performance.

These studies are combined in the next to last column of Table 1, as they generally provide support of components previously proposed, rather than developing new components or models.

Summary

Descriptive and field research in manufacturing flexibility primarily focuses on describing manufacturing flexibility components. Some components have been studied in-depth while others are implied within the discussions of manufacturing flexibility. Table 1 summarizes the components described in each study. The final column summarizes whether there is a consensus across the various studies supporting each component in the manufacturing flexibility construct. When looking for commonalities across proposed components, the following components are supported (8 or more studies): new product, modified product, operation/process plan, machine/equipment, material handling, routing, process/mix, volume, labor, and infrastructure.

Partial support (5 to 7 studies) is found for delivery, expansion, production/ manufacturing, technology/automation, and supplier/supply management indicating that these should be studied further for inclusion as components. Delivery flexibility is frequently defined relative to performance outcomes rather than as a manufacturing flexibility component, which explains its exclusion from some studies. Expansion and production/manufacturing flexibility are often defined as higher level components planned in upper organizational levels, while most studies have a unit of analysis at the plant level or below. Technology/automation flexibility is not well defined within these studies. Again, some researchers use the term to indicate whether flexibility is contained within the technology (e.g. FMS) while others define it more similarly to machine flexibility by describing flexibility of different manufacturing technologies (e.g. hand tools, machines, computers, etc.). Supplier/supply management is specifically proposed in later studies and may indicate a shift in organizational perspectives from focusing internally on improving the technical core's flexibility, to focusing externally on environmental factors, such as suppliers and customers, over which organizations have some influence. Additionally, supplier flexibility is often studied separately within the context of the supply chain or the buyer-supplier relationship, thus it is not surprising that this component is not fully developed in the manufacturing flexibility literature.

Weak support (4 or fewer studies) is found for program and market flexibility. Program flexibility is less applicable if a study is not focused exclusively on an FMS; thus, it is not surprising that this component has weak support. Market flexibility is a functional level flexibility, however, most descriptive/field studies focus on components directly related to manufacturing products. Some consider market flexibility an outcome or performance measure of manufacturing flexibility.

The main limitation of studies using this methodology is that they generally lack a strong theoretical foundation for proposed components and/or empirical evidence for inclusion of the proposed components and measures. Although Sethi and Sethi (1990) have theoretical support for their components, the study is limited due to a lack of empirical data supporting the proposed components. Due to the early emphasis on FMS in the manufacturing flexibility literature (Browne et al., 1984; Sethi & Sethi, 1990), many early definitions need adjustment to measure flexibility in non-FMS processes. An additional limitation is overlapping component definitions some of which are defined and measured across different planning horizons or with multiple hypothesized interrelationships among components. The lack of differentiation between components is highlighted when one measure is proposed for multiple components. These descriptive and field studies are the first step in describing the manufacturing flexibility components in quantifiable terms, and a natural beginning to the evolution of an emerging research topic. These studies provide initial theoretical support for the proposed components and model for the current study.

The validity of the proposed components and measures is not fully established within this group of studies. Thus, the next section describes survey studies that contribute to manufacturing flexibility component development by collecting and analyzing larger data sets.

Table 1 – Summary of Flexibility Components Proposed in Descriptive and Field Research

Components Described	Buzacott, 1982	Slack, 1983	Browne et al., 1984	Slack, 1987	Adler, 1988	Swamidass, 1988	Cox, 1989	Sethi & Sethi, 1990	Olhager, 1993	Watts, et al., 1993	Upton, 1994, 1995,1997	Koste & Malhotra, 1999	Vokurka & O'Leary-Kelly, 2000	Other Studies	Summary
New Product	I	X	X	X	I	X		X	I	X	X	X	X	X	S
Modified Product	I	I	I	I	I	X		I	I	X	X	X	I	X	S
Operation/Process Plan	I		X		I	I		X				X	X	X	S
Machine/Equipment	I		X	X	I	I		X	I	X		X	X	X	S
Material Handling	I	I	I			I		X				X	X	X	S
Routing	I		X		I			X		X		X	X	X	S
Process/Mix	I	X	X	X	I	X	X	X	X	X	X	X	X	X	S
Delivery		X		X						X	X		X		P
Volume		X	X	X	I		X	X	X	X		X	X	X	S
Expansion			X		I			X		X		X	X	X	P
Production/Manufacturing			X		X			X				I	X	X	P
Program								X					X		W
Market								X				I	X		W
Labor					I	I	I	I	I	X	I	X	X	X	S
Infrastructure		I	I	I	I	X	I	I	I	I	X		X	X	S
Technology/Automation					I	I		I			I		X	X	P
Supplier/Supply Management		I			I	I	I		I					I	P

X = Explicitly described within the study
(may have a different label but described similarly)
I = Implied within the descriptions

S = Supported (8 or more studies)
P = Partial support (5 to 7 studies)
W = Weak/No support (fewer studies)

Survey Research

Once a phenomenon is identified, scientists must find reliable and valid ways to measure it. Surveys are useful in determining the depth that manufacturing flexibility has been implemented in industry. Surveys also help determine how well practitioners understand manufacturing flexibility and are able to use it strategically. Several studies define components of manufacturing flexibility and develop measurement instruments (Dixon, 1992; D'Souza & Williams, 2000; Gupta & Somers, 1992; Koste, Malhotra, & Sharma, 2004; Suarez, Cusumano, & Fine, 1996; Zhang, Vonderembse, & Lim, 2003).

Early survey studies for manufacturing flexibility focus on measuring a limited number of components (Dixon, 1992; Suarez et al., 1996) or developing measurement items based on previously proposed component lists and definitions (Gupta & Somers, 1992). Later survey studies refine previous definitions and combine various theories to develop new measurement instruments (D'Souza & Williams, 2000; Koste et al., 2004; Zhang et al., 2003). These studies are described below in chronological order.

Dixon, 1992

Dixon (1992) presents empirical results of an instrument development study for mix, modification, and new product flexibility using questionnaire data collected in 29 U.S. textile mills. Factor analysis is used to validate the measurement items. For mix flexibility, one factor (8 items) accounts for 56.4% of the variance. For new product flexibility, one factor (7 items) accounts for 35.8% of the variance. For modification flexibility, one factor (7 items) accounts for 38.2% of the variance. The number of different product characteristics produced during one month and number of product characteristics produced simultaneously are positively correlated.

Additionally, the number of different product characteristics produced in one month is negatively correlated with changeover time and cost. Dixon suggests that organizations learn how to make faster changeovers by improving processes and modifying equipment. In the discussion, the importance of supplier cooperation and flexibility is implied.

In addition to measuring the three flexibility components, Dixon (1992) presents a methodology for comparing flexibility based on organizational characteristics and different flexibility components, thus providing managers a more complete understanding of other factors that affect flexibility. This allows plant level comparisons of flexibility.

Gupta and Somers, 1992

Gupta and Somers (1992) develop a survey to measure Sethi and Sethi's (1990) eleven components. Thirty-four items comprise the initial instrument. One question, about overall manufacturing flexibility, is included to measure criterion validity. Respondents are upper level managers of manufacturing firms.

During analysis, nine items are removed based on low item-to-total correlations. The remaining 25 items are analyzed using exploratory factor analysis, resulting in the removal of four additional items. The final instrument contains 21 items representing nine manufacturing flexibility components (expansion, material-handling, routing, machine, market, product/ production, process, program, volume). Seven factors have eigenvalues greater than one. Two of the factors have borderline eigenvalues (0.99995 and 0.98999), which is understandable as those factors are each measured with one item. Two items have factor loadings on more than one factor, and it is suggested that these could be measures of overall flexibility. The nine factors explain 72% of the variance in the data. All of the items on the modified instrument have item-to-total correlations of at least 0.655 and are correlated to the overall flexibility item at 0.60 or higher. A multitrait-multimethod matrix is developed using additional data gathered from 113 firms via phone interviews and is used to verify convergent and discriminant validity of the instrument.

The main contribution of this study is the development of a validated measurement instrument using data from multiple industries. The main limitation of this study is that two factors are represented by only one item and five are represented by two items each. Thus, only two factors out of nine are well measured with this instrument, but it does provide a foundation for subsequent studies.

Suarez, Cusumano, and Fine, 1996

Suarez, Cusumano, and Fine (1996) use survey, interview, and observational data to analyze the relationship between five organizational infrastructure factors and implementation of volume, mix, and new product flexibility.

Suarez et al. (1996) find that new, more automated technology is negatively related to mix and new product flexibility, but positively related to volume flexibility. This counter-intuitive result may be an industry effect, as one would expect newer technology to increase the ability to offer more products and allow easier changeover of the product mix. Alternately, it may reinforce the assertion that organizations underutilize flexible capabilities of advanced manufacturing technology (e.g. FMS) (Jaikumar, 1986). Formal group problem-solving is positively related to mix and new product flexibility. Close supplier and subcontractor relationships are positively related to mix, new product, and volume flexibility. Part commonality increases both mix and new product flexibility.

Suarez et al. (1996) find that facilities with mix flexibility have lower volume fluctuations, which affect the system less since they can switch between products or dedicate the production line to the product with highest demand. This stabilizes production output, increasing workforce stability and decreasing the need for volume flexibility. Mix flexibility is highly correlated with new product flexibility. Plants with higher mix flexibility had shorter new product development times. Suarez et. al propose that high mix or new product flexibility does not automatically involve higher costs or lower quality, and mix flexibility is useful for coping with changes in customer demand. The high correlation between mix and new product flexibility in a small sample may indicate that these components are not well differentiated and may need to be combined.

This study does provide some evidence of how these three components are related to other organizational characteristics. Limitations of this study include the small sample size (31 plants) and use of only one industry. Additionally, the processes and technology are very similar in the organizations studied. Only vertically integrated plants that produce downstream for other plants owned by the same parent organization are used, which insulates these organizations from some competitive market pressures. These results have limited generalizability beyond this industry, but the results further increase the understanding of manufacturing flexibility in a specific environment.

D'Souza and Williams, 2000

D'Souza and Williams (2000) divide flexibility components into two categories – internally-driven and externally-driven – based on Gerwin's (1993) component list (mix, changeover, modification, volume, rerouting, material). In this study, Gerwin's six components are combined into four. These are volume, variety (modification and mix), process (mix and changeover), and material handling, with each component having two parameters (range and mobility). These components are defined as “primary” to reduce overlap with other proposed components in the literature. Measurement items are developed for each component/parameter combination.

D’Souza and Williams (2000) collect survey data at the plant level to measure the proposed components. Respondents range from President/CEO to manufacturing/operations manager. Correlation analysis is performed on each of the four dimensions to differentiate between the range and mobility parameters. In general, items are significantly correlated as expected. Factor analysis is performed on the items and eight factors emerge as hypothesized.

D’Souza and Williams (2000) help confirm that flexibility is not contained in only one or two components, but requires measurement across multiple components within a system. Limitations of this study relate primarily to data analysis. The difference between the range and mobility elements is unclear as there are significant correlations among survey items and across components. This may be due to overlap between the definitions for variety and process. There is no explanation of the factor analysis process, with several factors measured by one item and the remaining factors measured by two items. Although parsimonious, alpha values can not be computed for factors measured with only one item, making it difficult to compare this new instrument with others.

Zhang, Vonderembse, and Lim, 2003

Zhang, Vonderembse, and Lim (2003) investigate manufacturing flexibility as a strategic dimension of value chain flexibility. A model is developed using machine, labor, material handling, and routing flexibility as predecessors to volume and mix flexibility, which are directly related to customer satisfaction. They consider flexible capability (volume and mix) as external or market-focused components that link marketing, manufacturing and corporate strategies. Flexible competence (machine, labor, material handling, routing) are internal, process-focused components that encompass processes and infrastructure that expand manufacturing capability. Five of Zhang et al.'s six component definitions use Sethi and Sethi's (1990) descriptions as a foundation, with the definition of labor flexibility based on other studies. Performance is measured using perceptual measures about the value, quality, and reputation of the organization's products and customer satisfaction along those dimensions.

Primarily smaller manufacturing firms are surveyed from five related industries (SIC 34-38) resulting in 273 usable responses. Respondents are from the Society of Manufacturing Engineers with titles ranging from CEO/President to Manager. Exploratory factor analysis is used to validate the scale items for each construct. Alpha values for the independent variables range from 0.83 (machine) to 0.92 (material handling, routing, mix) and 0.79 for customer satisfaction. The relationships between the constructs are then tested using structural equation modeling. All hypothesized relationships are statistically significant (.01 or .05).

The limitations of this study primarily relate to the data analysis. Both exploratory factor analysis and confirmatory factor analysis are used, but there is no discussion of whether the sample is split, thus making each analysis independent. In the confirmatory analysis, the flexible competence components (machine, labor, material handling, routing) are converted into aggregated scores, while volume flexibility, mix flexibility, and customer satisfaction are analyzed using individual items. It is unclear if the aggregated values are summations or averages. If they are summated, this is problematic, as there are different numbers of items on each scale (5, 5, 4, and 6 items, respectively). Additionally, with regard to the items for manufacturing flexibility, respondents are asked to agree or disagree with the statements by comparing their organization's capabilities to their competitors. It is often difficult for respondents to fully understand manufacturing capabilities within their own organization, much less in comparison to their competitor's capabilities. In addition, many of the respondents may be engineers who helped design the processes and may overstate their flexibility capabilities. Processes may have been designed for more flexibility than is actually needed or used, which may crate a bias that their organization's manufacturing expertise exceeds a competitor's. Lastly, there does not appear to be an analysis for common method variance and the investigators do not consider having one respondent per organization as a study limitation.

Koste, Malhotra, and Sharma, 2004

Koste, Malhotra, and Sharma (2004) develop a measurement instrument for six components of manufacturing flexibility (machine, labor, material handling, mix, new product, and modification), each having four parameters (range-number, range-heterogeneity, mobility and uniformity). They indicate that there remains a lack of generalizable measures reflecting manufacturing flexibility's multi-dimensionality. The unit of analysis is the manufacturing plant, although they measure items previously proposed at the individual resource level (Koste & Malhotra, 1999). Firms are selected based on process type, SIC code (34-36), and firm size. Targeted respondents are top management (e.g. VP of Manufacturing); however, with a sample that primarily represents large firms (80.1% have sales over \$50 million and 87.9% employ over 250 employees) over half of the respondents are labeled middle management or lower management based on job titles such as plant manager, operations manager, production manager, supervisor, and foreman.

Koste et al. (2004) collect data via mailed questionnaires resulting in 158 completed surveys. Content, convergent, discriminant, and criterion validity are confirmed. Reliability is analyzed using the squared standardized loadings; while internal consistency is verified with coefficient alpha. In general, organizations who indicated higher flexibility based on a single item aggregate measure also possessed higher component flexibility. This correlation is used only to verify whether respondents answered consistently between the component items and the aggregate measure.

Based on exploratory factor analysis, seven factors are extracted. The authors analyze a five-factor model and two-factor model. They do not report analyses of other interim factor models nor do they explain why these models were selected. Based on a second factor analysis using composite scores, two factors emerge with the two range elements loading together and the mobility/uniformity elements loading together. The two factors are compared to the overall flexibility rating. Koste et al. (2004) suggest that managers emphasize those components needed for an organization's particular situation. This study does contribute to the development of measures for the flexibility components.

There are two limitations with this study. First, Koste et al. (2004) use exploratory and confirmatory factor analyses without clarifying whether the sample is split in order to have independent datasets for each analysis. With less than 160 respondents, a split sample was likely not used. Second, the authors state that a previously proposed framework (Koste & Malhotra, 1999) is tested and validated. They did not explain, however, how the proposed parameters or hierarchical levels in the framework were validated by their results. Although there is insufficient support for the four proposed parameters, the development and testing of new measurement items is valuable.

Summary

These survey studies reiterate that research related to manufacturing flexibility is still fragmented with regard to the components of manufacturing flexibility. The items developed and validated in these studies are valuable for further instrument development. The common limitation in several studies is the use of only a few items or one item to measure constructs. Zhang et al. (2003) and Koste et al. (2004) used the most rigorous processes to develop their measurement instruments; however, each had limitations. Several studies use small samples or single industries, reducing generalizability. In one study, the timeframe respondents are asked to consider varied within the survey (one month to one year), possibly causing confusion. Several factor analyses do not fully explain critical issues related to how the analysis is conducted or the criteria for inclusion/exclusion of components or measurement items.

Table 2 summarizes the components measured in these studies. The same approach used in the descriptive/field research is used to create the categories for Table 2. A component is supported if a majority of the studies indicates that a component was measured and found to be valid. At least two studies measuring a component are necessary for the component to have partial support. Components measured in one study or no studies are considered to have weak/no support. Within survey research, new product, material handling, process/mix, and volume are supported as components. There is partial support for modified product, machine, routing, labor, and supplier/supply management flexibility as components. There is weak/no support for operation/process plan, delivery, expansion, production/manufacturing, program, market, infrastructure, and technology/automation flexibility based on these survey studies.

The next section contains a discussion of other research regarding organizational characteristics related to the manufacturing flexibility components.

Table 2 – Summary of Flexibility Components Measured in Survey Research

Components Measured	Dixon, 1992	Gupta & Somers, 1992	Suarez et al., 1996	D'Souza & Williams, 2000	Zhang et al., 2003	Koste et al., 2004	Summary
New Product	X	X	X	X		X	S
Modified Product	X			I		X	P
Operation/Process Plan							W
Machine/Equipment		X			X	X	P
Material Handling		X		X	X	X	S
Routing		X			X		P
Process/Mix	X	X	X	X	X	X	S
Delivery							W
Volume		X	X	X	X		S
Expansion		X					W
Production/Manufacturing							W
Program		X					W
Market		X					W
Labor					X	X	P
Infrastructure			I				W
Technology/Automation			I				W
Supplier/Supply Management	I		I				P

X = Explicitly described within the study
(may have a different label but described similarly)
I = Implied within the descriptions

S = Supported (4 or more studies)
P = Partial support (2-3 studies)
W = Weak/No support (fewer studies)

Other Relevant Research

The primary focus of this section is a discussion of the relevance of cross-trained workers and supply management to manufacturing flexibility, although support is also found for other components. Labor flexibility refers to workers having multiple skills and abilities that increase an organization’s options. Supplier/supply management flexibility refers to the characteristics of suppliers that enhance an organization’s flexible capability or, at a minimum, do not reduce the organization’s manufacturing flexibility. This section includes studies that do not specifically study or propose manufacturing flexibility components, but rather lend support for their inclusion. These studies relate to management techniques such as supply chain management, time-based competition, JIT/Lean, and mass customization. This group of studies provides support for several manufacturing flexibility components – new product, modified product, routing, process/mix, volume, labor, infrastructure, and supplier/supply management. A summary of the components supported in these studies is included in Table 3, which also contains an overall summary of the literature relevant to component development for manufacturing flexibility.

Hall and Nakane (1990) suggest that organizations should seek alliances and partnerships with suppliers who share the same principles. Flynn, Sakakibara, and Schroeder (1995) recommend that organizations select suppliers based primarily on quality and delivery reliability rather than lowest cost. They also suggest developing long-term, reciprocal relationships with suppliers. Extensive communication and frequent exchanges of information are needed to build these relationships and the requisite trust. Several manufacturing flexibility studies propose that supplier relations and materials management are integral to manufacturing flexibility (Adler, 1988; Chang et al., 2002; Cox, 1989; Slack, 1983). Narasimhan and Das (1999a, 1999b) found empirical support that strategic sourcing practices influence manufacturing flexibility and performance.

Uzzi (1997) studies buyer-supplier networks within the New York fashion industry and finds most organizations had two types of suppliers, those with embedded ties and those kept at arm's length. Embedded suppliers are Tier 1 suppliers that develop strong, long-term relationships with buying organizations that are reciprocal in nature. These relationships are characterized by trust, information sharing, joint problem-solving, satisficing rather than minimizing price, reciprocity, resource sharing, risk-sharing, adapting to changes, and adjusting to unexpected events. These relationships do not require detailed contracts with multiple contingencies due to the long-term nature of the relationship and expectations of reciprocity. Embedded supplier contributions often exceed what is specified in a contract. Buyers reward these suppliers via higher prices and additional orders. Other suppliers are kept at arm's length by the buying organizations due to a lack of trust. Relationships with such suppliers possess opposite characteristics to the trusted embedded suppliers and are only used when embedded suppliers are unavailable.

Time-based Competition

Intuitively, the more flexible an organization is, the more likely they can respond to market changes. Wacker (1987) finds that throughput time is negatively related to responsiveness (i.e. flexibility) and productivity, but positively related to product cost. Throughput time includes all of the associated internal times related to producing a product – transportation, waiting, setup, production, rework, machine downtime, stockouts, and preventive maintenance time. In addition, it includes external times related to supplier on-time deliveries and variability in the timing of customer demand. Raw material and finished goods inventories are often used to protect the technical core from extreme variations in these two areas. Increasing responsiveness by decreasing throughput time reduces the need for large buffers of finished goods (FG) inventory. Increasing part commonality and modular product design reduces the need for a large raw material (RM) inventory. Thus, systematically reducing inventories helps improve responsiveness (i.e. flexibility). Reducing work-in-process (WIP) inventories reduces the time required to identify quality problems, which reduces the time required for rework and improves throughput time and on-time delivery. Preventive maintenance improves first pass quality and reduces throughput time, rework, and equipment downtime. Reducing batch sizes and transferring batches more frequently is facilitated by reduced WIP inventory and setup times. Processing smaller batches with fewer products in the system at any given time, allows parts to travel faster through the system (throughput time) and reduces waiting time.

The overall goal is reducing system variability wherever possible and using flexibility to cope with any remaining variability (Wacker, 1987). Cellular layouts and group technology reduce transportation time, with related products produced within a cell or by a group of cells located in close proximity. Working with suppliers through better forecasting, part commonality, and frequent raw material deliveries reduces inventory shortages. Improving raw material quality further reduces rework. All of these improvements make the production floor operate smoother, thus allowing more time to work on process improvements. Thus, decreasing throughput time improves overall performance (Wacker). Throughput time can be reduced through new product, modified product, process/mix, routing, labor, volume and supplier/supply management flexibility.

Time-based competition is often considered synonymous with flexibility, since flexibility reduces the time required to process and deliver products to customers (Ferdows & De Meyer, 1990). Therefore, speed, response time, and flexibility are not separate practices, rather response time or speed as measured by throughput is a performance measure for manufacturing flexibility.

Just-in-Time/Lean Manufacturing

Just-in-Time/Lean manufacturing (JIT/Lean) focuses on improving throughput by reducing setup time, reducing downtime, using JIT purchasing, and developing multi-function employees (Flynn, Schroeder, & Sakakibara, 1994; Sakakibara et al., 1993; White, Pearson, & Wilson, 1999; White & Ruch, 1990). Fullerton and McWatters (2001) find that JIT changes improved organizational performance with regard to increased quality, reduced throughput time, improved worker flexibility, simplified accounting, improved profitability, and reduced work-in-process inventory.

Within JIT/Lean, multi-function employees are used to increase process/mix, labor and volume flexibility, while JIT purchasing and frequent supplier shipments affect process/mix, volume, and supplier/supply management flexibility. JIT purchasing requires reciprocal buyer-supplier relationships. Smaller batch sizes, shorter setup times, and lower WIP inventory should increase new product, modified product, process/mix, and volume flexibility. As WIP inventory and setup times decrease, there is less clutter on the production floor making it easier to identify bottlenecks and idle machines, which enhances routing flexibility. Using group technology also increases process/mix and routing flexibility, as manufacturing cells can not only produce any of the parts belonging to a particular part family but also process multiple part families. A group of cells can be highly flexible and function as a plant-within-a-plant to achieve some economies of scale and scope. All of these improvements are achieved by implementing an organizational infrastructure that supports the JIT/Lean practices to create a productive manufacturing system.

Mass Customization

For mass customization, an organization must determine at what point (early or late) during the manufacturing process a product can be customized choices (Pine et al., 1993). They must also decide how many product characteristics can be customized. These choices place less emphasis on how customizing is achieved. Organizations should recognize that the point at which customization occurs determines flexibility needs. Modular design or delayed differentiation are used to make mass customization feasible. If the organization allows customization early in the process, then full customization is possible if the manufacturing system can cope with multiple product designs, process changes, and has an infrastructure that efficiently communicates these changes. If customization occurs later in the process, then products and modules are designed flexibly to allow different combinations in the final assembly of the product. Many mass customizers use make-to-order or assemble-to-order planning systems, small batch processing, and CAD to facilitate customization. CAD in particular enhances product design flexibility and has an even greater influence on performance if integrated with CAM or CAE. (Duray et al. 2000).

Historical Flexibility Characteristics

For specialty manufacturers in the U.S. during the late 1800s and early 1900s, flexibility was achieved using general-purpose equipment easily adaptable to new products (Scranton, 1997). The ability to be flexible required recruiting and retaining multi-skilled workers. These workers were not only skilled in their craft, but also engaged in problem-solving to insure smooth product changeovers. Many were trained within the organization starting as apprentices, while some were specifically trained in vocational programs supported by an industry. Rather than finding “one best way” to perform each task, specialty producers created systems (e.g. route sheets, bills of material, inventory records, time cards) to better track costs, outputs, and productivity, rather than averaging costs across many products and orders. “Cooperative unionism” emerged with separate unions collaborating to stabilize an industry by promoting wage schemes emphasizing competition based on performance, rather than wage reductions to improve the bottom line. Higher wages acknowledged worker skills and indicated the organization’s strength in the market helping maintain harmony between workers and management while allowing an acceptable level of profit. Thus, specialty manufacturers typically had equipment flexibility, worker flexibility, process/mix flexibility, and overall manufacturing flexibility through the use of flexible systems rather than a single standardized process for every activity.

Other relevant research lends support to the previously proposed manufacturing flexibility components. Although not labeled using manufacturing flexibility terminology, support is found for new product, modified product, routing, process/mix, volume, labor infrastructure, and supplier/supply management flexibility.

Summary

Table 3 summarizes whether components have a consensus agreement and are considered for this study. Components are drawn from the previous three sections. In the first two columns, an “S” designates supported components, a “P” designates partially supported components, and a “W” designates components with weak or no support from Table 1 or Table 2. Other relevant research is summarized in a single column with the same designations. To have consensus agreement (final column), components had to have at least one S and one P in the other three columns. The majority of components with consensus have two or three "S" designations. An * indicates those components measured in this study.

Those components having consensus agreement are new product, modified product, machine/equipment, material handling, routing, process/mix, volume, labor, infrastructure, and supplier/supply management. Those components lacking agreement are operation/process plan, delivery, expansion, production/manufacturing, program, market, and technology/automation.

Table 3 – Summary of Component Development Studies

Components Defined or Measured	Component Development Literature			
	Summary of Descriptive and Field Research (Table 1)	Summary of Survey Research (Table 2)	Summary of Other Relevant Research	Summary
New Product	S	S	S	C
Modified Product	S	P	S	C
Operation/Process Plan	S	W	W	L
Machine/Equipment	S	P	W	C*
Material Handling	S	S	W	C
Routing	S	P	S	C*
Process/Mix	S	S	S	C*
Delivery	P	W	W	L
Volume	S	S	S	C*
Expansion	P	W	W	L
Production/Manufacturing	P	W	W	L
Program	W	W	W	L
Market	W	W	W	L
Labor	S	P	S	C*
Infrastructure	S	W	S	C
Technology/Automation	P	W	W	L
Supplier/Supply Management	P	P	S	C*

S = Supported
P = Partial Support
W = Weak/No Support

C = Consensus agreement
M = Minimal agreement
L = Lacks agreement
* = Construct in this study

Some explanation is warranted for components that are not included in this study. Operation/process plan, delivery, expansion, production/manufacturing, program, market and technology/automation flexibility lack support as components of manufacturing flexibility. The definitions for operation/process plan flexibility overlap with those of routing and process/mix flexibility, making this component redundant. Delivery flexibility relates to whether the schedule can be changed to allow expediting or de-expediting orders. This is a performance outcome related to the ability to adjust the product mix, re-route parts, use flexible equipment to process multiple products, increase output volume, and/or the ability of labor to cope with these changes. Thus, characteristics of delivery flexibility are measured in performance.

Expansion flexibility is defined throughout the literature as a mid-range or long-range increase in capacity. Capacity is only expanded if the organization needs to increase overall output volume, thus expansion flexibility is simply long-term volume flexibility.

Production/manufacturing flexibility generally is defined as an aggregate flexibility and is used interchangeably with manufacturing flexibility as a functional level concept encompassing all of the other components. Measuring overall manufacturing flexibility requires developing an aggregate measure. Thus, it is measured when all of the validated components are analyzed simultaneously relative to organizational performance.

Program flexibility is defined only in the context of an automated FMS, thus implying limited application for other process types. An FMS that runs untended does not guarantee higher flexibility. In many cases, these highly flexible systems are used as automated lines producing a narrow range of products (Jaikumar, 1986).

Market flexibility is also defined as an overall or functional flexibility that encompasses lower level components. Market flexibility is defined as a tactical or strategic component, implying it is an outcome of implementing other components. This component may appear related to the marketing function and beyond the scope of operations management; however, it is interpreted as a performance measure because several studies describe it as the ability to accommodate changes in customer demand or to adjust to environmental uncertainty. It also may be interpreted to overlap production/manufacturing flexibility as their definitions are similar.

The definitions for technology/automation flexibility overlap with those for machine flexibility; thus, this component is also redundant within the scope of this study.

The next section contains detailed theoretical definitions for the proposed components of manufacturing flexibility for this study.

Manufacturing Flexibility Component Definitions

The manufacturing flexibility components and the definitions for this study are derived from a review of the manufacturing flexibility literature as well as other relevant literature. Through a synthesis across the various studies, a consensus is found for new product, modified product, machine/equipment, material handling, routing, process/mix, volume, labor, infrastructure, and supplier/supply management. Due to overlapping definitions and interrelationships among components, product-mix includes characteristics of new product and modified product as well as process/mix, while material handling includes characteristics of routing flexibility. Machine/equipment flexibility is labeled as equipment flexibility in this study and supplier/supply management is labeled as supply management. Although infrastructure is supported within the flexibility literature, it is not a component of manufacturing flexibility. Rather, it is a mechanism either enabling or impeding an organization’s attempts to increase flexibility, which is discussed later in the manuscript. The remaining components lacked consensus agreement for inclusion. Thus, the manufacturing flexibility components for this study are product-mix, routing, machine/equipment, volume, labor, and supplier/supply management. The theoretical definition for each manufacturing flexibility component follows. A table of the operational definitions for each component is in Appendix D.

Product-Mix Flexibility

For clarity, the term product-mix flexibility is used in this study to refer to the process/mix and product components defined in other studies. This component relates not only to changing the mix of parts in the manufacturing process but also designing products.

Product-mix flexibility is the ability to offer a broad product line by adjusting the product mix within an existing set of products, introducing modified products, adding new products, or adding new product families to the product mix (Adler, 1988; D'Souza & Williams, 2000; Gerwin, 1993; Koste & Malhotra, 1999; Sethi & Sethi, 1990; Slack, 1987; Swamidass, 1988; Zhang et al., 2003). This component allows an organization to enter niche markets through the ability to respond to specific customer requests (Sethi & Sethi, 1990; Watts et al., 1993), thus increasing performance by pursuing underserved customers that competitors consider unprofitable.

In the short-term, product-mix flexibility is the ability to change the mix of products within existing product families (Adler, 1988; Browne et al., 1984; Buzacott, 1982; Dixon, 1992; Gupta & Somers, 1992; Koste et al., 2004; Narasimhan & Das, 1999a; Slack, 1983; Vokurka & O'Leary-Kelly, 2000). This type of mix change does not require new tooling, equipment, or worker training. In the mid-term, product-mix flexibility is the ability to change the mix of products with modified products (Narasimhan & Das, 1999a; Slack, 1983, 1987), which are incremental improvements similar in function or design to existing product families (Adler, 1988; Browne et al., 1984; Cox, 1989; Dixon, 1992; Gerwin, 1993; Koste et al., 2004; Watts et al., 1993). This type of mix change is generally achieved through modular design (Swamidass, 1988) or delayed differentiation (Sethi & Sethi, 1990). Thus, a modification may be as simple as substituting one module for another with the same function, or it may entail some reconfiguration of components. This mix change does not require new tooling or equipment and only minimal worker training (Gerwin, 1993; Jaikumar, 1986). In the long-term, product-mix flexibility is the ability to change the product mix by adding new products or new product families that may or may not be related to existing product families (Adler, 1988; Browne et al., 1984; Cox, 1989; Dixon, 1992; Gerwin, 1993; Jaikumar, 1986; Narasimhan & Das, 1999a, 1999b; Sethi & Sethi, 1990; Slack 1983, 1987; Suarez et al., 1996; Swamidass & Newell, 1987; Watts et al., 1993). A new product is one that has not been made previously by the organization and may require extensive retooling, new equipment, and/or worker training (Koste et al., 2004; Slack, 1987).

Higher product-mix flexibility should reduce the time to introduce modified or new products (Gupta & Somers, 1992) or to incorporate technology innovations into existing products (Gerwin, 1993; Koste et al., 2004; Swamidass, 1988). Product-mix flexibility should reduce throughput time (Browne et al., 1984), inventory levels (Upton, 1994), and backorders (Gupta & Somers, 1992). It should increase on-time delivery and equipment utilization.

Routing Flexibility

Routing flexibility is the ability to move parts between machines as well as along multiple routes between workstations or manufacturing cells (D'Souza & Williams, 2000; Koste

& Malhotra, 1999; Narasimhan & Das, 1999a; Sethi & Sethi, 1990; Zhang et al., 2003). This includes both loading and unloading parts and storing parts throughout the facility (Gupta & Somers, 1992). Routing flexibility allows production of parts to continue on schedule by rerouting parts onto different routes when there is a system disturbance (e.g. machine breakdown or bottleneck) (Browne et al., 1984; Buzacott, 1982; Watts et al., 1993; Zhang et al., 2003), or by using alternate process plans to balance the shop load (Gerwin, 1993; Koste & Malhotra, 1999; Sethi & Sethi, 1990).

Short-term routing flexibility is the ability to route products on the production floor using multiple routes (Adler, 1988; Gerwin, 1993; Koste et al., 2004; Slack, 1983; Swamidass, 1988). This may entail routing to an identically equipped machine, workstation, or cell (Koste & Malhotra, 1999; Sethi & Sethi, 1990), but also includes changing the processing sequence using an alternate process plan (Browne et al., 1984; Gupta & Somers, 1992; Sethi & Sethi, 1990; Zhang et al., 2003). In the mid-term, routing flexibility is the ability to modify the available routes parts can follow (Koste & Malhotra, 1999). This creates a more balanced system load and accommodates introduction of modified products to the product mix (Gupta & Somers, 1992; Sethi & Sethi, 1990). Long-term routing flexibility allows the addition of new routes to link new equipment or cells, as well as accommodating routes for new products (Koste et al., 2004).

Routing flexibility should improve throughput, scrap/rework cost, inventory levels, backorders, on-time delivery, and equipment utilization (Browne et al., 1984; Buzacott, 1982; Gupta & Somers, 1992; Sethi & Sethi, 1990). This requires a flexible material handling system that moves products along multiple routes (Koste & Malhotra, 1999; Swamidass, 1988), which may require new routes or a new production floor layout (Koste et al., 2004).

Equipment Flexibility

For clarity, the term equipment flexibility is used in this study, rather than machine flexibility. This more general term allows for a definition that includes hand tools, computers, machines, or any other tools that are flexible or can be used in a flexible manner.

Equipment flexibility is the ability of equipment to perform multiple operations and is achieved by using either general-purpose or special-purpose machines, tools, or other equipment (Adler, 1988; D'Souza & Williams, 2000; Koste & Malhotra, 1999; Koste et al., 2004; Narasimhan & Das, 1999a; Sethi & Sethi, 1990; Slack, 1983; Upton, 1994; Vokurka & O'Leary-Kelly, 2000; Zhang et al., 2003). This flexibility enhances the organization's ability to offer a broad product line that can be delivered on-time, as well as enhancing the system's ability to respond to customer requests (Olhager, 1993; Slack, 1987; Watts et al., 1993). Equipment includes individual tools and machines, cells with multiple machines, or the entire manufacturing system (Adler, 1988; Browne et al., 1984). Equipment flexibility is usually achieved by adjusting the equipment settings, changing tooling/fixtures, or adding new tooling/fixtures (Sethi & Sethi, 1990) to increase the number and the variety of operations equipment performs (Koste & Malhotra, 1999; Koste et al., 2004), which increases the possible output variety (Browne et al., 1984). Equipment may be arranged according to function, as in a job shop, or in mixed machine groups that operate as miniature assembly lines (e.g. cellular layouts), or in a traditional assembly line (Olhager, 1993; Sethi & Sethi, 1990; Swamidass, 1988). Machines within cells may run independently of each other or be fully automated with an automated material handling system (e.g. FMS) (Sethi & Sethi, 1990; Swamidass, 1988).

Short-term equipment flexibility is the ability to process existing parts and part families using existing tooling and other resources to perform different operations (Koste & Malhotra, 1999; Koste et al., 2004). In the mid-term, equipment flexibility is the ability to process existing or modified products, using existing tooling and resources to perform different operations (Koste et al., 2004; Slack, 1987). Within this timeframe, it is possible to adjust equipment parameters such as changing a fixture or modifying a software program (Sethi & Sethi, 1990). Long-term, equipment flexibility is the ability to add new equipment or shift existing equipment to the production of a new product family or multiple product families (Koste et al., 2004; Sethi & Sethi, 1990; Slack, 1987). This requires process layout changes which, at a minimum, require modifying routes to link new machines or workstations via the material handling system (Sethi & Sethi, 1990). Worker training is probably necessary since the equipment, process, and products all may be new (Sethi & Sethi, 1990).

Equipment flexibility should reduce setup times, throughput time, worker productivity, inventory levels, backorders, and manufacturing costs, while increasing utilization and on-time delivery (Koste & Malhotra, 1999; Koste et al., 2004; Sethi & Sethi, 1990). Increased technological sophistication is expected to increase equipment flexibility (Sethi & Sethi, 1990); however, higher complexity does not guarantee higher flexibility, as complex systems can be less flexible than simpler technology (Jaikumar, 1986). For example, job shops are highly flexible and produce parts with less automation and equipment complexity than a continuous flow process, which is more complex but highly inflexible.

Volume Flexibility

Volume flexibility is the ability to operate profitably at different output rates (Adler, 1988; Browne et al., 1984; D'Souza & Williams, 2000; Koste & Malhotra, 1999; Narasimhan & Das, 1999a, 1999b; Sethi & Sethi, 1990; Slack, 1983, 1987; Zhang et al., 2003). Volume flexibility increases an organization’s ability to respond quickly, efficiently, and profitably to changes in market demand (Cox, 1989; Gerwin, 1993; Vokurka & O’Leary-Kelly, 2000; Watts et al., 1993). The output rate itself can only be adjusted within a specific range but may not be adjustable for all products, as it is limited by system resources (Koste & Malhotra, 1999; Sethi & Sethi, 1990; Zhang et al., 2003). Capacity expansion, however, can increase the possible output range and increase the system capability through the addition of new resources (e.g. machines, employees, new technology) (Adler, 1988; Gupta & Somers, 1992; Sethi & Sethi, 1990; Vokurka & O’Leary-Kelly, 2000; Watts et al., 1993).

In the short-term, volume flexibility is the ability to adjust the rate of output within a specific range using current system resources (Slack, 1987). Volume flexibility can be increased in the short-term by using worker overtime or faster machines for higher volume products. These faster machines usually may be reserved for certain products or customers but can be temporarily reassigned, when necessary. Backup machines, such as those that are older or idle, can also be used to increase short-term output volume. In the mid-term, volume flexibility is the ability to adjust the output rate across a wider range (Slack, 1987). The primary means to increase volume flexibility is using non-fixed system resources, such as adding temporary workers, adjusting system parameters (i.e. inventory levels), or using short-term outsourcing. In the long-term, volume flexibility is the ability to expand overall capacity of the system by adding new resources either internally (i.e. new employees, overtime, etc) or externally (i.e. long-term outsourcing) (Browne et al., 1984; Gupta & Somers, 1992; Koste & Malhotra, 1999; Narasimhan & Das, 1999a; Sethi & Sethi, 1990). Internal capacity expansion requires expanding the material handling system and adding routes to new manufacturing resources. This requires cross-functional facilities planning and training for employees on new equipment or processes (Sethi & Sethi, 1990).

Volume flexibility should improve throughput time, scrap/rework cost, backorders, on-time delivery, and equipment utilization.

Labor Flexibility

Labor flexibility is the ability of workers to perform more than one task or job (Cox, 1989; Koste & Malhotra, 1999; Koste et al., 2004; Slack, 1987; Vokurka & O'Leary-Kelly, 2000; Zhang et al., 2003). In addition to making products, workers may be trained to complete routine equipment maintenance freeing full-time repair personnel for non-routine problems. They also may test, inspect, and repair defective products.

Labor flexibility includes both the number of different tasks and the variety of tasks workers perform (Koste & Malhotra, 1999; Swamidass, 1988). The goal is to have workers who are proficient at multiple tasks, so they can substitute for another worker when necessary, while maintaining product quality and output rates (Koste & Malhotra, 1999; Koste et al., 2004; Slack, 1987; Sethi & Sethi, 1990; Zhang et al., 2003). Cross-training increases labor flexibility by, not only increasing workers' technical skills, but also teaching workers to perform tasks that were previously the responsibility of managers (Adler, 1988; Sethi & Sethi, 1990; Watts et al., 1993). New responsibilities include maintaining process integrity, controlling quality, scheduling work within teams, and problem-solving (Sethi & Sethi, 1990).

In the short-term, labor flexibility is the ability of workers to perform more than one task with no additional training (Upton, 1994). This may include moving workers to different workstations or to different tasks within the same workstation (Koste & Malhotra, 1999; Koste et al., 2004). The larger the pool of cross-trained workers who are proficient at multiple tasks, the higher the labor flexibility (Cox, 1989; Slack, 1983). In the mid-term, workers are trained to complete additional tasks as the scope of a job expands to include new responsibilities (Olhager, 1993). In the long-term, labor flexibility is the worker's ability to add new skills and/or higher-level responsibilities, such as tasks previously performed by managers (Olhager, 1993; Slack, 1987).

Higher labor flexibility should reduce setup times, throughput time, scrap/rework cost, inventory levels, backorders, manufacturing costs, and material costs. Labor flexibility should increase worker productivity, effective capacity, and organizational problem-solving capability. Cross-training increases the options for transferring workers between tasks, which allows an organization to increase output of higher demand products because multi-skilled workers adapt faster to product modifications and new products (Olhager, 1993). Process and product improvements are part of the continuous improvement process necessary in flexible organizations and workers on the production floor are positioned to develop such knowledge. A managerial emphasis on innovation and improvement affect labor flexibility by encouraging curiosity and experimentation (Upton, 1995, 1997).

Supply Management Flexibility

This study uses the term supply management flexibility, rather than supplier flexibility, to reflect the reciprocal nature of the relationship between buyers and suppliers within this component.

Supply management flexibility is the ability of the supplier to respond to change requests from the buyer (Cox, 1989; Narasimhan & Das, 1999a; Olhager, 1993). This includes, not only whether suppliers have manufacturing flexibility, but also how a buying organization relates to suppliers (Flynn et al., 1994; 1995a, 1995b, 1999; Sakakibara et al., 1993; Uzzi, 1997). Supply management flexibility helps reduce the time to introduce new products, overcome system disturbances, and reduce environmental uncertainty (Slack, 1987). When a supplier is able to ship orders on-time, make frequent deliveries, increase order quantities without increasing lead time, expedite orders without increasing cost per part, make rapid volume changes, and insure product quality, the buying organization's flexibility also increases (Narasimhan & Das, 1999a, Olhager, 1993). Supply management flexibility is also measured indirectly within other flexibility components because the supply chain affects the buying organization's ability to produce a product (Cox, 1989). A supplier who has manufacturing flexibility is more likely to be more flexible in the buyer-seller relationship (Uzzi, 1997). This component also allows the buying organization to reduce its supplier base (Swamidass, 1988).

In the short-term, supply management flexibility is the supplier's ability to expedite an order or to adjust order volumes within a specific range without significantly increasing delivery time or costs (Cox, 1989; Narasimhan & Das, 1999a, 1999b; Olhager, 1993; Slack, 1987). This may include the supplier making some partial deliveries to bridge a gap between orders (Narasimhan & Das, 1999a, 1999b). In the mid-term, supply management flexibility is the supplier's ability to expedite multiple orders or to adjust order volumes across wider range without significantly increasing delivery time or costs (Cox, 1989; Narasimhan & Das, 1999a, 1999b; Olhager, 1993). Long-term supply management flexibility is the supplier's ability to be flexible across all system parameters. This includes modifying products, designing new products, changing output volume, and participating in the buyer's design process (Narasimhan & Das, 1999a, 1999b). Suppliers may play an active role by providing input on product designs such as modifying components to reduce cost or increase reliability, which reduces the time to introduce new products (Narasimhan & Das, 1999a, 1999b; Vokurka & O'Leary-Kelly, 2000).

The primary benefit of supply management flexibility is reducing product lead times. Supply management flexibility is affected by the same issues as other components, as it reflects suppliers' flexibility as well as the management of the buyer-seller relationship. Developing long-term relationships with suppliers is key to encouraging their flexibility (Adler, 1988; Flynn et al., 1994; 1995a, 1995b, 1999; Sakakibara et al., 1993; Uzzi, 1997). A supplier who is only used for occasional small purchases is unlikely to go out of their way to help a buying organization when they need a favor. The supplier with a long-term relationship is more willing to work on design modifications for the buying organization. Both parties have to feel the exchange is equitable and that the cost of flexibility is shared, or one party is likely to discontinue the relationship (Uzzi, 1997). In developing long-term relationships with suppliers, an organization can avoid suppliers who are inflexible and select suppliers who are willing to improve flexibility (Flynn et al., 1994; 1995a, 1995b, 1999; Uzzi, 1997). Supply management flexibility, as a direct influence on another organization's performance, has received minimal attention, despite the fact that it is a partially controllable environmental uncertainty (Narasimhan & Das, 1999a, 1999b). This component is overshadowed by a history of overemphasizing cost, which creates antagonism between buyers and suppliers (Flynn et al., 1994; 1995a, 1995b, 1999; Uzzi, 1997). Organizations should select suppliers based on product quality (Gerwin, 1993) and delivery reliability (Cox, 1989) rather than only focusing on cost (Flynn et al., 1994; 1995a, 1995b, 1999).

Supply management flexibility should reduce scrap/rework cost, inventory levels, manufacturing costs, and material costs. Supply management flexibility should increase worker productivity, on-time delivery, and utilization.

Summary

The manufacturing flexibility components retained for this study are product-mix, routing, equipment, volume, labor, and supply management. The components are independent variables and are measured using a survey instrument developed based on the components' operational definitions (Appendix D). Whenever possible, previously validated items are used to measure these manufacturing flexibility components. The instrument development process is discussed further in chapter 3. The following section contains information related to studies that investigate and test the relationship between manufacturing flexibility and organizational performance.

Manufacturing Flexibility – Organizational Performance Research

Once manufacturing flexibility was better understood and initial system components defined, researchers began investigating relationships between manufacturing flexibility and performance. In the next group of studies, flexibility is shown to produce many performance benefits for organizations, including improvements in financial performance, flow time, throughput, on-time delivery, makespan, efficiency, utilization, idle time, and productivity. These are discussed below with regard to which performance indicators are measured and the type of methodology used. The first group of studies includes analytical models and simulations that confirm relationships between manufacturing flexibility components and organizational performance under specific model parameters. The second group includes surveys that confirm relationships between components and performance in actual organizations. The last section contains other relevant research that measure performance improvements related to implementation of various manufacturing practices.

Analytical Models and Simulation Research

Analytical models are used to determine the relationship between manufacturing flexibility components and various performance measures. Much of the early research using analytical models focuses on issues related to designing an FMS, maximizing FMS utilization, minimizing tool duplication (Atan & Pandit, 1996), optimizing machine loading (De Groote, 1994), optimizing tool investment (Barad & Hoang, 1995), and efficiently grouping parts (Ben-Arieh & Sreenivasan, 1999). These FMS issues continued to be studied into the 1990s. Beginning in the mid-1990s, however, some researchers broadened the scope of analysis to look at other process types in which manufacturing flexibility is also advantageous, such as job shops or non-FMS cellular manufacturing.

Analytical models and simulations are useful when actual system parameters can not be manipulated and analyzed due to disruption, cost, or infeasibility. For simple systems, analytical models are preferred where an exact solution can be calculated. Analytical models of manufacturing flexibility generally investigate the relationships of scheduling, worker, routing, machine, operation, and material handling flexibility to performance in manufacturing systems. Most manufacturing systems, however, are too complex to be solved with analytical models due to complicated interactions and interrelationships, (Buzacott & Yao, 1986; Law, 1986; Nagarur & Azeem, 1999). Although simulations have the ability to test more interactions than an analytical model, most tend to focus on only one or two flexibility components, typically routing, machine, or operation.

The analytical models and simulations discussed below confirm relationships among various manufacturing flexibility components with performance measures, such as financial performance, costs, traditional production measures, and throughput time. Ramasesh and Jayakumar (1991) provide a good analysis of the individual and synergistic effects of multiple flexibility components in a system, as well as their effects on performance.

Financial

Ramasesh and Jayakumar (1991) develop an analytical model to assess aggregate flexibility and its effect on net revenue. Four tactical flexibility components are tested individually against a base case to compare changes in an aggregate flexibility measure. In all cases, the net revenue increases as aggregate flexibility increases. Machine flexibility has the largest individual impact on performance and increases aggregate flexibility by 6.42%. The results indicate that different flexibility components impact the system to differing degrees, which could help organizations determine the most beneficial components to implement. When all four flexibility components are tested simultaneously, the aggregate flexibility measure increases by 15.59 %. Thus, combining components creates a synergy. Although they did not use industry data in their example, this model could be used to measure the flexibility to performance relationship with actual organizations.

Jack and Raturi (2003) use return on assets (ROA) and return on sales (ROS) to analyze the impact of volume flexibility on performance. They use archival industry data about inventory and cost of goods sold as proxies to measure volume flexibility. This study uses industry data to build model parameters and to test the model relationships.

Costs

Various types of cost are used in manufacturing flexibility research as measures of performance. Stewart et al. (1994) create their model to minimize both training cost and training time. Egbelu (1996) and Brandimarte (1999) test minimizing total manufacturing cost. Boyer and Leong (1996) use changeover cost and expected output volume as performance measures.

Traditional Production Measures

Traditional production measures used in analytical models and simulations to measure performance include: efficiency (Buzacott, 1982; Kher et al., 1999), utilization (Byrne & Chutima, 1997; Chen & Chung, 1996; Jordan & Graves, 1995; Nagarur & Azeem, 1999), idle time (Dobson & Khosla, 1995; Gupta & Goyal, 1992), and productivity (Buzacott, 1982; Nagarur & Azeem, 1999).

Throughput Time

Throughput time and other time-related measures, such as makespan and flow time, are the most commonly used performance measures in analytical models and simulations. Wacker (1987) uses a simulation to test the relationship between JIT manufacturing goals and throughput time. Throughput time is negatively related to responsiveness (i.e. flexibility) and productivity, and positively related to product cost. This means that, as responsiveness (i.e. flexibility) increases, productivity increases and throughput time decreases. When throughput time increases, product cost also increases. Thus, increasing flexibility improves system performance by decreasing throughput.

Average job flow time is a common performance measure in analytical models and simulations (Benjaafar, 1996; Byrne & Chutima, 1997; Das & Nagendra, 1993; Dobson & Khosla, 1995; Hutchinson & Pflughoeft, 1994; Jensen et al., 1996; Kher et al., 1999; Mahmoodi et al., 1999; Tsubone & Horikawa, 1999) as is the percentage change in average flow time used by Pflughoeft & Hutchinson (1999).

Makespan (Chen & Chung, 1996; Daniels et al., 2004; Hutchinson & Pflughoeft, 1994; Mohamed et al., 1999; Nagarur & Azeem, 1999), WIP inventory (Benjaafar, 1996; Das & Nagendra, 1993), and the percentage change in makespan, which is a surrogate for decreasing WIP (Pflughoeft & Hutchinson, 1999), are performance measures used in analytical models and simulations to assess the relationships with the manufacturing flexibility components.

Order lateness and related measures are also used as performance measures. Average tardiness is used by Byrne & Chutima (1997), Jensen et al. (1996), and Mahmoodi et al. (1999). The average percentage of late orders is measured by Jensen et al. (1996) and Mahmoodi et al. (1999). Byrne & Chutima (1997) also measure the number of orders completed and the ratio of late orders to completed orders.

Summary

Analytical models and simulations are often limited either through the constraints used to make the models tractable or by the development of model parameters. Few mention exactly how model parameters are derived, so it appears that parameters are not based on industry data, but may be chosen to show a particular relationship. Another drawback to these studies is that many only investigate one component in isolation from the rest of the system. These studies expand the knowledge related to manufacturing flexibility and its impact on performance; however, the generalizability of the results is limited.

Survey Research

Surveys go beyond analytical models and simulations by testing analytically confirmed relationships in actual organizations. Several survey studies measure the relationship between manufacturing and performance which are described below in chronological order (Chang, Lin, & Sheu, 2002; Chang, Yang, Cheng, & Sheu, 2003; Gupta & Somers, 1996; Swamidass & Newell, 1987).

Swamidass and Newell, 1987

Swamidass and Newell (1987) present results from a survey with 35 manufacturers investigating relationships between uncertainty, strategy formulation, manufacturing flexibility, and performance. Although the sample is small, the results are interesting.

Two questionnaires are administered in each organization: one to the chief executive and one to the manufacturing manager. The chief executive answers questions about all four variables, while manufacturing managers answer 11 items related to flexibility. Path analysis is used to analyze the relationships between the constructs. Growth indicators for the past five years are objective performance measures, while the other measures are perceptual.

Swamidass and Newell (1987) find a significant positive relationship between manufacturing flexibility and performance, as well as between the manufacturing manager's involvement in strategic planning and performance. No significant relationships are found between uncertainty and flexibility or uncertainty and the manufacturing manager's involvement in strategic planning. Additionally, the indirect effect of uncertainty on performance is insignificant in the regression, while the correlation coefficient is statistically significant, implying that this construct needs further refinement and study. Swamidass and Newell use average annual growth indicators related to ROA, ROS, and sales growth over five years to measure performance.

The indirect effects are only mentioned briefly in the study but are early indicators of the validity of including other relevant variables related to strategy and planning. The main limitation of the Swamidass and Newell (1987) study is the small sample drawn from one industry, all of which have similar processes. This reduces the generalizability of the results to other industries while a larger sample for statistical inference is preferable.

Gupta and Somers, 1996

Using previously collected survey data (Gupta & Somers, 1992), Gupta and Somers (1996) analyze the relationships between business strategy, manufacturing flexibility, and performance. Twenty-four items represent six strategy constructs (aggressiveness, analysis, defensiveness, futurity, proactiveness, riskiness). Manufacturing flexibility is measured with 21 items representing nine constructs (expansion, material handling, routing, machine, market, product/production, process, program, volume). Six items measure financial performance (operating profits, cash flow from operations, return on investment, and the ratio of profit to sales) and growth performance (sales growth and market share). Respondents are asked to answer relative to their competitors on each item.

A factor analysis confirms the flexibility components validated in the previous study with 72% of the variance in the data explained by nine factors. Regression is used to analyze the direct effect of strategy on flexibility component selection. Although strategy had a statistically significant effect on eight of the nine flexibility components, the highest adjusted R^2 is 17% while the lowest is 1%. Strategy explains only a small percentage of the variance across the flexibility components, implying there are unmeasured variables affecting component selection.

None of the manufacturing flexibility components have a significant direct effect on financial performance; however, four strategies (aggressiveness, analysis, proactiveness, riskiness) have a significant direct effect on financial performance. Four components (expansion, routing, volume, product/production) and one strategy (proactiveness) have significant direct effects on growth performance. Approximately 19% of the variance in growth performance is explained by the proposed model; however, none of the strategies have a significant indirect effect on financial or growth performance when mediated by manufacturing flexibility. Thus, this indicates that strategy more likely strengthens the relationship between the components and performance, rather than preceding implementation of manufacturing flexibility.

Although none of the hypotheses are fully supported, there are a few significant relationships between variables, implying that some of the strategies are linked to flexibility and that there may be direct and indirect effects on performance. This study is limited by the lack of items measuring several flexibility components (see Gupta & Somers, 1992). In addition, using performance measures related to financial and growth performance, which tend to be considered long-range performance measures, is problematic as several of the flexibility components are frequently described as short-range capabilities (e.g. routing, machine, material handling). As a result, it may be that some of the components and their influence on performance are not well established.

Narasimhan and Das, 1999a

Narasimhan and Das (1999a) use a survey to investigate the effect of strategic sourcing on manufacturing flexibility and performance. A hierarchical structure of the flexibility components is proposed. Operational components are equipment, material, routing material handling, and program. Tactical components are mix, volume, expansion, and modification. Strategic components are new product and market. Seven hypotheses related to strategic sourcing, advanced manufacturing technology, manufacturing flexibility, and performance (measured via cost reductions) are tested. The survey has 16 items measuring three flexibility components, strategic sourcing, and advanced manufacturing technology usage.

Sixty-eight usable surveys are returned by senior level purchasing managers who are members of the National Association of Purchasing Managers. Confirmatory factor analysis is used to validate the flexibility components. The alpha coefficients range from 0.60 for modification flexibility to 0.92 for supplier involvement. These factors are used to evaluate the proposed model.

Narasimhan and Das (1999a) use structural equation modeling to test the proposed relationships. Strategic sourcing has a positive relationship to modification flexibility. A positive relationship is found between advanced manufacturing technology usage and volume flexibility. There is a positive relationship between volume and new product flexibility, as well as between modification and new product flexibility. The authors suggest that organizational learning should be investigated with regard to the relationship between modification, volume, and new product flexibility. Narasimhan and Das also suggest that new product flexibility and performance may be more relevant in certain industries, but a different performance measure such as customer satisfaction or the ability to customize, is more relevant for other industries. Lastly, there is a positive relationship between modification flexibility and manufacturing cost reduction.

Narasimhan and Das (1999a) posit that the positive relationship between modification flexibility and cost reductions may be an artifact of the overrepresentation of respondents from more mature product groups (e.g. mechanical subassembly, automotive, chemicals, earthmoving machinery, etc.). In these industries, cost reductions frequently are pursued as part of the organizational strategy. They have fewer respondents in industries where cost reduction may be less important (telecommunications, electronics, nuclear subs, etc.). Narasimhan and Das propose the potential for strategic sourcing and advanced manufacturing technology usage to have indirect effects on new product flexibility through modification and volume flexibility; however, they do not test this proposition.

This study confirms several relationships between variables using organizational data. The development of validated survey items related to suppliers' influence on flexibility is relevant to the current study, and supports supply management's inclusion as a flexibility component. The limitations of the study relate to the small sample size. It is not completely clear whether confirmatory factor analysis is appropriate because the authors stated that an alpha of 0.50 was acceptable in exploratory studies. With only 68 responses, minimum requirements for exploratory or confirmatory factor analysis are barely met (Hair, Anderson, Tatham, & Black, 1998). In addition, a general rule of thumb for confirmatory factor analysis is to have at least 100 responses for valid confirmatory factor analysis results. A full explanation of why confirmatory factor analysis is chosen for the study is not included, other than citing an article describing exploratory factor analysis limitations.

Chang, Lin, and Sheu, 2002

Chang, Lin, and Sheu (2002) develop a survey instrument to investigate the relationship between environmental uncertainty, manufacturing flexibility, and performance. The model includes four environmental uncertainties whose effect on business performance is mediated by manufacturing flexibility components (product-mix, new product, volume). Surveys are mailed to top executives in high-tech manufacturing.

Four dimensions of environmental uncertainty are assessed. New product flexibility is the total number of new models introduced in two years. Product-mix flexibility is the total number of distinct part/product families produced during the last two years. Volume flexibility is a ratio of the variance of monthly production and the unit cost. Performance is measured using the sales growth rate and net profit. Fifteen hypotheses are tested.

Eighty-seven surveys are analyzed (Chang et al., 2002). The environmental uncertainty items are analyzed with factor analysis. Cronbach's alpha ranged from 0.60 to 0.71, which are considered acceptable for this exploratory study. The entire data set is analyzed with path analysis to determine the direction and strength of proposed relationships. The results indicate that demand uncertainty has a positive relationship with volume and product-mix flexibility. Supply uncertainty does not have a significant relationship with volume or product-mix flexibility. Competition uncertainty has a positive relationship with new product and product-mix flexibility. Product technology uncertainty has a positive relationship with product-mix flexibility. New product and product-mix flexibility have a positive relationship to sales growth. Volume flexibility has a negative relationship to net profit while product-mix flexibility has a positive relationship to net profit.

Chang et al. (2002) make several contributions by developing and validating a survey to measure uncertainty, flexibility, and performance in dynamic industries. The industries cope with similar challenges using similar production processes, thus the sample is very homogeneous. The results support previous proposals that flexibility components should be compatible with organizational goals, thus, implying that strategies need to be integrated.

Limitations of Chang et al. (2002) include a lack of generalizability due to a small sample surveying four interrelated industries in Taiwan, making it unclear whether the results are generalizable to other industries with more diverse products and processes. Additionally, respondents ranked survey items according to importance and averaged them on a separate page, creating a weighted average which may have influenced their responses.

Chang, Yang, Cheng, and Sheu, 2003

Chang, Yang, Cheng, and Sheu (2003) develop a survey instrument to assess the relationship between business strategy, manufacturing flexibility, and performance. The model includes three business strategies (preemptive/first mover, differentiation/follower, low cost/follower) that moderate the relationship between six manufacturing flexibility components (product-mix, new product, volume, delivery, modification, service) and business performance. Plant managers in machine tool and machinery manufacturing responded, resulting in 83 responses. Factor analysis is used to identify characteristics of different business strategies. Cluster analysis is used to assess the organizational characteristics and business strategies implemented among firms. Four hypotheses are tested using the clusters of firms to analyze the effect of manufacturing flexibility components on firm performance within each cluster.

Chang et al. (2003) find a significant relationship between business strategy and manufacturing flexibility, as well as some significant relationships between manufacturing flexibility and performance. The results indicate that, for the preemptive/first mover firms, new product, product-mix, and volume flexibility have a positive effect on performance. For the differentiated/follower firms, modification and delivery flexibility have a positive effect on performance. For the low cost/follower firms, product-mix has a positive effect on performance, while modification flexibility has a negative effect on performance.

Limitations of Chang et al. (2003) include the small sample and possible issues associated with the clustering process; in particular, this process reduces the sample size for a comparative analysis. The researchers also state that all six flexibility components are considered at the strategic level, yet no theoretical evidence is provided supporting this. Single items are used to measure some components, limiting validity. Only small and medium-sized firms in related industries responded, limiting generalizability to larger organizations and other industries.

Summary

These survey studies (Chang et al., 2002; Chang et al., 2003; Gupta & Somers, 1996; Narasimhan & Das, 1999a) provide potential measurement items for the flexibility components and performance, as well as testing the relationship between manufacturing flexibility and performance.

Other Relevant Research

Numerous other performance measures are suggested in the manufacturing flexibility literature, yet most have not been tested. Some of these measure flexibility components rather than performance. They are listed here to show the broad differences in how performance is operationalized in the manufacturing flexibility literature. The following measures are proposed to decrease with the implementation of flexibility: setup time, setup cost, inventory cost, new product development lead time, changeover time, lost production time, scrap, material transfer times, cost to transfer material, time lost to transfer workers between tasks, time and/or cost to switch process plans, cost to changeover the product mix, ratio of switching time to total production time, ratio of switching cost to total production cost, ratio of total output to total setup cost, time to add new resources and restart processes, and lead time to change output volume. Additionally, changes in quality, cost, or profitability due to volume changes, as well as changes in quality, cost, or productivity due to expansion are also expected to decrease. The following measures are proposed to increase with the implementation of flexibility: product complexity, product quality, productivity, machine availability, number of parts moved in the system, consistent worker performance on all tasks, schedule efficiency, on-time delivery, scheduling options, equipment utilization, accurate part tracking, and balanced machine loading.

Financial or market performance measures, such as market share and sales growth, are frequently used in the operations management literature (Gupta and Lonial, 1998; Ward & Duray, 2000; Ward, Leong, & Boyer, 1994). Gupta and Lonial (1998) also measure operating profit, profit to sales, cash flow, and return on investment relative to competitors. Vickery, Droge and Markland (1993) measure returns on assets, investments, and sales, as well as growth in return on investment relative to competitors and actual values of each. Swink et al. (2005) measure total manufacturing overhead cost, profitability, market share, and sales growth rate, as well as unit cost and productivity, all measured relative to their primary competition.

White, Pearson, and Wilson (1999) measure 10 changes in performance relative to the implementation status of 10 JIT management practices. The results indicate that implementation of the JIT practices and changes in performance often varied with firm size. Throughput time is the most frequent performance improvement, followed by inventory reductions and higher internal quality. Reduced setup times and multi-function employees have similar effects on changes in throughput time and labor productivity, respectively, regardless of firm size. For small manufacturers, JIT purchasing has a significant effect on improving throughput and inventory levels, while reduced setup times have a significant effect on lower unit cost. Thus, the relevant performance measures are changes in throughput time, labor productivity, inventory levels, and unit manufacturing cost. Additionally, the significant relationships between setup time reductions and other factors support its inclusion as a performance measure, as this is also an expected outcome of manufacturing flexibility.

Shah and Ward (2003) measure performance within the context of lean manufacturing. Flexibility is an implied element within lean manufacturing, thus several of their performance measures are applicable to this study. The relevant measures are scrap and rework costs, worker productivity, unit manufacturing costs, and manufacturing cycle time (throughput). The scale for these measures is the percentage by which the performance increased or decreased over the past five years. These performance measures are shown to have relationships with the implementation of lean practices such as cross-functional workers, cellular manufacturing, continuous improvement, autonomous teams, and quick changeovers. They also found synergistic effects from implementing multiple lean practices.

Upton (1997) suggests flexibility measures need to be easy for managers to calculate with easily accessible data; otherwise, they are impractical and will not be used. For the current study, the proposed performance measures were culled to remove those that measure the flexibility components or those where data is not easily accessible to the target population. Additionally, respondents were not asked in the current study to compare their organization to competitors, as in previous studies (Gupta & Lonial, 1998; Swink et al., 2005; Vickery et al., 1993; Zhang et al., 2003), as this further increases the possibility of perceptual bias in the data. The dependent variables for this study measured performance changes in setup time, throughput time, scrap and rework cost, worker productivity, raw material inventory, work-in-process inventory, finished goods inventory, number of backorders, on-time delivery, unit manufacturing cost, cost of purchased materials, and machine utilization.

Summary

The literature provides evidence of relationships between the proposed components of manufacturing flexibility (product-mix, routing, equipment, volume, labor, supply management) and organizational performance. Each individual component is expected to contribute to performance in different ways. Thus, the first hypothesis for this study is concerned with the relationship between the individual flexibility components and organizational performance.

H1: Individual flexibility components contribute to organizational performance.

Product-mix flexibility is the ability to offer existing, modified, or new products by switching quickly and easily between products. Higher product-mix flexibility is expected to decrease all types of inventory as well as the number of backorders. It is also expected to increase on-time delivery. Thus, the following hypothesis is proposed.

H1a: Product-mix flexibility contributes to organizational performance.

Routing flexibility is the ability to move parts between machines/workstations using different paths. Higher routing flexibility is expected to decrease setup times, throughput time, scrap/rework cost, all types of inventory, unit manufacturing cost, and backorders. Additionally, higher routing flexibility is expected to increase worker productivity and machine utilization. Thus, the following hypothesis is proposed.

H1b: Routing flexibility contributes to organizational performance.

Equipment flexibility is the ability to use machinery, tools, or other equipment for performing multiple operations to produce different products. Higher equipment flexibility is expected to reduce setup times, throughput time, backorders, and unit manufacturing cost. It is also expected to increase on-time delivery and machine utilization. Thus, the following hypothesis is proposed.

H1c: Equipment flexibility contributes to organizational performance.

Volume flexibility is the ability of the system to operate profitably at different output volumes. Higher volume flexibility is expected to decrease setup times, throughput time, scrap/rework cost, all types of inventory, backorders, and unit manufacturing cost. It is also expected to increase on-time delivery and machine utilization. Thus, the following hypothesis is proposed.

H1d: Volume flexibility contributes to organizational performance.

Labor flexibility is the ability of workers to perform multiple tasks efficiently. Higher labor flexibility is expected to decrease setup times, throughput time, scrap/rework cost, all types of inventory, backorders, unit manufacturing cost, and material cost. It is expected to increase worker productivity, on-time delivery, and machine utilization. Thus, the following hypothesis is proposed.

H1e: Labor flexibility contributes to organizational performance.

Supply management flexibility is the ability of suppliers to respond to the changing needs of buyers without significantly increasing delivery lead time or cost. Higher supply management flexibility is expected to reduce throughput, scrap/rework cost, raw material inventory, backorders, unit manufacturing cost, and material cost. It is also expected to increase worker productivity and on-time delivery. Thus, the following hypothesis is proposed.

H1f: Supply Management flexibility contributes to organizational performance.

Manufacturing requires multiple systems with interacting elements. The manufacturing flexibility components when considered simultaneously comprise a system. It is expected that when manufacturing flexibility is comprised of two or more components, a synergistic effect is created. Therefore, with aggregated manufacturing flexibility, it is expected that setup times, throughput time, scrap/rework cost, all types of inventory, backorders, unit manufacturing cost, and material cost will decrease more than if only one manufacturing flexibility component is implemented. It is also expected that aggregated manufacturing flexibility will increase worker productivity, on-time delivery, and machine utilization more than if only one manufacturing flexibility component is implemented. Therefore, the following hypothesis is also proposed.

H2: Manufacturing flexibility contributes to organizational performance.

These proposed relationships provide a basic picture of the way in which manufacturing flexibility and performance are related. They do not, however, provide a complete picture. As previously discussed, some research suggests that this relationship is influenced by other factors. Vokurka and O'Leary-Kelly (2000) found four factors that change or moderate the relationship – technology, environmental attributes, strategy, and organizational characteristics. The first two are beyond the scope of this study, but the other two are discussed further in the next section.

Influence of Strategic Integration and Organizational Infrastructure

Strategic Integration Research

Research in the 1980s indicates minimal emphasis on manufacturing flexibility in U.S. organizations (De Meyer, Nakane, Miller, & Ferdows, 1989; Hall & Nakane, 1990). When flexibility is considered, organizations and managers tend to focus on operational and short-term flexibility, often failing to consider mid-term and long-term issues (Slack, 1987). Firms tend to use two dimensions to determine whether they are flexible: cost to change and time to change. Even when firms emphasize flexibility as a long-term goal, few prioritize it high enough to receive organizational resources. Much of this is attributed to a lack of understanding regarding the definition of manufacturing flexibility, as well as a lack of generalizable measurement instruments.

Several authors suggest that it is infeasible for an organization to develop every flexibility component (Boyer & Leong, 1996; Browne et al., 1984; Jordan & Graves, 1995). Slack (1987) suggests that different process types require different types of flexibility and Cox (1989) suggests that strategy should be considered when selecting manufacturing flexibility as a competitive capability. This implies that planning is helpful in selecting the appropriate flexibility components to implement. Upton (1995, 1997) does find support for this concept. He finds that different system features influence the need for different types of flexibility, thus the organization must understand what type of flexibility is needed to enhance organizational competency and performance.

Early Strategic Integration Research

Skinner's (1969) seminal article emphasizes the importance of developing a manufacturing strategy integrated with overall organizational strategy to exploit manufacturing capabilities. As a result, flexibility as a strategic objective is a common theme in the manufacturing flexibility literature (Ferdows & De Meyer, 1990; Gerwin, 1993; Hall & Nakane, 1990; Slack, 1983; Swamidass & Newell, 1987). The issue relevant to this study relates to the selection of the appropriate flexibility for an organization's particular situation. Hayes and Wheelwright (1984) propose that management's task is to select a process and size "that makes it possible to manufacture its products at a low total delivered cost, or the one that promises the highest total profits (which sometimes leads to a different answer), and at the same time is compatible with the company's values and attitudes regarding competitive priorities, desirable working environments, and risks of various types" (p. 64-65).

Wheelwright and Hayes (1985) suggest that continuous improvement in the manufacturing process must be strategically planned in all functions and is the foundation for improving organizational performance. Strategic planning can not be isolated from the rest of the organization with only top executives dealing with the external environment. They suggest that organizations are systems of interactions where decisions related to one function affects other functions.

Wacker (1987) finds that manufacturing goals can be complementary and do not necessarily require a tradeoff. Based on observational data, Hall and Nakane (1990) propose that, rather than assuming there will be a tradeoff between manufacturing goals (i.e. flexibility sacrifices efficiency), organizations should build strategic objectives by layering capabilities.

Vickery et al. (1993) investigated the relationship between manufacturing competence, business strategy, and performance. They found significant positive relationships between production competence (e.g. product, volume, and process flexibility) and performance, but no direct relationship between strategy and performance. They also found that strategy and flexibility had an interaction effect. A pure differentiation strategy with high manufacturing competence is related to the highest performance, while the lowest performance is related to a differentiation/cost strategy and low production competence. Thus, in the selection of a strategy, an organization must take into account their manufacturing capabilties to achieve desired performance results.

Ettlie and Penner-Hahn (1994) study the relationship between manufacturing strategy and flexibility. Results indicate that tradeoffs between flexibility and efficiency are not clear-cut when formulating manufacturing strategy. Companies with greater strategic manufacturing focus tend to schedule fewer different parts on newer advanced manufacturing technology, underutilizing the flexible capability. Of the measures evaluated, changeover time had a direct relationship to both a focus on flexibility and a focus on delivery. A strategic focus on quality or cost is unrelated to the flexibility measures, again suggesting that the strategy and related capabilities must be integrated.

Ward et al., (1994) investigate the relationship between proactive participation of manufacturing in strategic planning, planning for structural and infrastructural manufacturing capabilities, and organizational performance. Structural capability relates to technology such as CAD/CAM, FMS, numerical control, robots, automated material handling, and real-time process control. Infrastructural capabilities are job design, multi-function employees, planning responsibility, training, improving worker/management relations, and increased job automation. They find that manufacturing involvement in strategic planning and a long-term investment in developing manufacturing capabilities has a positive relationship with performance. Additionally, involvement in strategic planning and investments in either structure or infrastructure programs also has a positive effect on performance. Organizations with high strategic planning involvement and high investments in infrastructure, but without investments in structure, do not have better performance, reemphasizing the importance of investing in structural capabilities. Likewise, high manufacturing involvement in strategic planning without investments in either type of manufacturing capability is not positively related to performance.

Wheelwright and Bowen (1996) suggest that manufacturing operations cannot be isolated from the rest of the organizational system. They observe that many organizations approach problem-solving as a “one-time fix” that is considered finished once a solution is implemented. They propose that, no matter how good the manufacturing process is, unless the organization and its functions are integrated, it can not compete with highly integrated organizations. The piecemeal implementation of systems like TQM and JIT/Lean diminish the performance benefits. Toyota and its suppliers consider the entire organizational system when making decisions, and functional optimization is not allowed to the detriment of the whole system.

Gupta and Lonial (1998) find that manufacturing strategy directly affects organizational performance. Manufacturing strategy requires input from other functions, such as marketing and R&D, when planning the product line and its production. Business strategy also affects performance indirectly through manufacturing strategy, thus emphasizing the importance of integrating strategies across functions, as well as with organizational strategy.

Berry and Cooper (1999) find a negative relationship with both cost and profit margin when manufacturing and marketing strategies are not integrated. Ward and Duray (2000) find that organizations using differentiation strategies in dynamic environments also have manufacturing strategies that emphasize quality and flexibility. The results of these studies reiterate the importance of integration among organizational, manufacturing, and other functional strategies.

Later Strategic Integration Research

Swink, Narasimhan, and Kim (2005) find that strategic integration moderates the influence of manufacturing practices (product-process development, supplier relationship management, workforce development, JIT flow, process quality management) on manufacturing capability development (new product flexibility, process flexibility, cost efficiency) while having a direct effect on capability development and organizational performance. Workforce development practices, such as cross-training employees, are positively related to the three capabilities. Process quality and supplier relationship management practices are not related to the three capabilities. JIT flow is significantly related to process flexibility. Strategic integration has a positive relationship with both cost efficiency and new product flexibility. The manufacturing practices overlap with the definitions for several components in the current study. Thus, strategic integration has a moderating effect between manufacturing flexibility and performance.

Swink, Narasimhan, and Wang (2007) investigate strategic customer integration, strategic supplier integration, product-process technology integration, and corporate strategy integration and the effects on manufacturing capabilities (includes process and new product flexibility) and performance. They have similar results to Swink et al. (2005) in that new product flexibility and process flexibility are related to performance; however, process flexibility has a negative relationship. One possible explanation is the inclusion of one item in the process flexibility scale that lowered reliability (alpha = .57) and possibly influenced the results.

Operational Definition

When manufacturing strategy and other functional strategies support the corporate strategy, an organization has strategic integration. Manufacturing strategy must complement other functional strategies. This necessitates that all functional strategies as well as corporate strategy should leverage existing capabilities. The strategies, goals, and objectives of manufacturing must be clearly defined as well as reviewed for revision as needed. Strategies and goals for the manufacturing function as well as the organization must be clearly communicated to those who must work within those parameters and expectations. Those who formulate the manufacturing strategy should also be involved in corporate strategy formulation to insure that manufacturing flexibility is central to corporate strategy.

Summary

Strategies related to flexibility generally focus on differentiation, such as the breadth and depth of product lines, product customization, and quick response. Each strategy has a slightly different emphasis and requires different supporting organizational characteristics. The selection of specific manufacturing strategies must be both compatible and integrated with organizational strategy and other functional strategies. A mismatch within the organization’s strategies will cause them to be less effective and possibly detrimental to performance and the organization.

Within a systems perspective, strategic integration is implied, as organizations can no longer isolate a function like manufacturing from the rest of the organization. It takes planning for systems to operate smoothly. In larger organizations, the task of planning is usually divided across the three organizational planning horizons (strategic, tactical, and operational). A rational reason for an organization to pursue flexibility is to reduce uncertainty; however, more recent studies emphasize that it is a strategic choice to exploit an organization's capabilities and environmental conditions. Knowledge and skills learned through the supply management process can help with integrating manufacturing and organizational strategy. Supply management requires managing process across functional lines using metrics designed to meet process and product objectives, rather than functional objectives (Lummus & Vokurka, 1999).

Several studies suggest that, rather than using flexibility as a response to uncertainty, it can be used proactively to create uncertainty in the environment for competitors. Investing in flexibility "just-in-case" is not rational or economical, but using flexibility proactively to compete in dynamic environments is rational (Hayes & Wheelwright, 1984; Narain et al., 2000; Swamidass, 1988). The extent that flexibility affects performance depends upon the strategic context the organization chooses to pursue. Strategic integration is expected to influence the previously discussed relationship between manufacturing flexibility and performance, since successful implementation of flexibility requires integration across all planning horizons.

Flexibility should affect performance positively if the strategic context requires flexibility (Upton, 1994) and it is planned throughout the organization (Slack, 1983, 1987). The label of strategic integration implies a relationship between manufacturing and organizational strategy. Flexibility in manufacturing can be achieved without a specific organizational strategy and in spite of a lack of integration between manufacturing and organizational strategy. Manufacturing flexibility, however, will have a stronger effect on performance if a particular business strategy is designed to exploit manufacturing flexibility. As a result, flexibility can be used proactively within strategic planning. Thus, strategic integration moderates the previously proposed relationship between manufacturing flexibility and performance. The following hypothesis is proposed.

H3: Strategic integration strengthens the relationship between manufacturing flexibility and organizational performance.

Organizational Infrastructure Research

Although Swamidass (1988) proposes infrastructure as a component of manufacturing flexibility, and it is mentioned extensively throughout the flexibility literature, in this study, it is defined as a moderator of the relationship between manufacturing flexibility and organizational performance. Skinner (1985) suggests that the implementation failure rate of advanced manufacturing technologies is not necessarily due to an improper choice of technology, but rather an organizational infrastructure that is inconsistent with the demands of new manufacturing technologies. Infrastructure is primarily comprised of organizational attributes or support systems within the organization. These systems may be technological, administrative, or social systems. Skinner (1985) defines infrastructure as "organizational levels, work-force management, supervisory practices, production control and scheduling approaches, and job design and methods" (p. 30). Additionally, infrastructure that connects the organization to the external environment is important for dealing with external parties such as suppliers and customers. Hall and Nakane (1990) propose that organizational attributes, such as culture, help enable the development of manufacturing capabilities related to quality, dependability, cost, flexibility, and innovation.

In a series of studies investigating World Class Manufacturing, infrastructure is included as a key organizational feature required for implementing practices such as JIT/Lean and TQM (Flynn et al., 1994, 1995a, 1999; Sakakibara et al. 1993, 1997). Previous definitions of organizational infrastructure include factors such as: policies, procedures, management tools, management personnel, information feedback, information technology, plant environment, workforce management, management support, and other characteristics, which support the implementation of manufacturing flexibility. Organizational infrastructure should: remove barriers between functions, allow networking between organizations, develop worker capabilities, provide open communication, value people in the organization, and create a value system compatible with strategic initiatives. These organizational characteristics can be divided into three main categories: management support, information management, and organizational attributes.

Management Support

Management support is often cited as the one characteristic that can make or break implementation of new techniques or processes. Management support includes leadership, management attitudes toward change, and management presence on the production floor (Jaikimar, 1986; Koste & Malhotra, 1999; Ward, McCreery, Ritzman, & Sharma, 1998). Evaluating managers regarding performance improvements related to manufacturing flexibility, as well as encouraging the pursuit of "best practices" are also part of management support (Boyer, Leong, Ward, & Krajewski, 1997; Flynn et al., 1994, 1995a, 1999; Sakakibara et al., 1993, 1997). When managers are responsible for implementation success, they encourage working together, sharing resources, and continuous improvement. Liker and Morgan (2006) suggest that the difference between short-term success and long-term sustainability of JIT/Lean manufacturing practices is an organization with top and middle management who lead by example (Adler, 1988).

Information Management

Information feedback provides workers with information related to the process and performance. Similar concepts include data collection, storage, and retrieval (Swamidass, 1988), information availability (Schmidt, 1991), information technology (Beach et al., 2000), transparent information (Sethi & Sethi, 1990), coordination between activities (Schmidt, 1991; Slack, 1983), and communication protocols (Cusumano & Selby, 1997; Schmidt, 1991; Sethi & Sethi, 1990), all of which enhance decentralized decision-making to solve non-routine problems (Corrêa, 1994). Information management is needed to support production planning and control, scheduling, inventory management, and maintenance procedures (Browne et al., 1984; Cox, 1989; Sethi & Sethi, 1990; Slack, 1983; Swamidass).

The concept of information management includes the need for immediate and unimpeded access to complete and accurate information, both internal and external (Eng, 2006; Flynn et al., 1994; Li, Rao, Ragu-Nathan, & Ragu-Nathan, 2005). This concept increasingly relies on information systems and other electronic devices (e.g. cell phones, radio frequency identification) that provide real-time information for decision-making. Information technology is expected to make information easily accessible and to enhance manufacturing flexibility, although more sophisticated technology does not guarantee performance improvements, as seen in the implementation of advanced manufacturing technologies (Jaikumar, 1986). Additionally, information management includes effectively communicating with supply chain partners about changes which affect them.

Organizational Attributes

Organizational attributes include real-time coordination of activities and decision-making, decentralization of authority, stable employment, cross-functional cooperation (Schmidt, 1991; Sethi & Sethi, 1990; Slack, 1983), workforce management (Hall & Naknae, 1990), and reciprocal interdependency (Thompson, 1967). Several researchers propose that organizational policies and procedures should be flexible enough to allow for changes (Adler, 1988; Koste & Malhotra, 1999; Swamidass, 1988), as well as include a specific organizational change process (Adler; Sethi & Sethi, 1990). Scranton (1997) finds that flexible organizations develop systems that could be flexible, rather than creating standard operating procedures that do not allow for variability. Organized, clutter-free work environments facilitate quick changeovers and problem-solving, allowing faster identification of problems within product designs and the manufacturing process (Hall & Nakane, 1990).

Workforce management includes human resource policies and procedures for selection, training, retention, and overall development of workers. Hall and Nakane (1990) state “the most important foundation of flexibility is human resource development” (p. 16). A number of researchers agree with this statement emphasizing the importance of implementing human resource practices compatible with manufacturing flexibility (Cox, 1989; Hayes & Wheelwright, 1984; Jaikumar, 1986; Koste & Malhotra, 1999; Schmidt, 1991; Scranton, 1997; Slack, 1983; Stewart et al., 1994; Swamidass, 1988; Witt, 1996). In addition, several studies propose training workers not only in technical skills, but also in problem-solving and experimenting with system capabilities. Such experimentation allows workers the opportunity to improve the process or the product (Hyun & Ahn, 1992) and to develop problem-solving skills as well as planning skills to control their own work (Corrêa, 1994; Hyun & Ahn, 1992; Jaikumar, 1986; Scranton, 1997; Sethi & Sethi, 1990).

Scranton (1997) finds that flexible organizations not only create respect between workers and managers, but they also develop trust, reciprocity, and solidarity within an industry. Personal relationships, both within the organization and outside, are encouraged, which increases information sharing and industry knowledge. Flexible organizations tend to treat workers better than average and provide better benefits and higher wages than their competitors. Higher wages attract more skilled workers, as well as those willing to learn new skills. Flexible organizations retain skilled workers – rather than laying them off – by keeping plants operating through innovative strategies, such as targeting new markets, creating new products, or entering new industries with either new applications of existing technology or new technology. Information sharing (Scranton, 1997); knowledge management, transfer, and modification (Sethi & Sethi, 1990); and organizational learning (Narasimhan & Das, 1999a) are all proposed to expand the general knowledge base and increase innovation. A system of ongoing learning enhances the organization's ability to respond to unexpected changes, as well as proactively exploiting this capability. Workers are encouraged to pursue continuous learning through reward systems linked to increased skill levels.

Ward et al. (1994) defined infrastructural capabilities as job design, multi-function employees, planning responsibility, training, improving worker/management relations, and increased job automation. Cross-functional teams for new product development as well as treating suppliers as team members, can also increase flexibility. An increase in teamwork requires increased communication and coordination. This is accomplished by not only using information management systems, but also by having frequent two-way communication and interaction with all relevant parties.

To improve responsiveness to both internal and external customers, internal functions and supply chain functions must be integrated. For example, product-mix, equipment, and volume flexibility require coordination between functional areas such as manufacturing, capacity planning, production planning, process design, product design, purchasing, and human resources. Labor flexibility primarily requires coordination between human resources, production planning, and production workers. Routing flexibility primarily requires coordination between product design, process design, production planning, and production workers. For supply management flexibility, a reciprocal relationship that is viewed by both parties as mutually beneficial, takes time to cultivate. Extensive communication and frequent exchanges of information build these relationships and the requisite trust. Coordination is primarily through the buying organization's purchasing agent and the seller's representative; however, as the supplier gets more involved with the buyer, coordination extends to functions such as product design and engineering, process design, and manufacturing.

Operational Definition

Organizational infrastructure provides a framework for how organizations operate and enable employees to do their jobs. It includes management support and information management processes as well as other organizational attributes such as policies and procedures. These factors should enhance or enable the organization's flexibility.

Management plays a critical role in ongoing process improvement by emphasizing information sharing and change management while pursuing best practices. Management must be responsible for implementing manufacturing flexibility through personal guidance and an evaluation system emphasizing the flexibility's importance.

Information management in dynamic business environments is increasingly important. Pertinent information for managing supply chain activities must be available to managers when needed. The information exchanged with supply chain members should be timely, complete, and accurate with any changes communicated to those in the supply chain that are affected. Information systems should increase rather than decrease flexibility through real-time, direct links between supply chain members.

Organizational attributes should strengthen rather than inhibit an organization's flexibility. Teams should meet frequently whether they are responsible for daily operations or special projects. Product changes should involve a cross-functional team. Suppliers should be involved in appropriate tasks, such as product changes, and treated as team members. Business processes should integrate to improve supply chain functionality. Decisions should be made and coordinated throughout the organization based on real-time information. Improving responsiveness to customers whether internal or external is emphasized while rewarding employees for learning new skills.

Summary

The infrastructure elements may or may not be flexible themselves. For example, policies allowing workers the options of job sharing or flex-time are flexible. A managerial emphasis on reducing inventory that subordinates other organizational goals, however, is an example of an infrastructure characteristic that, while inflexible in itself, may encourage a desired outcome of flexibility. Organizational infrastructure characteristics that influence flexibility are discussed throughout the manufacturing flexibility literature, yet they do not appear in most models. The lack of measurement attempts for infrastructure likely stems from the difficulty in measuring the less tangible aspects it represents, such as culture or attitudes. Thus, infrastructure is not a component of flexibility as some have suggested, rather it supports the implementation of manufacturing flexibility. As a result, infrastructure with three proposed sub-dimensions (management support, information management, organizational attributes) is a moderator between manufacturing flexibility and organizational performance. Thus, the following hypothesis is proposed.

H4: Organizational infrastructure strengthens the relationship between manufacturing flexibility and organizational performance.

Summary

This section contains descriptions of two additional moderating variables (strategic integration and organizational infrastructure) that influence the relationship between manufacturing flexibility and performance. The literature related to the development of each variable was discussed, as well as how each is expected to affect the implementation of manufacturing flexibility and its performance outcomes. Table 4 contains a list of the hypotheses for this study.

Table 4 – Study Hypotheses

H1	Individual flexibility components contribute to organizational performance.
H1a	Product-mix flexibility contributes to organizational performance.
H1b	Routing flexibility contributes to organizational performance.
H1c	Equipment flexibility contributes to organizational performance.
H1d	Volume flexibility contributes to organizational performance.
H1e	Labor flexibility contributes to organizational performance.
H1f	Supply management flexibility contributes to organizational performance.
H2	Manufacturing flexibility contributes to organizational performance.
H3	Strategic integration strengthens the relationship between manufacturing flexibility and organizational performance.
H4	Organizational infrastructure strengthens the relationship between manufacturing flexibility and organizational performance.

Manufacturing Flexibility System Model

A synthesis of the literature related to manufacturing flexibility, performance, strategic integration, and infrastructure addresses the four proposed research questions. The manufacturing flexibility system model proposed in this study follows (Figure 4). Manufacturing flexibility is comprised of six components: product-mix, routing, equipment, volume, labor, and supply management. These components are expected to have a direct relationship to organizational performance as measured in previous studies. When more than one of the components is present in the manufacturing system simultaneously, they are expected to create a synergistic effect that influences performance more than any individual component. The relationship between manufacturing flexibility and organizational performance is expected to strengthen when manufacturing strategies are integrated with other organizational strategies. If strategy is integrated, then organizations should have a match between the flexibility components implemented and the strategy pursued. In addition, an organizational infrastructure which enables and encourages flexibility is also expected to strengthen the relationship between manufacturing flexibility and organizational performance.

Summary

A proliferation of both qualitative and quantitative research related to manufacturing flexibility has not specifically shown the way in which organizations can implement specific components to become more flexible. Although manufacturing flexibility has become a common term in operations management literature, unresolved issues remain, such as improper terminology usage, no definitive component list, overlapping component definitions, a weak understanding of relationships among components, and a lack of empirical evidence supporting whether manufacturing flexibility improves performance. The inclusion of additional organizational factors is important in assessing complex systems.

This chapter includes a synthesis of manufacturing flexibility literature and the relationships between the components. Additionally, the relationship between the components and performance is reviewed, as well as strategic integration and organizational infrastructure. The literature review and Thompson's (1967) theoretical framework of interdependence and coordination form the foundation for the manufacturing flexibility system model and the proposed hypotheses.

The next chapter presents the research methodology for this study, including the details of the instrument development.

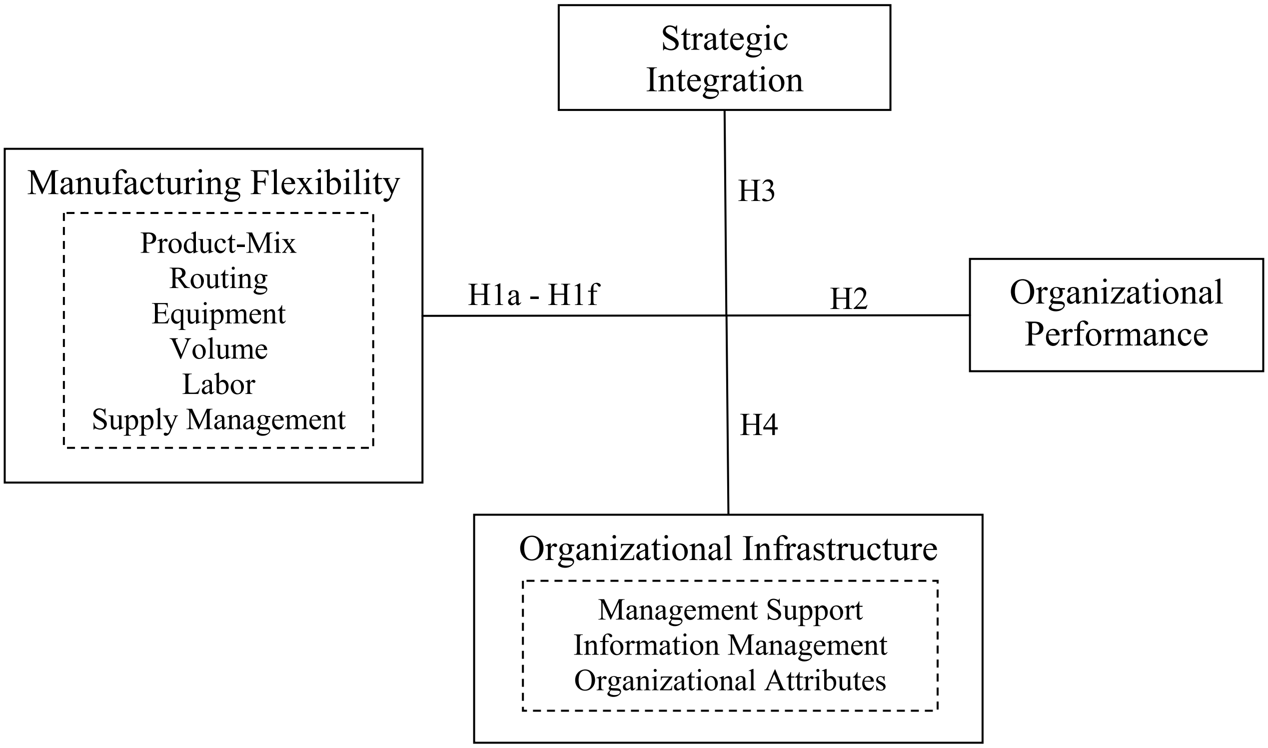


Figure 4 – Manufacturing Flexibility System Model

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

The study's research methodology is discussed in this chapter. It includes a discussion of the instrument development process, the independent variables, moderating variables, and the dependent variable. Validity and reliability of the instrument is also discussed. In addition, the chapter includes a discussion of the data collection procedures, including a description of the target population, the sample, and the procedures for interpreting data.

This study used a cross-sectional survey to collect data from manufacturing organizations in a variety of industries. In chapter 2, a model was presented representing the influence that manufacturing flexibility has on organizational performance, as well as the influence of strategic integration and organizational infrastructure on that relationship. Data were collected using a self-administered questionnaire. A traditional mail survey was selected over an online survey for several reasons. First, a reliable email list is difficult to procure and firewalls at many organizations block email identified as bulk mail. Second, it was suggested that middle and upper mangers prefer paper surveys. This allows them to: see questions as they answer, use the definition list, adjust answers if later questions give them information to more accurately respond, and complete the survey while traveling, if necessary. The research methodology for this study is provided in Figure 5.

Measurement Instrument Development

This section describes the overall process used to develop the measurement instrument. This is followed by a description of how specific scales for each variable in the study were developed. A discussion of information related to the business unit and respondent demographics also follows. Lastly, reliability and validity of the instrument are discussed.

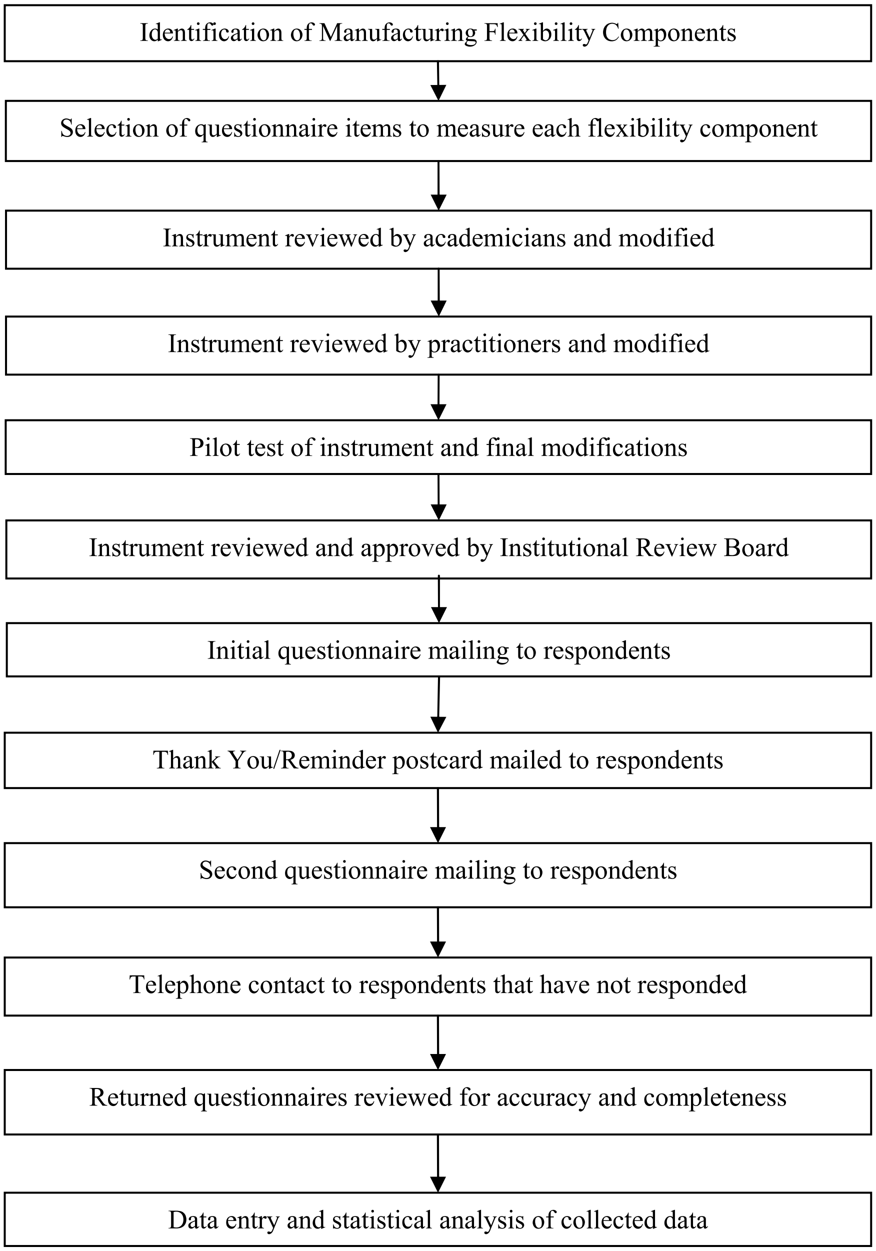


Figure 5 – Summary of Research Methodology

Questionnaire Construction

The survey development and administration procedures for this study were based on

Dillman’s (2000) Tailored Design Method. In previous research, Dillman’s method for instrument development and administration has resulted in high response rates. The design of the questionnaire, using these guidelines, was expected to help reduce non-response issues and measurement error. The measurement instrument items were primarily drawn from previous validated instruments and modified where necessary. New items were developed based on the literature review presented in chapter 2.

The questionnaire was first submitted to a group of four academicians to review the overall purpose of the survey and initial content validity. These academicians were either experts in survey research methodology, manufacturing practices, or both. The instrument was modified several times to include their suggestions related to content, wording, and formatting. Next, the survey instrument was reviewed by 16 academicians and practitioners to further clarify survey items and to help insure that the survey covered all relevant areas related to manufacturing flexibility. Based on the feedback, modifications were made to the instrument prior to the pilot study. For the pilot study, names of potential respondents were gathered from personal networking, as well as contacts through the university. Eighty-four emails were sent to managers in manufacturing organizations asking them to participate by accessing an online survey. If their name was from a specific source, then that information was included in the email. Twenty-one potential respondents either declined to participate or the email address provided was no longer valid resulting in an effective sample size of 63. Thirty-two people accessed the survey form online with 17 of those respondents (34.7% of those who accessed the survey) completing the survey in its entirety, translating in an effective response rate of 26.98%. Respondents were asked to make any additional comments with regard to each scale if there were wording issues, a lack of understanding of the topic, or if they were unsure how to respond to a question (e.g. if it didn't apply). Of the 17 respondents, eleven included their contact information and were willing to be contacted for further follow-up and discussion. A summary of the response rate information for the pilot study is below in Table 5.

Table 5 – Summary of Pilot Study Response Rate

Contact by Category of Response	Frequency
Initial Sample	84
Undeliverable or Declined to Participate	21
Incomplete Responses (Excluded)	0
Effective Sample Size	63
Complete Responses	17
Response Rate	17 / 63 = 26.98%

Follow-up phone and personal interviews with several respondents were conducted to further clarify items and to determine whether further refinement of the instrument was necessary. Due to the small sample size, only basic statistical analysis was conducted. Based on the results of the pilot study, comments made online, and follow-up interviews, some additional changes were made to the scales and layout of the survey, as well as the instructions. The instrument was deemed ready for use and reviewed by the University of North Texas Institutional Review Board (IRB) for compliance with rules governing research using human subjects.

Independent Variables

The independent variables for this study were the components related to the implementation of manufacturing flexibility. It is not necessary for organizations to have every component in order to be flexible. Rather, organizations should select and implement only those components that are compatible with their strategies and capabilities. Six flexibility components were identified in the literature review as relevant to this study. The items that measure product-mix, routing, volume, equipment, labor, and supply management flexibility were in section 11 of the survey instrument. The primary source for items for the first five components was Zhang et al. (2003), with Narasimhan and Das (1999a) the primary source for the sixth component. For each independent variable, a 5-point Likert scale (Never to Always) assessed respondents' perceptions as to the frequency that the statement applied in their business unit.

Measures of Product-Mix Flexibility

Product-mix flexibility (PMX) is the ability to offer customers a broad product line through the ability to change the product-mix frequently. High product-mix flexibility allows the organization to introduce new and modified products more frequently. This component includes concepts related to product design as well as the ability to quickly and easily changeover the process. The eleven items for product-mix were primarily from two sources. Five items (a, b, c, d, e) were based on Zhang et al. (2003). Three items (f, g, k) were modified from Koste et al. (2004). Three new items (h, i, j) were developed based on the literature and feedback during the instrument development process. The scale for product-mix was larger than the other components as its definition is broader than previous studies because it combines characteristics of process/mix, new product, and modified product flexibility.

Measures of Routing Flexibility

Routing flexibility (RTG) is the ability to move parts, tooling, and materials along multiple routes in the production facility. This includes moving parts between machines or workstations/cells, as well as loading and unloading. It also includes the ability to change the route of a particular product when needed. The first five items were based on Zhang et al.'s (2003) routing flexibility scale (a, b, c, d, e), and two items (f, g) from Zhang et al.'s (2003) material handling scale were added to measure this combined flexibility component.

Measures of Equipment Flexibility

Equipment flexibility (EQP) is present when machines can perform multiple operations for different products. This may be achieved using general-purpose equipment that uses multiple tools and programs or special-purpose equipment, like an FMS, that is designed to perform multiple operations. Four items (a, b, c, d) were based on Zhang et al.'s (2003) equipment flexibility scale. One item (f) was modified from Ariss and Zhang's (2002) scale. Two new items (e, g) were developed to better measure this construct as defined for this study.

Measures of Volume Flexibility

Volume flexibility (VOL) is the ability of the system to increase or decrease volume and still remain profitable. Typically, this change is implied to be within a small range (at least in the short-term); however, previous studies often use a generic item such as "Output volume can vary and still remain profitable." For this study, a more specific measure was desired. In addition to considering volume changes in the short-term, the concept of long-term volume changes (capacity expansion) was also included. Six items (a, b, c, d, e, f) were modified from Zhang et al.'s (2003) scale. Two new items (g, h) were developed based on the literature review.

Measures of Labor Flexibility

Labor flexibility (LBR) is a newer construct proposed within the flexibility literature, though it was implied or discussed in many studies. This is the ability of workers to perform more than one task within the organizational system and includes, not only the number of different tasks, but also the variety of those tasks. Four items (a, c, e, f) were modified based on Zhang et al. (2003). Two items (b, d) were based on Swink et al. (2005). A final item (g) was modified from Ariss and Zhang (2002).

Measures of Supply Management Flexibility

Supply management flexibility (SPM) is the ability of suppliers to respond to changes requested by the customer (in this study, the customer is the manufacturing organization). This may include participating in product and process design or increasing their flexibility to cope with changes in the products, volumes, or delivery dates requested by the customer. Six items (b, c, e, f, i, j) based on Narasimahn and Das (1999a, 1999b) form the foundation for this scale. One item (a) from Flynn et al. (1999) and two items (g, h) from Flynn et al. (1994) were modified to fit the study's definition of supply management flexibility. A final item (d) was developed based on Swink et al. (2005).

Moderating Variables

The moderating variables for this study are strategic integration and organizational infrastructure. Data were collected to measure both of these constructs. For both moderators, a 5-point Likert scale (Never to Always) assessed respondents' perceptions as to the frequency that each statement applied to their business unit.

Measures of Strategic Integration

Strategic integration (STR) is the development of manufacturing strategy that supports corporate strategy and complements other functional strategies. Section 9 of the survey contained items specifically related to measuring strategic integration. Swink et al.'s (2005) organizational strategic integration scale was modified as the foundation for six items on this scale (a, b, c, d, f, i). One item (e) was based on the study by Swamidass and Newell (1987). Two new items (g, h) were developed based on the literature review.

Measures of Organizational Infrastructure

Organizational infrastructure (INF) is framework for operating within the organization which enables employees to do their jobs. The infrastructure itself may or may not be flexible, but of interest is whether it enhances the ability of the organization to be flexible. Organizational infrastructure was measured in section 10 of the survey.

No intact scales were used to measure this construct. Three sub-constructs were proposed – management support, information management, and organizational attributes. The presence of management support indicates whether an organization has leadership that attempts to involve all employees in decision-making by emphasizing the pursuit of manufacturing flexibility. Management support was measured with six items (b, g, j, n, q, s) based on the literature (Boyer et al., 1997; Flynn et al., 1994, 1999). Information management relates to an organizational emphasis on communicating openly and frequently with employees and supply chain members. It was measured with seven items (d, f, h, l, p, t, v) based on the literature (Eng, 2006; Flynn et al., 1994; Krause et al., 2007; Li et al., 2005) and two new items based on feedback from practitioners (x, y). Organizational attributes include an organization's policies and procedures that enable workers to produce quality outputs, as well as enabling the pursuit of manufacturing flexibility and continuous improvement. These attributes were measured with seven items (a, c, e, i, k, m, o) modified from previous studies (Eng, 2006; Flynn et al., 1994, 1995) with three new items (r, u, w) developed based on the literature.

Dependent Variables

Data were gathered for changes in performance related to setup time, throughput time, scrap and rework cost, worker productivity, raw materials inventory, WIP inventory, finished goods inventory, number of backorders, on-time delivery, unit manufacturing cost (without purchased materials), cost of purchased materials, and machine utilization. Performance was measured in section 15 of the survey. For measures of business unit performance (PER), respondents indicated on a 9-point Likert scale whether these variables increased or decreased within a particular range, or remained constant after implementing manufacturing flexibility. Five items (b, d, e, f, g) were modified based on White et al. (1999) and two items (c, j) were modified from Shah and Ward (2003). Five new items (a, h, i, k, l) were developed based on the literature.

Control Variables

Control variables for this study are industry and business unit size (number of employees and annual sales).

Industry is a control variable in this study to insure that no single industry or group of industries unduly influence the results. It is possible that some industries more frequently employ manufacturing flexibility. Previous manufacturing flexibility studies have limited the number of industries to those in SIC categories 34 to 38 (Zhang et al., 2003) or to 34 to 36 (Koste et al., 2004). These industries include fabricated metal (SIC 34), industrial/commercial machinery (SIC 35), electronics/electrical equipment (SIC 36), transportation equipment (SIC 37), and instruments/measurement equipment (SIC 38). These SIC categories (34 to 38) are also utilized throughout operations management research in other areas such as purchasing (Narasimhan and Das, 2001), JIT/Lean (Sakakibara et al., 1993), and TQM (Flynn et al., 1994).

Size based on the number of employees is the second control variable. It is suggested throughout the operations management literature that the size of the organization affects implementation of manufacturing practices. It is typically suggested that larger organizations with more resources are better able to implement new practices (Shah & Ward, 2003). Thus, the number of employees in the business unit is considered. Number of employees ranged from less than 100 to 1000 or more.

The third control variable is size based on the business unit's annual sales. This is a second test of whether size affects the results. Both of the size controls are necessary as it is possible for one of the size measures to be "large" relative to the other. For example, it is possible to have an organization with less than 250 employees but over 100 million dollars in annual sales. Annual sales ranged from less than $5 million to $100 million or more.

Business Unit Demographics

Information was collected about the business unit for which the respondent is answering the questionnaire. This includes the type of business unit, its size (number of employees and annual sales), unionization of employees, industry, and the type of manufacturing processes. Basic information related to the respondents' demographics also were collected. This included information about their manufacturing and business experience, their education level, and their position/job title. A summary of this data appears in chapter 4.

Reliability

Internal consistency of the instrument was assessed using Cronbach's alpha (Cronbach, 1951) in SPSS® version 15. The correlation of each item to its scale also was analyzed to evaluate whether items were assigned correctly to a scale. The alpha values from this study were compared to available alpha values from previous studies to determine if the scales improved by adding new items. For early stages of scale development, it is suggested that a reliability of .70 is acceptable (Nunnally & Bernstein, 1994). This was the minimum level used to assess the scales for reliability. The specifics of the analysis are contained in chapter 4.

Validity

To reduce measurement error, the survey instrument was designed according to Dillman's instrument design process (Dillman, 2000). The survey was a multiple item self-administered questionnaire used to operationalize manufacturing flexibility, strategic integration, organizational infrastructure, and organizational performance (Appendix D). To develop validity for the survey, items were drawn from previous studies having validated survey instruments.

Zhang et al. (2003) and Narasimhan and Das (1999a) were the primary sources for items related to the manufacturing flexibility components. Additional items were added from other validated surveys to create scales that better fit the construct definitions for this study. A group of studies by Flynn and her coauthors (Flynn et al. 1994, 1995, 1999) were used to develop portions of the infrastructure variable as were studies by Eng (2006) and Li et al. (2005). Items from other relevant areas were added to measure performance, the dependent variable (Shah & Ward, 2003; White et al., 1999) and strategic integration (Swink et al., 2005). Validity of the instrument was established in three ways: by verifying content validity, construct validity, and criterion-related validity (Nunnally & Bernstein, 1994). Statistical analyses are included in chapter 4.

Content Validity

Nunnally and Bernstein (1994) recommend two methods for assessing content validity: having a representative collection of items and using sensible methods of instrument construction. First, representative items were based on an extensive review of the literature related to operations management and manufacturing flexibility (see Table 3 in chapter 2), using previously validated instruments when available. Second, newly proposed items were developed from the literature, as several components were not well represented in past empirical studies. A focus group of experts, both of academicians and practitioners, reviewed the questionnaire items for content validity and to help clarify ambiguous wording.

Construct Validity

The purpose of assessing construct validity was to insure that each item measured only the particular construct it was designed to measure. Construct validity was determined through principal components factor analysis and item-to-scale correlation analysis. The results show that the items represent the expected construct. Construct validity related to the expected relationships between manufacturing flexibility and organizational performance was partially validated by previous studies that found a relationship between various manufacturing flexibility components and performance. Detailed descriptions of those studies are in chapter 2.

Convergent validity confirmed that items expected to be related based on theory, were, in fact, related. Likewise, discriminant validity confirmed that items expected to be unrelated were not highly correlated. These were both determined by analyzing the item inter-correlations.

Criterion-related Validity

The flexibility component measures were correlated with the measures of performance to establish criterion-related validity. As expected, each manufacturing flexibility component was related to some of the performance measures in the study. As flexibility increased, some performance measures were expected to increase (d, i, l), while the others were expected to decrease (a, b, c, e, f, g, h, j, k).

Data Collection

This section includes a detailed discussion of how data were collected from the population. Dillman's (2000) Tailored Design Method was followed to the extent possible. Although surveys do have some benefits over other research methods, they also have potential weaknesses. As many of these issues as possible were addressed prior to data collection and are discussed in the relevant sections that follow. With a mail questionnaire, respondents usually do not have the opportunity to ask for clarification as they would in a face-to-face interview. This issue was addressed by providing respondents with contact information (email and phone number) for two people who could answer questions about the study and/or questionnaire. Respondents were not asked follow-up questions in the mail survey, but were asked to provide contact information in the form of a business card. This information creates an opportunity for future research and data gathering with those respondents.

Target Population

The entire population consists of manufacturers that have adopted some form of manufacturing flexibility. The preferred respondent is a middle or senior manager within that type of U.S. manufacturer. This serves two purposes within the research framework. First, those managers are knowledgeable about the flexibility components as well as relevant performance data. Secondly, these respondents should understand the levels of strategic planning and be involved in developing and implementing the organizational strategy. As a result, the sampling frame was narrowed to the membership of APICS – The Association for Operations Management.

APICS is a non-profit organization comprised of operations management professionals whose goal is to improve their personal performance, as well as the competitiveness of their organizations, by staying abreast of new management and operations techniques. They are knowledgeable about manufacturing practices and highly motivated, since they want to continually learn techniques to make their organizations more competitive. Total membership at the time of data collection was approximately 30,000. Members stay current through a variety of activities including: annual international conference, networking at local meetings, electronic discussion boards, and society publications. Members of APICS represent organizations often on the leading edge of implementing new management and operations techniques. Tomaskovic-Devey, Leiter, and Thompson (1994) found non-response is less likely when respondents clearly have the authority to respond, the capacity to respond (knowledge and information access), and the motive to respond (respondent’s interest in responding).

The logistics and expense of a census was not justified when a representative sample was acceptable for this study. A systematic sampling plan was used to select managers from the target population to receive a questionnaire. Consultants and academicians were removed from the list prior to sample selection, as they were not part of the target population. The membership list was sorted in ascending order by zip code. By sorting the list by zip code and using a random starting point, systematic sampling was equivalent to using random probabilistic sampling and allows for generalization to the population (Cochran, 1977). Due to financial constraints, a smaller sample (1500) than proposed (2500) was selected to determine the response rate for the membership list. The first sample of 1500 was selected from 4456 member names. It was determined that selecting every third name would result in the desired number of respondents for the mailing. By choosing a random starting point (record 640) in the list and selecting every third member, every member of the target population had an equal chance of being selected. If the organization was identified for a member, then only one respondent per business unit was selected. Based on the response rate from the first sample (9.97%) a second sample was selected with the expectation that the response rate would be similar. The second sample of 1000 was selected from 2749 member names. A random starting point (record 1192) was again chosen in the list and every third member was selected, so every remaining member of the target population had an equal chance of being selected. Again, if the organization was identified, then only one respondent per business unit was selected. To reduce potential bias, organizations that were included in the first sample were excluded prior to selecting the second sample.

Survey Administration Procedures

Dillman's Tailored Design Method (2000) recommends five guidelines to improve response rates. Each guideline and its application to this study is discussed below.

The first guideline was to provide a user-friendly questionnaire with regard to layout, font, etc. The questionnaire was printed back-to-back on white, high quality paper with the pages forming a booklet. A single font was used throughout the questionnaire, as more formal or official looking surveys tend to have higher response rates. Pages contained a single column of questions for better readability. Within the main body of the questionnaire, alternating questions were highlighted to visually assist respondents in answering questions on the correct line. A page of general instructions and definitions (Appendix D) were separate from the questionnaire making them easily accessible while completing the questionnaire (Appendix E).

The second guideline related to the contact procedures for the data collection. The initial mailing included an introductory letter (Appendix A), general instructions and definitions (Appendix D), the questionnaire (Appendix E), and a business reply envelope. The introductory letter was printed on university letterhead and described the purpose of the study, as well as a guarantee of confidentiality of individual responses. Obtaining a sponsor for a study has been shown to increase response rates. Although APICS deemed the survey appropriate for their membership and partially funded data collection, their organizational policies prevent them from sponsoring surveys; therefore, their name was not printed on any correspondence. Responses were returned directly to the researcher. Respondents were asked to enclose a business card if they wanted to receive a summary of the results. For follow-up mailings, this reduced the necessity of resending the survey to the entire list.

After approximately two weeks, a thank you/reminder postcard (Appendix B) was sent to the sample list to thank those who had returned the survey, and to remind others of the importance of their participation. Research shows that people appreciate being thanked for helping others, thus this was expected to further increase the response rate (Dillman, 2000).

Approximately, three weeks after the thank you/reminder postcard, a second mailing was sent with a replacement questionnaire. Previous respondents who enclosed a business card with their survey from the first mailing were not sent a replacement questionnaire. The cover letter (Appendix C) was modified to ask those who had not responded to do so. This letter reiterated the importance of each individual's participation. A caveat was included stating that if the recipient had already completed the survey, then the second copy should be discarded. Each packet included the cover letter (Appendix C), the general instructions and definitions (Appendix D), the questionnaire (Appendix E), and a business reply envelope.

The final step was to contact non-respondents to try to convince them to respond to the survey. If they agreed to participate, the survey was delivered to them in a different mode – either by fax or email. For those that choose not to participate, this contact was used to determine the reason for not responding. This information was used to assess non-response bias.

The third guideline was to use a return envelope with a first-class stamp, as this was previously found to increase response rates. A business reply envelope, however, was substituted for a first-class stamped envelope, due to increasing postage rates. It was not expected to significantly affect the response rate, as some professionals would interpret pre-paid postage as financially irresponsible, since an additional expense is incurred with no guaranteed return.

To meet Dillman's fourth guideline, all correspondence was personalized for the intended recipient, rather than using a generic salutation.

The final guideline was to provide a token financial incentive to respondents. This practice has been shown to increase response rates with the general public; however, this was problematic with a business survey, as some organizations require employees to report all employment-related gifts. Instead of offering a financial incentive, respondents were offered the opportunity to receive a summary copy of the research findings. It was expected that this population would prefer receiving the study results over a token monetary incentive.

Dillman's Total Design Method (1978) for instrument development and administration has resulted in very high response rates, averaging 74% for 48 mail surveys. Using the Tailored Design Method requires more effort, incentives, and contacts per respondent to achieve higher response rates, thus the cost of data collection increases (Dillman, 2000).

Non-response Bias

Non-response bias is a potential issue with all self-report surveys. It is difficult to obtain objective data for a specific business unit that did not respond to allow comparisons to organizations that did respond. To address this, non-response bias was assessed in three ways. First, a random sample of non-respondents remaining after the second questionnaire mailing was contacted. These non-respondents were asked why they chose not to participate. This information was used to determine if these non-respondents were significantly different from respondents. Generally, these persons stated that they did not respond because they did not have time to respond within the requested time, they were not in a position to respond to most of the questionnaire, or their organization had a policy of not responding to surveys. Second, the characteristics of early respondents (received before the final mailing) and late respondents (received after the final mailing) were analyzed to determine if there were significant differences between these groups. Some consider this a weaker method for determining non-response bias, as late respondents do not necessarily have the same characteristics as non-respondents. A final analysis of non-response bias was to compare the characteristics of respondents who included their business cards with those who did not (BarNir & Smith, 2002). Respondents who choose to remain completely anonymous were expected to be similar to non-respondents who choose not to participate to avoid answering specific questions that may identify them. Non-response bias was not found to be an issue in this dataset.

Sample

Data Review

The first step of the data review process was to determine the completeness of the 234 returned questionnaires. Missing data, ambiguities in responses, and irregularities were examined to determine if each questionnaire could be included in analysis. After review, the forms were prepared for data entry. Once data entry was complete, the data were reviewed to insure that the data from the questionnaire were input correctly.

Data were first reviewed to determine whether the provided information was usable in the statistical analysis. Three aspects were considered to determine whether a respondent remained in the sample. First, responses were scrutinized to determine if any consultants or academicians returned a completed questionnaire. Consultants and academicians were supposed to be removed from the mailing list prior to selecting the sample. Three consultants did return completed questionnaires, thus their responses were removed from the dataset.

Second, each respondent was asked to indicate the percentage of sales their business unit earned from manufacturing activities. A frequency distribution (Figure 6) was used to determine the appropriate cut-off point for inclusion. The study focuses on manufacturing characteristics, thus primarily service-oriented business units were not representative of the target population, and their inclusion would reduce the interpretability of the results. Consequently, inclusion in the study required that manufacturing activities must constitute at least 70% of sales, resulting in the removal of 10 responses. A majority of the business units (174, or 84.466%) generated 90% or more of their annual sales from manufacturing. Missing data were replaced with the mean for an item. The 94 missing data points were 0.47% of the total dataset (209 respondents x 96 items = 20,064 data points) which was well below the recommendation to use mean substitution only when less than 10% of the data were missing (Tsikriktsis, 2005).

Lastly, responses were reviewed for general usability. This primarily included analysis of survey forms with a large amount of missing data that would prevent accurate statistical analysis. This review resulted in the removal of 12 sets of responses that were missing data on one or more main variables in the study (manufacturing flexibility, strategic integration, organizational infrastructure, or business performance). Initial statistical analysis of frequencies and descriptive statistics revealed three sets of responses that were outliers. These were removed, resulting in a final dataset comprised of 206 sets of responses.

Response Rate

A total of 2500 questionnaire packets were mailed to middle and upper managers in U.S. manufacturing organizations. From those, 70 packets were returned as undeliverable and 23 people declined to participate. Of the completed questionnaires, 28 were either incomplete or unusable as the respondents did not represent the target population (see previous explanation). Although the overall response rate was below 10%, the 206 responses met the power analysis requirements.

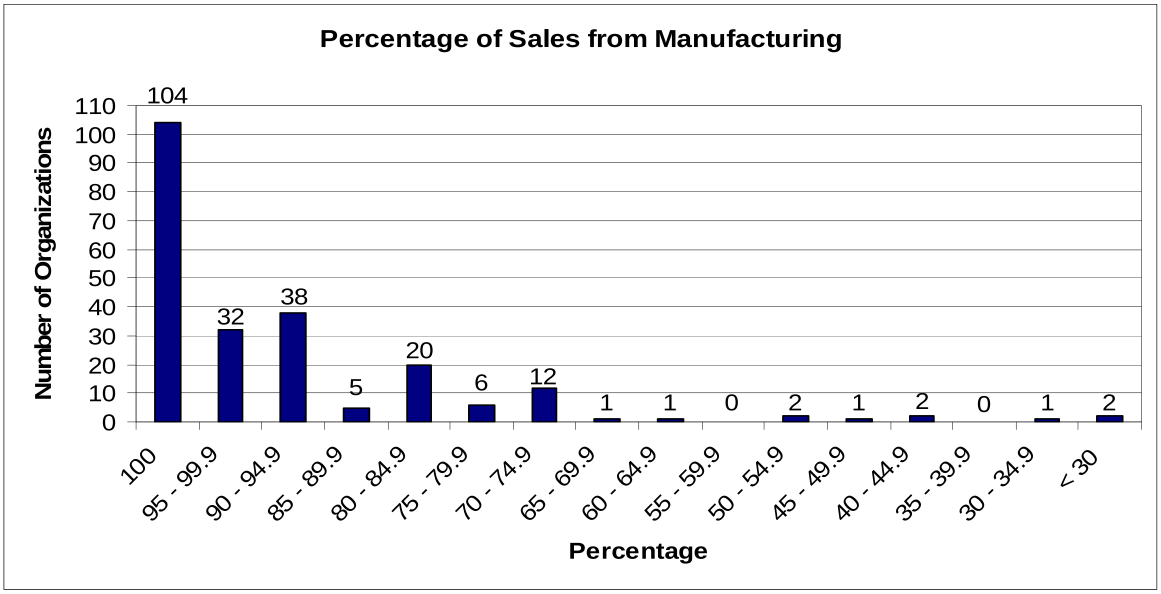


Figure 6 – Percentage of Sales from Manufacturing

Table 6 contains a summary of the response rate information. The sample is representative of both the target population (middle and upper managers in U.S. manufacturing organizations) and the accessible population (middle and upper managers in U.S. manufacturing organizations who are members of APICS) for this study. Further discussion of the response rate appears in chapter 5.

Table 6 – Summary of Full Study Response Rate

Contact by Category of Response	Group 1	Group 2
Initial Sample	1500	1000
Undeliverable / Bad Addresses	(19)	(51)
Declined to Participate	(17)	(6)
Incomplete/Unusable Responses	(20)	(8)
Effective Sample Size	1444	935
Complete/Usable Responses	144	62
Response Rate	144 / 1444 = 9.97%	62 / 935 = 6.63%
Combined Response Rate	206 / 2379 = 8.66%	

Power Analysis

To insure acceptable statistical power, two estimates were made to determine the necessary sample size. Based on power analysis, a medium effect size (0.15) required a sample size of 194. This sample size would achieve a statistical power of .99 with an alpha level of .05 for the largest model in the study, which includes all six manufacturing flexibility components as independent variables (Cohen, Cohen, West, & Aiken, 2003). The study sample (N = 206) meets the requirement for power of .99 for the largest model. Another estimate of sample size required the collection of at least 10 data points for each independent variable, including moderators (Hair et al., 1998). To provide a more conservative sample size estimate for this type of study, a minimum of 20 data points for each of the six manufacturing flexibility components and two moderating variables was calculated. This required a minimum sample size of 160 responses (8 x 20 = 160). The number of usable responses (N = 206) in the study sample also exceeds this estimate of required sample size.

Common Method Variance

Common method variance is more problematic for data gathered using a self-report methodology (Podsakoff & Organ, 1986). Two methods (one procedural and one post-hoc) were used to reduce and to test for common method variance. The procedural method involved formatting the questionnaire so the dependent variables' measurement items followed the items for the independent variables.

The post-hoc analysis used factor analysis (Harman's single-factor test) to assess the presence of common method variance in the data. Harman's single-factor test required entering the six independent variables into a factor analysis and analyzing the unrotated factor solution. If a substantial amount of common method variance was present, either a single factor emerges, or one factor accounts for the majority of total variance. The first four factors in the unrotated factor solution for the manufacturing flexibility components accounted for 22.675%, 7.287%, 6.194%, and 5.635% of the variance. More than one factor accounted for the majority of the variance in the unrotated factor solution. Therefore, common method variance does not appear to be present in the dataset.

Summary

This chapter focused on the research methodology for this study. A detailed discussion of the instrument development process described the reviews of the questionnaire by experts in both survey research methodology and manufacturing practices, the research variables and their measurement items, the sources for the items, and the instrument's reliability and validity. A discussion of the actual data collection followed which included a description of the target population, the sample selection process, survey administration procedures, non-response bias analysis, and the data review process. The final section discussed the actual sample selection, response rate, power analysis, and common method variance issues.

Full data analysis results of the data set are presented in chapter 4. Chapter 5 contains a discussion of the results, study limitations, and future research.

CHAPTER 4

ANALYSIS OF RESULTS

Sample

This chapter contains the analysis results used to test the hypotheses proposed for this study. Demographic data for the business units and respondents are discussed first. Following the demographic information, details of the factor analysis related to the instrument development are described. Lastly, the regression analyses used to test the study hypotheses are presented.

Characteristics

The sample consisted of 206 usable responses from business units that generate 70% or more of their annual sales from manufacturing. The first section below includes basic demographic information pertaining to the business unit. The second section contains a description of the study respondents.

Business Unit Demographics

The first eight questions on the questionnaire pertained to the business unit for which the respondent was responding. The majority of the data for these questions is contained in Table 7 and Table 8. Table 7 contains the frequency and percentage in the sample from each industry. A wide variety of industries were represented in the sample. This insures that no single industry had excessive influence on the data. The Metal Fabrication industry with 24 business units represents the largest percentage (11.7%) of the sample, followed closely by the Electronics industry with 21 business units (10.2%). Business units in the Transportation and Software/Hardware industries represent the smallest percentage of the sample both having 3 business units, each of which represents 1.5% of the sample. The "Other" category was selected by 67 respondents, which represents 32.5% of the sample. These industries specified in the "Other" category could not be classified into the 11 designated categories.

Table 7 – Business Unit – Industry

Survey Item	Categories	N	Percentage
Industry	Metal Fabrication	24	11.7 %
	Electronics	21	10.2 %
	Automotive	18	8.7 %
	Healthcare/Medical Devices	18	8.7 %
	Aviation/Aerospace	14	6.8 %
	Food/Beverages	10	4.9 %
	Plastics/Rubber	10	4.9 %
	Electrical	9	4.4 %
	Pharmaceuticals/Chemicals	9	4.4 %
	Transportation	3	1.5 %
	Software/Hardware	3	1.5 %
	Other (specify)	67	32.5 %

Table 8 contains information related to the size of the business unit. With regard to business unit size, 57 business units with 100 to 249 employees represented the highest individual category percentage (27.7%). Business units with 1000 or more employees (49, or 23.8%) comprised the second largest category, followed by business units with fewer than 100 employees (41, or 19.9%). Organizations with 500 to 999 employees occurred with the lowest frequency in the sample with 22 business units (10.7%). The majority of the business units in the sample (52.5%) had 250 or more employees.

Organizations earning more than $100 million in annual sales comprised the largest group (83, or 40.3%). The second highest frequency for annual sales was $20 million to $50 million (42, or 20.4%). Organizations with $5 million to $10 million in annual sales occurred with the lowest frequency (10, or 4.9%) in the sample. The majority of the business units in the sample earned more than $20 million in annual sales (77.2%). Seven respondents (3.4%) left this item blank, with several of them stating that the information was confidential.

Table 8 – Business Unit – Size

Survey Item	Categories	N	Percentage
Employees	Under 100	41	19.9 %
	100 – 249	57	27.7 %
	250 – 499	37	18.0 %
	500 – 999	22	10.7 %
	1000 or more	49	23.8 %
Annual Sales Dollars	Less than $5 million	12	5.8 %
	$5 million to < $10 million	10	4.9 %
	$10 million to < $20 million	18	8.7 %
	$20 million to < $50 million	42	20.4 %
	$50 million to < $100 million	34	16.5 %
	$100 million or more	83	40.3 %
	Confidential/Blank	7	3.4 %

Lastly, data related to unionization of the business unit was collected. Non-union business units (160) represented 77.7% of the sample. Unionized business units and business units that had a combination of both union and non-union employees occurred with similar frequencies of 26 (12.6%) and 20 (9.7%), respectively. Overall, the business units in the sample are diverse and represented a variety of U.S. manufacturing organizations.

Respondent Demographics

The first two personal questions for respondents related to the amount of time they have worked for the organization as well as their total business experience. This was important, because the survey required some in-depth knowledge of the firm regarding its business structure, manufacturing processes, and business unit performance. The average time of employment with the organization was approximately 11.9 years and an average of 26.3 years of business experience.

Table 9 contains the remaining respondent demographics. The largest group of respondents (110) held Bachelor's degrees, and the second largest group held graduate degrees (59, or 28.6%). Thus, the majority of the respondents (82%) held a Bachelor's degree or higher, as would be expected for those who have attained positions in middle or upper management. Respondents also categorized themselves with regard to their position within the business unit hierarchy. A majority of the respondents (142, or 68.9%) indicated that they are middle or top managers.

Respondents also identified the department in which they currently work. Sixty-two respondents (30.1%) indicated they were in the Inventory/Materials department, while those in Production departments comprised the next largest group with 39 respondents (18.9%). The final section of the table contains information pertaining to the respondent's current job title. Respondents who identified themselves as Inventory/Materials Managers comprised the largest group with 48 (23.3%), followed by 11 respondents (5.3%) who were either a VP of Manufacturing or Chief Operating Officer (COO). The smallest category was Engineers with only three respondents.

Summary

Based on the above, the sample was considered representative of both the target population and accessible study population of middle and upper managers in U.S. manufacturing organizations of varying size, representing multiple industries.

Table 9 – Respondent Demographics

Survey Items	Categories	N	Percentage
Education Level	Graduate degree	59	28.6 %
	Bachelor’s degree	110	53.4 %
	Associate’s degree	17	8.3 %
	Some college	13	6.3 %
	Other	7	3.4 %
Management Level	Top Management	46	22.3 %
	Middle Management	96	46.6 %
	Production Management	26	12.6 %
	Support	30	14.6 %
	Other	8	3.9 %
Department	Inventory/Materials	62	30.1 %
	Production	39	18.9 %
	Purchasing	23	11.2 %
	Quality	4	1.9 %
	Engineering	3	1.5 %
	Other	75	36.4 %
Job Title	Inventory/Materials Manager	48	23.3 %
	VP Manufacturing/COO	11	5.3 %
	Manufacturing Manager	10	4.9 %
	Purchasing Manager	10	4.9 %
	Plant Manager	9	4.4 %
	CEO/President	6	2.9 %
	Production Supervisor	5	2.4 %
	Engineer	3	1.5 %
	Other	104	50.59 %

Factor Analysis

Data related to the manufacturing flexibility components, strategic integration, organizational infrastructure, and changes in performance were analyzed using principal components factor analysis with varimax rotation. The constructs are discussed specifically as to the factor analysis and the final determination of factors. The overall process that was used for each scale analysis is explained next, with specific results for each scale in the following sections.

The determination of factors and items to retain was a multi-step process (Figure 7). The first step was analyzing the individual scales for reliability. Reliability for each scale was assessed using two methodologies. First, Cronbach's Alpha for each scale was calculated as a measure of internal consistency. Generally, an alpha value of .70 is considered acceptable (Nunnally & Berstein, 1994) and was used for this study. Second, the corrected item to total correlation (CITC) was evaluated (Kerlinger & Lee, 2000). The recommended CITC for each item was .40 or higher. These values are reported for each scale individually. An item was deleted if its omission increased the scales alpha value, except in the case of items from previously validated scales. Those items were retained for further scrutiny during factor analysis.

Once the initial scale reliability was determined and poorly correlated items deleted, the second step was to determine the number of factors to retain for each scale. Three methods were used during this process. Principal components factor analysis yielded eigenvalues for each factor, which were plotted on a scree plot. Factors with eigenvalues greater than 1.0 were reviewed first. Next, the scree plot was interpreted to determine if all factors with eigenvalues greater than 1.0 should be retained, and if any factors with eigenvalues less than 1.0 should be considered. Finally, parallel analysis was conducted and the results were compared to those of the first two procedures (Hayton, Allen, & Scarpello, 2004; Horn, 1965; Sharma, 1996). Parallel analysis was employed to correct for the tendency of both the eigenvalue and scree plot procedures to overestimate the number of factors as the number of variables in the analysis increases. The scree test can result in one to three more factors than the eigenvalue procedure (Hair et al., 1998). Parallel analysis (PA) was accomplished using a Monte Carlo simulation to create a dataset comparable in size and scope to the study dataset. The simulation also calculated eigenvalues for the simulated dataset, which were compared to the eigenvalues for the study dataset. As long as the actual eigenvalues were larger than the simulated eigenvalues, then factors continued to be included. Simulated eigenvalues that equaled or exceeded the actual eigenvalues indicated that the relationships in the simulated data were as strong as or stronger than those in the study data. At this point, factors were no longer retained.

Once the number of factors was determined for a group of variables, the individual items were then considered. Factor analysis was used with the number of factors specified. Only those items with factor loadings of .40 or higher were retained. Additionally, items cross-loading onto more than one factor were analyzed for deletion. Literature on factor analysis suggests that a loading as low as .30 could be used; however, for this study a minimum loading of .40 was used for better scale reliability. All of the retained items across the scales loaded at .50 or higher.

The scales were analyzed for convergent and discriminant validity. Convergent validity was assessed by examining: the factors having eigenvalues greater than 1.0; the percent of variance explained; and the factor loadings for each item on a construct. Discriminant validity was assessed by calculating the difference between Cronbach's Alpha and the average interscale correlation (AVISC). This study required a minimum AVISC between .30 and .40, as suggested in previous research (Ahire & Devaraj, 2001).

Each survey item was assigned a code consisting of three parts. The first part consisted of a three letter code representing the variable or sub-dimension, followed by a number indicating the survey section in which the item appeared. Lastly, the letter that identified a specific survey item was added. For example, the first item representing product-mix is coded PMX11A. The data analysis codes for the survey sections and items are in Table 10.

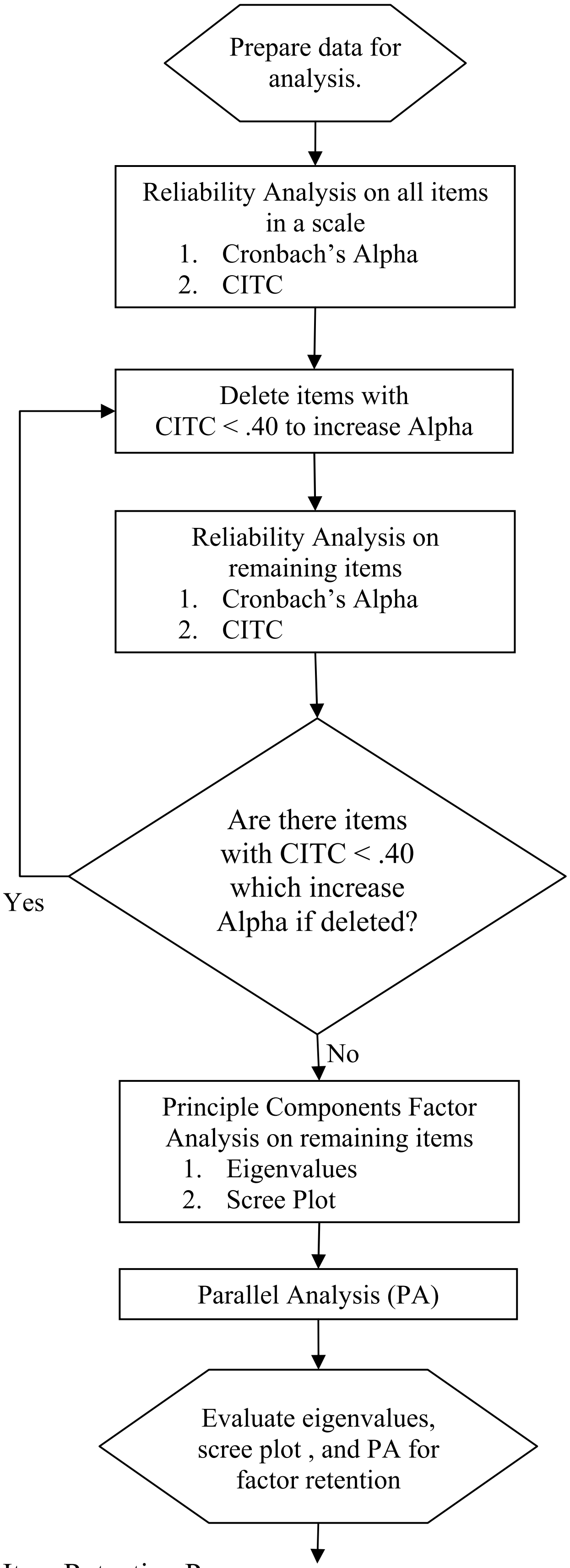


Figure 7 – Factor and Item Retention Process

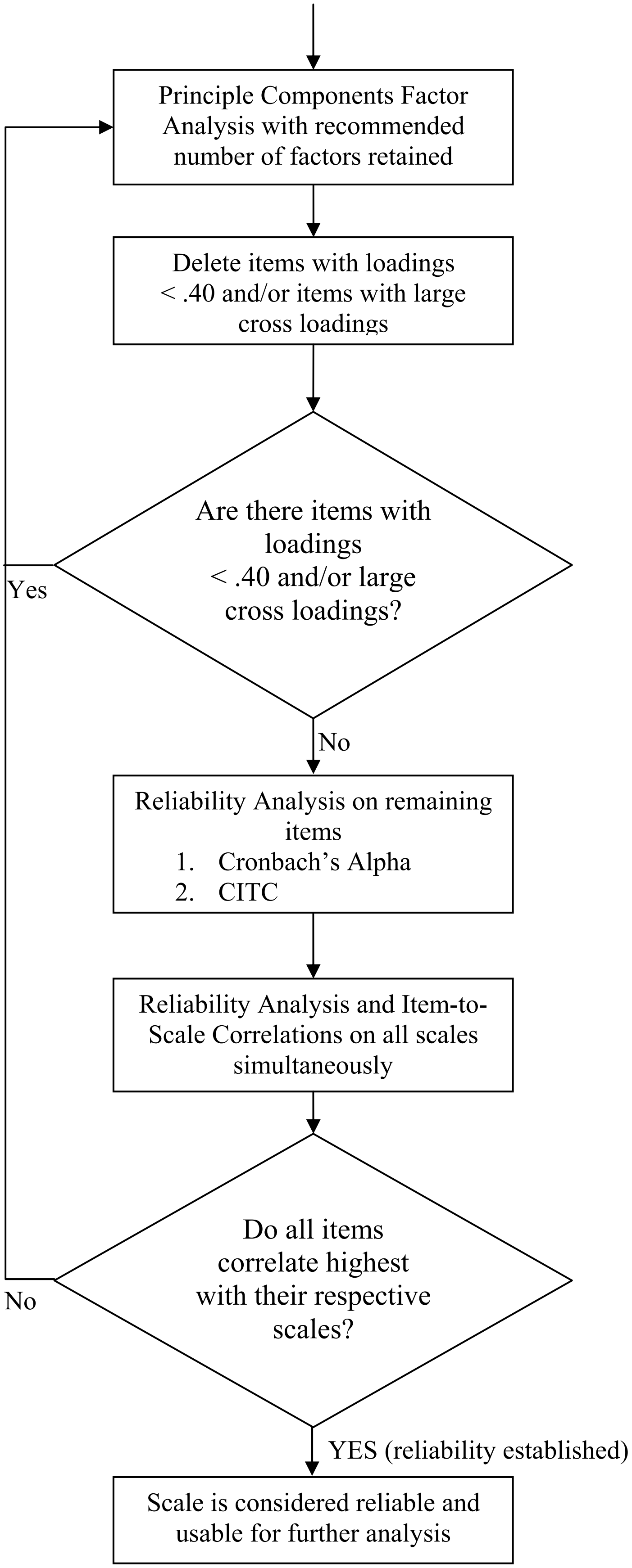


Figure 7 – Factor and Item Retention Process (continued)

Table 10 – Data Analysis Survey Item Codes

Variable / Sub-dimension	Code	Survey Section	Items
Strategic Integration	STR	9	A through I
Organizational Infrastructure	INF	10	A through Y
Product-Mix Flexibility	PMX	11	A through K
Routing Flexibility	RTG	11	A through G
Equipment Flexibility	EQP	11	A through G
Volume Flexibility	VOL	11	A through H
Labor Flexibility	LBR	11	A through G
Supply Management Flexibility	SPM	11	A through J
Organizational Performance	PER	15	A through L

Independent Variables – Manufacturing Flexibility Components

The initial step of scale analysis (Alpha and CITC analysis) resulted in the following changes. The product-mix flexibility component consisted of 11 items. Six items (PMX11F to PMX11K) were removed from the scale and the alpha value increased from .710 to .715. The routing flexibility component consisted of seven items. Two items (RTG11F, RTG11G) were removed from the scale and the alpha value increased from .818 to .851. The equipment flexibility component consisted of seven items. One item (EQP11C) was removed from the scale and the alpha value increased from .696 to .741. The volume flexibility component consisted of eight items. Two items (VOL11G, VOL11H) were removed from the scale and the alpha value increased from .728 to .787. The labor flexibility component consisted of seven items. No items were removed from the scale, resulting in an alpha value of .825. The supply management flexibility component consisted of ten items. No items were removed from the scale, resulting in an alpha value of .845. This reduced the number of items representing the manufacturing flexibility components from 50 to 39.

After initial item deletions for each scale, based on Cronbach's Alpha and CITC values, 39 items representing the manufacturing flexibility components remained. Principal components factor analysis was used to analyze the structure of patterns in the data. Twelve potential factors with eigenvalues greater than 1.0 emerged several of which only had one or two items load. Analysis of the scree plot indicated, however, there was a two, six or eight factor solution. The PA for the manufacturing flexibility components (N = 206) indicated a six factor solution (Table 11).

Table 11 – Parallel Analysis for Manufacturing Flexibility (39 items)

Factor	Study Eigenvalues	Simulated Eigenvalues
1	9.259	1.9467
2	3.115	1.8298
3	2.413	1.7428
4	2.336	1.6656
5	1.897	1.6004
6	1.606	1.5396
7	1.395	1.4835

The six factor solution with varimax rotation of these 39 items resulted in factor loadings that could not be interpreted. The most problematic items were on the equipment scale. Only two of the equipment items loaded together on a factor with one item from the labor flexibility scale. One equipment item did not load onto any factor and the remaining equipment items loaded onto other scales. In addition, some items from other scales were loading in uncharacteristic ways. It was determined the equipment items should be removed to see if the factor loadings improved. PA for this new dataset (N = 206) suggested that a five factor solution was appropriate (Table 12).

The elimination of the six equipment flexibility items resulted in a five factor solution with varimax rotation with cleaner loadings and improved interpretability. The items generally

Table 12 – Parallel Analysis for Manufacturing Flexibility (33 items)

Factor	Study Eigenvalues	Simulated Eigenvalues
1	8.191	1.8416
2	2.807	1.7248
3	2.274	1.6364
4	2.161	1.5653
5	1.647	1.5020
6	1.431	1.4433

loaded as expected. Items with a factor loading below .50 were analyzed for removal as well as items that cross-loaded onto multiple factors. Items were deleted as follows. VOL11B had the weakest factor loading at .450 and cross loaded onto another factor. VOL11A had the second weakest loading (dropped from .462 to .417 after VOL11B was removed) as well as a cross-loading of .407. SPM11H had a factor loading of .486 and was removed. Although SPM11B had a factor loading of .632, it had a statistically significant cross-loading making it the final item removed. This resulted in 29 items remaining after this stage. The items and their factor loadings are contained in Table 13. One item (PMX11E) was retained from Zhang et al.'s (2003) original scale, even though it continued to cross-load, because its removal would decrease the alpha value for the product-mix flexibility scale from .715 to .651. Overall, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .838, which is considered excellent for this statistic. The results of Bartlett's test of sphericity are significant, indicating the presence of significant correlations between at least two of the items in the analysis (Hair et al., 1998). This is as expected, since all five manufacturing flexibility component scales were analyzed simultaneously and were expected to be related from a systems perspective.

These five factors represent the components of manufacturing flexibility (Table 13). Component 1 is supply management flexibility, with factor loadings ranging from .710 to .570 and an alpha value of .822. Component 2 is labor flexibility, which has factor loadings ranging

Table 13 – Manufacturing Flexibility Rotated Component Matrix (29 items)

	Survey Item	Component				
		1	2	3	4	5
Supply Management Flexibility (SPM)	SPM11J	.710				
	SPM11I	.666				
	SPM11F	.663				
	SPM11E	.650				
	SPM11D	.632				
	SPM11A	.609				
	SPM11C	.580				
	SPM11G	.570				
Labor Flexibility (LBR)	LBR11E		.790			
	LBR11C		.704			
	LBR11B		.681			
	LBR11F		.665			
	LBR11A		.651			
	LBR11G		.579			
	LBR11D		.509			
Routing Flexibility (RTG)	RTG11B			.835		
	RTG11A			.806		
	RTG11D			.751		
	RTG11C			.729		
	RTG11E			.688		
Volume Flexibility (VOL)	VOL11D				.776	
	VOL11E				.731	
	VOL11F				.703	
	VOL11C				.581	
Product-Mix Flexibility (PMX)	PMX11C					.781
	PMX11A					.700
	PMX11D					.652
	PMX11E					.548
	PMX11B					.511
Alpha Values		.822	.825	.851	.777	.715

from .790 to .509 and an alpha value of .825. Component 3 is routing flexibility, which has factor loadings ranging from .835 to .688 and an alpha value of .851. Component 4 is volume flexibility, which has factor loadings ranging from .776 to .581 and an alpha value of .777.

Component 5 is product-mix flexibility, which has factor loadings ranging from .781 to .511 and an alpha value of .715.

The reliability for each scale was analyzed a final time to insure that the best possible scale was used for further analysis. Cronbach's Alpha for each manufacturing flexibility component was .70 or higher. Additionally, internal consistency of each scale was analyzed individually with factor analysis to insure only one factor was extracted.

Product-Mix Flexibility Scale. The alpha value for the product-mix flexibility scale was above the acceptable cutoff of .70 and deleting any items would decrease alpha (Table 14 and Table 15). The five items loaded onto a single factor with an eigenvalue of 2.344 and a minimum loading of .511.

Table 14 – Product-Mix Flexibility Scale

	Survey Item	Alpha	Orig Alpha
PMX11A	We produce a wide variety of products in our plant(s).	.715	.920
PMX11B	We produce different product types without major changeovers.		
PMX11C	We build different products in the same plant at the same time.		
PMX11D	We vary the product mix from one period to the next.		
PMX11E	We easily change from one product to another.		

Table 15 – Product-Mix Flexibility Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
PMX11A	14.800	9.689	.494	.279	.648
PMX11B	15.103	10.976	.379	.232	.693
PMX11C	14.337	10.053	.529	.296	.637
PMX11D	15.256	9.086	.444	.242	.678
PMX11E	14.946	10.174	.509	.302	.645

<u>Routing Flexibility Scale.</u> The alpha value for the routing flexibility scale was well above the acceptable cutoff of .70 and deleting any items would decrease alpha (Table 16 and Table 17). The five items loaded onto a single factor with an eigenvalue of 3.138 and a minimum loading of .688.

Table 16 – Routing Flexibility Scale

	Survey Item	Alpha	Orig Alpha
RTG11A	A typical part can be routed to alternate machines.	.851	.920
RTG11B	A typical part can use many different routes.		
RTG11C	The system has alternative routes in case machines break down.		
RTG11D	The sequence for parts flow can be changed.		
RTG11E	The processing sequence can be changed quickly.		

Table 17 – Routing Flexibility Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
RTG11A	10.726	13.877	.685	.580	.813
RTG11B	11.120	13.775	.746	.614	.797
RTG11C	10.984	13.925	.630	.457	.828
RTG11D	11.083	14.313	.655	.573	.821
RTG11E	11.139	14.815	.591	.534	.837

Table 18 – Volume Flexibility Scale

	Survey Item	Alpha	Orig Alpha
VOL11C	We economically run various batch sizes.	.777	.900
VOL11D	We quickly change the quantities of our products produced.		
VOL11E	We vary total output from one period to the next.		
VOL11F	We easily change the output volume of a manufacturing process.		

<u>Volume Flexibility Scale.</u> The alpha value for the volume flexibility scale was above the acceptable cutoff of .70 and deleting any items would decrease alpha (Table 18 and Table 19).

The four items loaded onto a single factor with an eigenvalue of 2.411 and a minimum loading of .581. VOL11C was retained because it was part of the original scale and its deletion would not raise the alpha value significantly.

Table 19 – Volume Flexibility Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
VOL11C	10.500	6.280	.442	.266	.791
VOL11D	10.238	5.772	.668	.455	.672
VOL11E	10.117	5.996	.586	.454	.713
VOL11F	10.505	5.734	.624	.430	.693

Labor Flexibility Scale. The alpha value for the labor flexibility scale was well above the acceptable cutoff of .70 and deleting any items would decrease alpha (Table 20 and Table 21). The seven items loaded onto a single factor with an eigenvalue of 3.467 and a minimum loading of .509.

Table 20 – Labor Flexibility Scale

	Survey Item	Alpha	Orig Alpha
LBR11A	A typical worker uses different tools effectively.	.825	.910 (A, C, E, F, G)
LBR11B	Employees are cross-trained to perform a variety of activities.		
LBR11C	Workers operate various types of machines.		
LBR11D	Our employees have strong problem-solving abilities.		
LBR11E	Workers are cross-trained in multiple cells/teams.		
LBR11F	Workers are cross-trained in diverse departments in a plant.		
LBR11G	Teams are reorganized in response to product or process changes.		

Table 21 – Labor Flexibility Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
LBR11A	19.401	17.474	.471	.289	.817
LBR11B	19.277	15.817	.641	.469	.791
LBR11C	19.469	15.872	.623	.437	.794
LBR11D	19.802	17.338	.432	.194	.823
LBR11E	19.753	14.052	.740	.562	.770
LBR11F	20.268	15.385	.606	.409	.796
LBR11G	20.035	15.880	.491	.325	.818

<u>Supply Management Flexibility Scale.</u> The alpha value for the supply management flexibility scale was above the acceptable cutoff of .70 and deleting any items would decrease alpha (Table 22 and Table 23). The eight items loaded onto a single factor with an eigenvalue of 3.576 and a minimum loading of .570.

Table 22 – Supply Management Flexibility Scale

	Survey Item	Alpha	Orig Alpha
SPM11A	Our suppliers make frequent deliveries.	.822	N/A
SPM11C	Suppliers adjust quantities without significantly increasing leadtime.		
SPM11D	We provide technical assistance to our suppliers.		
SPM11E	Suppliers modify products to meet our needs.		
SPM11F	Our suppliers assist in product design and innovation.		
SPM11G	We establish long-term relationships with suppliers.		
SPM11I	Our suppliers adjust delivery times to meet changing requirements.		
SPM11J	Suppliers assist with reducing our overall customer leadtime.		

In addition to the factor analysis and the reliability analysis, item-to-scale correlations were calculated to confirm whether items were correctly loaded onto the factor. Table 24 contains the results. Every item had the highest correlation to the flexibility component scale it was intended to measure and lower correlations with the other five scales. This indicates that each item correctly loaded to its intended factor. The highlighted values indicate the highest item-to-scale correlation for each row in the table. The correlations were significant for almost every correlation. This was as expected, since the five individual flexibility scales should be somewhat correlated. Additionally, significant correlations would also be expected in the presence of a synergistic effect resulting from the implementation of multiple manufacturing flexibility components in a manufacturing system.

Table 23 – Supply Management Flexibility Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
SPM11A	23.785	19.597	.523	.344	.801
SPM11C	23.989	19.946	.505	.336	.803
SPM11D	24.062	18.070	.574	.384	.794
SPM11E	24.180	18.732	.498	.357	.805
SPM11F	24.674	18.665	.511	.320	.803
SPM11G	23.591	19.719	.525	.304	.801
SPM11I	23.877	19.526	.565	.417	.796
SPM11J	24.264	18.011	.631	.427	.785

Table 24 – Item-to-Scale Correlations for Manufacturing Flexibility Components

	Survey Item	Scale				
		PMX	RTG	VOL	LBR	SPM
Product-Mix Flexibility (PMX)	PMX11A	.705**	.295**	.263**	.148*	.154*
	PMX11B	.595**	.118	.233**	.209**	.166*
	PMX11C	.709**	.157*	.076	.218**	.223**
	PMX11D	.706**	.014	.267**	.153*	.065
	PMX11E	.694**	.226**	.463**	.302**	.132
Routing Flexibility (RTG)	RTG11A	.285**	.809**	.304**	.202**	.194**
	RTG11B	.217**	.844**	.290**	.225**	.158*
	RTG11C	.213**	.778**	.333**	.310**	.229**
	RTG11D	.092	.785**	.221**	.296**	.214**
	RTG11E	.092	.740**	.267**	.302**	.145*
Volume Flexibility (VOL)	VOL11C	.246**	.333**	.697**	.333**	.248**
	VOL11D	.352**	.290**	.821**	.231**	.334**
	VOL11E	.281**	.156*	.774**	.193**	.248**
	VOL11F	.303**	.324**	.802**	.412**	.376**
Labor Flexibility (LBR)	LBR11A	.244**	.183**	.115	.597**	.171*
	LBR11B	.302**	.225**	.368**	.748**	.438**
	LBR11C	.197**	.278**	.334**	.735**	.317**
	LBR11D	.154*	.274**	.206**	.577**	.289**
	LBR11E	.162*	.284**	.310**	.836**	.394**
	LBR11F	.206**	.291**	.258**	.734**	.325**
	LBR11G	.199**	.129	.257**	.655**	.298**
Supply Management Flexibility (SPM)	SPM11A	.171*	.142*	.325**	.288**	.642**
	SPM11C	.140*	.162*	.334**	.272**	.622**
	SPM11D	.149*	.185**	.284**	.410**	.707**
	SPM11E	.044	.053	.180**	.229**	.647**
	SPM11F	.117	.098	.173*	.234**	.656**
	SPM11G	.160*	.284**	.252**	.396**	.641**
	SPM11I	.169*	.169*	.274**	.285**	.672**
	SPM11J	.189**	.210**	.290**	.344**	.743**

Highlighted values indicate the highest item-to-scale correlation for each row

* Correlation is significant at the .05 level (2-tailed)

** Correlation is significant at the .01 level (2-tailed)

Moderating Variable – Strategic Integration

For strategic integration, a single factor emerged with an eigenvalue of 4.533 with all items loading on this factor (.828 to .644). All nine items were retained, as further analysis revealed that dropping items would reduce scale reliability (Table 25 and Table 26). The scale was modified from Swink et al. (2005) which had an alpha of .85 for six items. The new scale has an alpha of .875; thus, the three new items (E, F, H) slightly increased scale reliability.

Table 25 – Strategic Integration Scale

	Survey Item	Alpha	Orig Alpha
STR9A	Manufacturing strategy supports corporate strategy.	.875	.850 (A, B, C, D, G, I)
STR9B	We clearly define manufacturing strategies, goals, and objectives.		
STR9C	Our corporate strategy leverages existing capabilities.		
STR9D	Manufacturing strategy complements other functional strategies.		
STR9E	Manufacturing is involved in corporate strategy formulation.		
STR9F	Manufacturing strategy is frequently reviewed and revised.		
STR9G	Flexibility is a central element of manufacturing strategy.		
STR9H	Our manufacturing strategy makes the most of existing capabilities.		
STR9I	Manufacturing strategies and goals are clearly communicated to employees.		

Table 26 – Strategic Integration Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
STR9A	29.785	26.033	.550	.424	.864
STR9B	29.995	23.439	.751	.609	.846
STR9C	30.111	25.525	.604	.422	.860
STR9D	30.130	25.463	.617	.397	.859
STR9E	30.188	24.119	.559	.372	.866
STR9F	30.242	23.871	.661	.468	.854
STR9G	30.127	24.628	.547	.312	.866
STR9H	30.014	25.948	.581	.381	.862
STR9I	30.354	23.543	.666	.514	.854

Moderating Variable – Organizational Infrastructure

Three sub-constructs of organizational infrastructure (Management Support, Information Management, Organizational Attributes) were proposed in the theoretical development of the research model. The analysis process as outlined above for the manufacturing flexibility components was modified slightly for this variable. During an initial factor analysis, four factors emerged with eigenvalues greater than 1.0. Analysis of the scree plot indicated a two or three factor solution. Parallel analysis for organizational infrastructure (N = 206) indicated a two factor solution (Table 27).

Table 27 – Parallel Analysis for Organizational Infrastructure (25 items)

Factor	Study Eigenvalues	Simulated Eigenvalues
1	10.972	1.7042
2	2.041	1.5873
3	1.172	1.5002

Since the number of factors was changed from the proposed factors, the next step was to determine which items would load onto each factor before reliability was analyzed. The twenty-five items were analyzed with factor analysis. The items were divided according to their highest loading even if an item cross-loaded, as this was an initial solution.

The two scales were analyzed for initial reliability (Cronbach's Alpha and CITC). For Factor 1, there were no items with a CITC less than .50. With an alpha of .921, removing any items would reduce alpha. For Factor 2, however, several items were removed from the scale. INF10Y was the first item removed as it had a CITC of .411, which increased alpha from .908 to .910. INF10U was the next item removed as it had a CITC of .433. Its removal increased alpha for the scale from .910 to .912.

The revised scales were then subjected to principle components factor analysis to determine the factor loadings and whether additional items were candidates for deletion. All items loaded high on one of the factors, although four items cross-loaded. From Factor 1, INF10I was the first item removed as it had the lowest loading (.507) for that factor and a significant cross-loading (.454). INF10R was removed next from Factor 1, as it had the lowest loading (.520) and a significant cross-loading (.488). INF10W was the third item removed from Factor 1, as it had the lowest loading (.629) and a significant cross-loading (.409). From Factor 2, INF10K was removed next, as it had the lowest loading (.665) with a significant cross-loading (.415). After this process, factor analysis with varimax rotation was used to determine the final items for each factor. Factor 1 retained ten items while Factor 2 retained nine items (Table 28).

Table 28 – Infrastructure Rotated Factor Matrix (19 items)

Survey Item	Factor	
	1	2
INF10C	.734	
INF10B	.725	
INF10A	.702	
INF10J	.701	
INF10G	.697	
INF10O	.691	
INF10Q	.667	
INF10N	.631	
INF10S	.629	
INF10M	.596	
INF10L		.831
INF10H		.816
INF10E		.737
INF10V		.736
INF10T		.699
INF10F		.650
INF10P		.618
INF10X		.601
INF10D		.592
Alpha Values	.901	.902

Infrastructure Factor 1 included the following items: INF10A, INF10B, INF10C, INF10G, INF10J, INF10M, INF10N, INF10O, INF10Q, and INF10S (Table 29 and Table 30) with an alpha value of .901. Infrastructure Factor 2 included the following items: INF10D, INF10E, INF10F, INF10H, INF10L, INF10P, INF10T, INF10V, and INF10X (Table 31 and Table 32) with an alpha value of .902. The Cronbach's Alpha values exceed the acceptable cutoff of .60 for new scales. These values were not compared to existing scales, as the items were taken from multiple sources, and they did not load with respect to the three proposed sub-dimensions.

Table 29 – Organizational Infrastructure – Management Coordination Scale

	Survey Item	Alpha	Orig Alpha
INF10A	Cross-functional teams have regular meetings.	.901	N/A
INF10B	Managers focus on continuous process improvement (kaizen).		
INF10C	Resources, ideas and information are shared among functions.		
INF10G	Management emphasizes change and pursuing "best practice."		
INF10J	Managers provide personal guidance for improving flexibility.		
INF10M	Planning for product changes involves a cross-functional team.		
INF10N	Management emphasizes information sharing.		
INF10O	Employees are rewarded for learning new skills.		
INF10Q	Management is evaluated on improving flexibility.		
INF10S	Management is responsible for improving flexibility.		

Table 30 – Organizational Infrastructure – Management Coordination Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
INF10C	30.947	42.001	.722	.592	.884
INF10B	30.945	40.689	.654	.585	.888
INF10J	31.076	41.373	.731	.566	.883
INF10O	31.421	42.087	.628	.477	.890
INF10G	30.789	41.173	.707	.566	.884
INF10A	30.877	41.254	.599	.467	.892
INF10Q	31.293	41.324	.634	.486	.889
INF10N	30.702	42.778	.652	.498	.888
INF10S	30.702	42.952	.607	.451	.891
INF10M	30.682	42.111	.572	.471	.894

After analyzing the items that comprise Infrastructure Factor 1, it was decided that the label of Management Coordination (MGTCOOR) was appropriate. The items were split between the original sub-dimensions of management support and organizational attributes. The retained items emphasize management's role and those attributes related to coordinating organizational activities. For Infrastructure Factor 2, the label Information Management (INFOMGT) was selected. All of the items, but one (INF10E), were from the original proposed sub-dimension of Information Management. These sub-dimensions are referred to using these new labels for the remainder of the discussion.

Table 31 – Organizational Infrastructure – Information Management Scale

	Survey Item	Alpha	Orig Alpha
INF10D	Our information system makes pertinent information available.	.902	N/A
INF10E	We work as a team with our supply chain members.		
INF10F	Managers have full access to information on supply chain needs.		
INF10H	Information exchange between our suppliers and us is timely.		
INF10L	Information exchange between our suppliers and us is complete.		
INF10P	Our supply chain is informed about changes that may affect them.		
INF10T	Information exchange between our suppliers and us is accurate.		
INF10V	Our supply chain has effective communication processes.		
INF10X	Our information systems increase our manufacturing flexibility.		

Table 32 – Organizational Infrastructure – Information Management Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
INF10L	27.571	25.588	.745	.618	.882
INF10H	27.293	26.277	.717	.567	.885
INF10E	27.220	25.758	.720	.570	.884
INF10V	27.444	26.556	.707	.538	.886
INF10T	27.254	27.049	.639	.488	.890
INF10F	27.288	25.863	.625	.445	.892
INF10X	27.632	25.528	.621	.501	.893
INF10P	27.354	26.453	.634	.453	.890
INF10D	27.366	25.959	.624	.480	.891

In addition to factor analysis and reliability analysis, item-to-scale correlations were calculated to confirm whether items loaded correctly onto the factor. Table 33 contains the results for the three moderating variables. Every item had the highest correlation to the moderator scale it was intended to measure and lower correlations with the other two scales. This indicates that each item correctly loaded to its intended factor. The highlighted values indicate

Table 33 – Item-to-Scale Correlations for Moderating Variables

	Survey Item	Scale		
		STR	MGTCOOR	INFOMGT
Strategic Integration (STR)	STR9A	.641**	.419**	.417**
	STR9B	.817**	.643**	.462**
	STR9C	.688**	.431**	.473**
	STR9D	.699**	.440**	.408**
	STR9E	.679**	.429**	.346**
	STR9F	.751**	.541**	.321**
	STR9G	.663**	.487**	.398**
	STR9H	.665**	.499**	.533**
	STR9I	.758**	.668**	.478**
Management Coordination (MGTCOOR)	INF10A	.456**	.693**	.339**
	INF10B	.533**	.737**	.428**
	INF10C	.535**	.778**	.524**
	INF10G	.555**	.772**	.564**
	INF10J	.605**	.789**	.599**
	INF10M	.445**	.667**	.467**
	INF10N	.499**	.719**	.553**
	INF10O	.557**	.707**	.431**
	INF10Q	.568**	.718**	.463**
	INF10S	.478**	.684**	.446**
Information Management (INFOMGT)	INF10D	.457**	.513**	.717**
	INF10E	.545**	.529**	.787**
	INF10F	.447**	.457**	.719**
	INF10H	.404**	.414**	.780**
	INF10L	.385**	.448**	.807**
	INF10P	.446**	.560**	.718**
	INF10T	.398**	.473**	.714**
	INF10V	.457**	.520**	.770**
	INF10X	.452**	.503**	.721**

Highlighted values indicate the highest item-to-scale correlation for each row
** Correlation is significant at the .01 level (2-tailed)

the highest item-to-scale correlation for each row in the table. Every correlation was significant at the .01 level. This was as expected since the individual moderating variable scales should be somewhat correlated. It was expected that organizational structure could influence the organization's strategic integration and vice versa. Additionally, significant correlations would be expected in the presence of a synergistic effect resulting from the strategic implementation of multiple manufacturing flexibility components and an infrastructure that enables manufacturing flexibility. Table 34 contains a summary of the scales and the changes for the five independent variables and the moderating variables.

Table 34 – Summary of Items Omitted from Scales

Variable	Original Number of Items	Number of Items Deleted	Final Number of Items
Product-Mix Flexibility	11	6	5
Routing Flexibility	7	2	5
Equipment Flexibility	7	7	0
Volume Flexibility	8	4	4
Labor Flexibility	7	0	7
Supply Management Flexibility	10	2	8
Strategic Integration	9	0	9
Management Coordination	25	6	10
Information Management			9
Total	84	27	57

Dependent Variable – Organizational Performance

The items representing changes in organizational performance were not intended to be combined into a single factor. It was assumed that the performance measures would be correlated yet separate, depending on the area they represented (i.e. production, time, inventory, etc.) but would not necessarily form factors. Table 35 contains the results of the correlation analysis used to analyze the relationships among these performance measures. This analysis was used to establish reliability and validity. Three items (PER15D, PER15I, PER15L) were reverse coded as they had negative correlations to every other performance item but positive correlations with each other.

Table 35 – Organizational Performance Scale Inter-Item Correlations

	Performance Scale										
	15A	15B	15C	15D RC	15E	15F	15G	15H	15I RC	15J	15K
PER15A											
PER15B	.557**										
PER15C	.320**	.425**									
PER15DRC	.165*	.102	.158*								
PER15E	.242**	.230**	.365**	.061							
PER15F	.332**	.350**	.424**	.177*	.695**						
PER15G	.268**	.237**	.325**	.228**	.547**	.571**					
PER15H	.268**	.320**	.235**	.196**	.243**	.337**	.252**				
PER15IRC	.029	.134	.163*	.327**	.109	.231**	.204**	.285**			
PER15J	.323**	.287**	.471**	.361**	.293**	.351**	.266**	.293**	.145*		
PER15K	.195**	.195**	.144*	.158*	.125	.133	.024	.142*	.069	.403**	
PER15LRC	.249**	.141*	.293**	.314**	.085	.175*	.142*	.044	.159*	.175*	.051

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Due to the number of significant correlations, reliability analysis was used to determine if the items related to organizational performance formed a single factor. Reliability of the scale was evaluated based on Cronbach's Alpha as well as CITC. The alpha value for these items was .798 which was well above the cutoff value of .60 for new scales. This implied that the scale items measured related concepts (Table 36).

An analysis of the CITC values (Table 37) indicated that several item values were below the standard cutoff of .40 and should be deleted if the items were considered a factor. Since the scale was not intended to be a factor, further analysis appears in the additional analysis section of this chapter.

Table 36 – Organizational Performance Scale

	Survey Item	Alpha	Orig Alpha
PER15A	Setup times	.798	N/A
PER15B	Throughput time (from order release to completion)		
PER15C	Scrap and rework cost		
PER15DRC	Worker productivity		
PER15E	Raw materials (RM) inventory levels		
PER15F	Work-in-Process (WIP) inventory levels		
PER15G	Finished Goods (FG) inventory levels		
PER15H	Number of backorders		
PER15IRC	On-time delivery		
PER15J	Unit manufacturing costs (excluding purch. materials)		
PER15K	Cost of purchased materials		
PER15LRC	Machine utilization		

Table 37 – Organizational Performance Scale Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
PER15A	48.050	72.729	.475	.392	.781
PER15B	47.940	71.462	.484	.414	.779
PER15C	47.689	72.031	.541	.401	.775
PER15DRC	47.529	75.834	.347	.289	.792
PER15E	47.234	70.865	.504	.539	.777
PER15F	47.406	66.849	.644	.592	.762
PER15G	47.190	70.201	.516	.410	.776
PER15H	47.430	72.251	.429	.233	.785
PER15IRC	47.617	75.447	.296	.201	.799
PER15J	47.251	74.535	.544	.429	.777
PER15K	46.695	79.155	.247	.192	.800
PER15LRC	47.473	78.877	.285	.200	.796

Descriptive Statistics for Variables

Once the reliability of each scale was analyzed and items deleted, the resulting scales were analyzed for a basic understanding of the structure of each scale. Table 38 contains the means and standard deviations for the manufacturing flexibility component scales, the strategic integration scale, the organizational infrastructure scales, and the performance items. Manufacturing flexibility, strategic integration, and organizational infrastructure were measured on a 5-point Likert scale where a 1 indicated that the statement “Never” applied to the business unit and a 5 indicated that the statement “Always” applied to the business unit. For business unit performance, a 9-point Likert scale was used. This scale measured changes in performance where a 1 indicated that the performance had decreased more than 50%, a 5 indicated there was no change, and a 9 indicated that the performance measure had increased more than 50%.

Among the manufacturing flexibility components the highest mean was 3.7221 for product-mix flexibility with a standard deviation of .7631, indicating that on average organizations were using product-mix flexibility more than half the time. The lowest mean was 2.7526 for routing flexibility with a standard deviation of .9230, which indicated that on average organizations were using routing flexibility less than half of the time. The mean for strategic integration was 3.7631 with a standard deviation of .6167. This indicated that organizations on average were using strategic integration more than half of the time. For organizational infrastructure, a mean of 3.4381 with a standard deviation of .7141 and a mean of 3.4225 with a standard deviation of .6348 were calculated for Management Coordination (MGTCOOR) and Information Management (INFOMGT), respectively. Both sets of values indicated that on average organizations use organizational infrastructure in the form of management coordination and information management more than half the time.

Changes in performance were analyzed as individual items, rather than aggregated. Among the performance measures, the highest mean was 5.078 with a standard deviation of 1.1786 for PER15K and the lowest was 3.723 with a standard deviation of 1.3708 for PER15A. PER15K asked whether the cost of purchased materials had changed. This result for PER15K suggests that on average the cost of purchased materials had not changed since a value of 5.0 indicates "no change." PER15A asked respondents to evaluate the change in setup times. This result indicates that on average organizations had decreased setup times between 11% and 30%.

Table 38 – Descriptive Statistics for Variables

Scale / Item	Mean	Standard Deviation
PMX	3.722	.7631
RTG	2.753	.9230
VOL	3.447	.7837
LBR	3.286	.6567
SPM	3.436	.6154
STR	3.763	.6167
MGTCOOR	3.438	.7141
INFOMGT	3.423	.6348
PER15A	3.723	1.3708
PER15B	3.833	1.4755
PER15C	4.084	1.3058
PER15DRC	4.244	1.3395
PER15E	4.539	1.4893
PER15F	4.368	1.5608
PER15G	4.583	1.5263
PER15H	4.343	1.5270
PER15IRC	4.156	1.5381
PER15J	4.522	1.0699
PER15K	5.078	1.1786
PER15LRC	4.300	1.1102

Regression Analysis

The data were first examined to determine if they met the regression assumptions and could be used for hypothesis testing. Second, the control variables were analyzed to insure that they did not unduly influence the results. Hypothesis testing was then conducted using regression analysis. Lastly, some additional analyses were performed to investigate several results in earlier analyses.

Regression Assumptions

Regression analysis is one of the most common statistical methods used for analyzing survey data. Thus, it was necessary to check the data for adherence to the five assumptions of linear regression: multicollinearity, linearity, homoscedasticity, independence of the residuals, and normality.

Two tests for multicollinearity were used. The more common method compared the correlations between each of the independent variables. The largest correlation was .459 between labor flexibility and supply management flexibility, which was well below the suggested cutoff of .90. The second method was to regress each independent variable onto all other independent variables. The adjusted R^2 values for the regression equations ranged from .159 to .293, indicating some intercorrelation was present. In addition, the variance inflation factor (VIF) was also assessed to test for collinearity with a VIF below 10 considered acceptable. The VIF values ranged from 1.124 to 1.417. Since the largest R^2 (.293) and VIF (1.417) values were well under the suggested cutoffs, multicollinearity was not considered to be an issue in the data (Hair et al., 1998).

Two regression assumptions (linearity and homoscedasticity) were assessed using scatter plots of the residuals against predicted values. A scatter of values around the centerline, with no apparent pattern, indicated both linearity and homoscedasticity. Independence of the residuals was assessed by using a sequencing variable to determine if there was a correlation between the results and the time period of data collection. The respondent number was used for sequencing, as it reflects the order in which responses were received. This analysis also indicated that the residuals were independent with no patterns in the data. Thus, these three assumptions for regression analysis were satisfied.

The final assumption of normality was assessed using the normal probability plots of the standardized residuals and the histograms of the residuals. Assessment consisted of a visual check confirming that the distributions approximated a normal distribution. Results indicated that the variables appear to be normally distributed and there were no significant outliers that would affect the analysis.

Testing of Control Variables

To assess the influence of the control variables on the performance variables, each control was regressed onto the individual performance items to determine if the resulting model was significant. Controls assessed were business unit size in annual sales dollars, business unit size by number of employees, and industry. These controls were assessed using regression analysis. No significant models were fitted with the control variables, thus, for simplicity, these variables were not included below in the regression models.

Hypothesis Testing

A table for each hypothesis test is below. Each table includes the size of the standardized regression coefficients (β), coefficients of determination (Adjusted R^2), and the F ratios (F) for each model. Only significant parameter estimates of fitted models are included. All nonsignificant parameter estimates are omitted from the tables for readability. Further discussion of all of the results of hypothesis testing is presented in the results section of chapter 5.

Hypothesis Test for H1a to H1f

H1: Individual flexibility components contribute to organizational performance.

- H1a: Product-mix flexibility contributes to organizational performance.
- H1b: Routing flexibility contributes to organizational performance.
- H1c: Equipment flexibility contributes to organizational performance.
- H1d: Volume flexibility contributes to organizational performance.
- H1e: Labor flexibility contributes to organizational performance.
- H1f: Supply Management flexibility contributes to organizational performance.

To test Hypothesis 1, linear regression analysis was used developing separate regression models to analyze each of the 12 performance measures with each manufacturing flexibility component. This hypothesis had six sub-hypotheses related to the influence of the individual manufacturing flexibility components on organizational performance. Hypothesis 1c was not evaluated, as the equipment component items were removed during factor analysis. All other hypotheses were tested and are discussed below. The results of the regression analysis are presented in Table 39. The remaining five sub-hypotheses (H1a, H1b, H1d, H1e, H1f) were supported, since each of the individual components had a significant relationship with 5 or more of the 12 performance measures. Only significant relationships are presented in the tables and discussed below with the β values indicated in ( ).

Product-mix flexibility (H1a) had significant negative relationships with raw material (RM) inventory (-.215), work-in-process (WIP) inventory (-.151), finished goods (FG) inventory (-.147), and number of backorders (-.192). This means that as product-mix flexibility increases the RM, WIP, FG inventory levels decrease, as does the number of backorders. This was the only component with a significant relationship to on-time delivery (.187). Thus, as product-mix flexibility increases, on-time delivery increases.

Table 39 – Relationships between Manufacturing Flexibility Components and Performance

Variable	Performance Measures											
	Setup Times			Throughput			Scrap/Rework Cost			Worker Productivity		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
PMX												
RTG	-.184	.029	7.163**	-.145	.016	4.386*	-.175	.026	6.442*			
VOL	-.209	.039	9.324**	-.220	.044	10.329**	-.222	.045	10.585**	.150	.018	4.669*
LBR	-.346	.115	27.726***	-.356	.123	29.632***	-.319	.097	23.067***	.262	.064	14.979***
SPM							-.217	.042	10.046**	.157	.020	5.186*
	RM Inventory			WIP Inventory			FG Inventory			Backorders		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
PMX	-.215	.042	9.932**	-.151	.018	4.791*	-.147	.017	4.527*	-.192	.032	7.822**
RTG	-.151	.018	4.768*							-.210	.039	9.419**
VOL				-.170	.024	6.081*	-.187	.030	7.429**	-.255	.061	14.225***
LBR				-.268	.067	15.837***	-.194	.033	8.006**	-.265	.066	15.460***
SPM	-.185	.029	7.213**	-.149	.018	4.663*						
	On-Time Delivery			Unit Mfg Cost			Material Cost			Utilization		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
PMX	.187	.030	7.419**									
RTG										.162	.021	5.497*
VOL				-.184	.029	7.159**				.209	.039	9.364**
LBR				-.351	.119	28.586***	-.211	.040	9.543**			
SPM				-.227	.047	11.119**	-.189	.031	7.536**			

* significant at .05 (p <.05)
** significant at .01 (p <.01)
*** significant at .001 (p <.001)
β and F values have the same significance

Routing flexibility (H1b) had significant negative relationships with setup times (-.184), throughput time (-.145), scrap/rework cost (-.175), RM inventory (-.151), and backorders (-.210). These results indicate that as routing flexibility increases setup times, throughput time, scrap/rework cost, RM inventory, and backorders decrease. Routing flexibility had a positive relationship with machine utilization (.162), indicating that as routing flexibility increases, machine utilization increases.

Volume flexibility (H1d) had significant negative relationships with setup times (-.209), throughput time (-.220), scrap/rework cost (-.222), WIP inventory (-.170), FG inventory (-.187), backorders (-.255), and unit manufacturing cost (-.184). This indicates that, as volume flexibility increases, each of these performance measures decreases. Worker productivity (.150) and machine utilization (.209) had positive relationships with volume flexibility, indicating that as volume flexibility increases, these two performance measures increase.

Labor flexibility (H1e) had significant negative relationships with setup times (-.346), throughput time (-.356), scrap/rework cost (-.319), WIP inventory (-.268), FG inventory (-.194), backorders (-.265), unit manufacturing cost (-.351), and purchased material cost (-.211), indicating that as labor flexibility increases, each of these performance measures decreases. Labor flexibility had a significant positive relationship with worker productivity (.262); thus, as labor flexibility increases, so does worker productivity.

Supply management flexibility (H1f) had significant negative relationships with scrap/rework cost (-.217), RM inventory (-.185), WIP inventory (-.149), unit manufacturing cost (-.227), and purchased material cost (-.189). These results indicate that, as supply management flexibility increases, each of these five performance measures decreases. Supply management had a significant positive relationship with worker productivity (.157); thus, as supply management flexibility increases worker productivity increases.

Hypothesis Test for H2

H2: Manufacturing flexibility contributes to organizational performance.

A summated scale (MFLX) was created using the averages from the five manufacturing flexibility components to represent the presence of all five flexibility components within a manufacturing system. Hypothesis 2 was supported, since the aggregated manufacturing flexibility measure had significant relationships with 11 of the 12 performance measures (Table

40). The only performance measure not significantly related to aggregated manufacturing flexibility was on-time delivery. This was expected, since only one individual manufacturing flexibility component, product-mix, was significantly associated with it. As manufacturing flexibility increases, each of the following performance measures decreases: setup times (-.278), throughput time (-.267), scrap/rework cost (-.302), RM inventory (-.230), WIP inventory (-.223), FG inventory (-.199), backorders (-.301), unit manufacturing cost (-.279), and purchased material cost (-.207). As manufacturing flexibility increases, worker productivity (.219) and machine utilization (.193) increase.

Table 40 – Relationships between Manufacturing Flexibility and Performance

Variable	Performance Measures											
	Setup Times			Throughput			Scrap/Rework Cost			Worker Productivity		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX	-.278	.073	17.106***	-.267	.067	15.672***	-.302	.087	20.451***	.219	.043	10.318**
	RM Inventory			WIP Inventory			FG Inventory			Backorders		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX	-.230	.048	11.357**	-.223	.045	10.667**	-.199	.035	8.375**	-.301	.086	20.369***
	On-Time Delivery			Unit Mfg Cost			Material Cost			Utilization		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX				-.279	.073	17.221***	-.207	.038	9.092**	.193	.033	7.888**

* significant at .05 (p <.05)
** significant at .01 (p <.01)
*** significant at .001 (p <.001)
β and F values have the same significance

Hypothesis Test for H3

H3: Strategic integration strengthens the relationship between manufacturing flexibility and organizational performance.

The aggregated manufacturing flexibility measure (MFLX) and strategic integration (STR) were both significant when included in the models as independent variables with 10 of the 12 performance measures. Aggregated manufacturing flexibility and strategic integration were not significant when either on-time delivery or raw material inventory were the dependent variable. When the interaction term (MFLX x STR) was added, both of the independent variables were insignificant in nine of the models, while the interaction between the two variables was significant. This indicates the presence of a significant moderating effect by strategic integration on the relationship between manufacturing flexibility and performance. Only the significant models are included in Table 41.

As manufacturing flexibility increases with strategic integration, each of the following eight performance measures decreases: setup times (-.327), throughput time (-.275), scrap/rework cost (-.362), WIP inventory (-.257), FG inventory (-.235), backorders (-.309), unit manufacturing cost (-.312), and purchased material cost (-.235). As manufacturing flexibility increases, worker productivity (.286) increases. Strategic integration as an independent variable had one significant relationship with machine utilization (.238), indicating a direct positive effect but no interaction effect. The larger variance explained (R^2) by these models that include strategic integration (versus the H2 models) indicate that strategic integration strengthens the relationship between manufacturing flexibility and performance. Therefore, Hypothesis 3 was supported in 9 of the 12 models.

Table 41 – Relationships between Manufacturing Flexibility and Strategic Integration

Variable	Performance Measures											
	Setup Times			Throughput			Scrap/Rework Cost			Worker Productivity		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFGFLEX												
STR												
MFLX x STR	-.327	.103	24.418***	-.275	.071	16.725***	-.362	.127	30.755***	.286	.077	18.180***
	RM Inventory			WIP Inventory			FG Inventory			Backorders		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFGFLEX												
STR												
MFLX x STR				-.257	.061	14.400***	-.235	.051	11.926**	-.309	.091	21.521***
	On-Time Delivery			Unit Mfg Cost			Material Cost			Utilization		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFGFLEX												
STR										.238	.052	12.197**
MFLX x STR				-.312	.093	22.043***	-.235	.050	11.886**			

* significant at .05 ($p < .05$)
** significant at .01 ($p < .01$)
*** significant at .001 ($p < .001$)
β and F values have the same significance

Hypothesis Test for H4

H4: Organizational infrastructure strengthens the relationship between manufacturing flexibility and organizational performance.

Organizational infrastructure has two sub-dimensions – management coordination and information management. The aggregated manufacturing flexibility measure (MFLX) and management coordination (MGTCOOR) were both significant when included in the models as independent variables with 7 of the 12 performance measures. The performance measures not significantly related to aggregated manufacturing flexibility and management coordination were throughput, worker productivity, RM inventory, and on-time delivery. When the interaction term (MFLX x MGTCOOR) was added, in a majority of the significant models, both independent variables were insignificant, while the interaction between the two variables was significant. This indicates the presence of a significant moderating effect by management coordination on the relationship between manufacturing flexibility and performance. Only the significant models are included in Table 42.

Table 42 – Relationships between Manufacturing Flexibility and Management Coordination

Variable	Performance Measures											
	Setup Times			Throughput			Scrap/Rework Cost			Worker Productivity		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX							-.167*					
MGTCOOR							-.268	.137	17.217***			
MFLX x MGTCOOR	-.308	.091	21.457***									
	RM Inventory			WIP Inventory			FG Inventory			Backorders		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX												
MGTCOOR												
MFLX x MGTCOOR				-.297	.084	19.756***	-.224	.046	10.773**			
	On-Time Delivery			Unit Mfg Cost			Material Cost			Utilization		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX												
MGTCOOR										.199	.035	8.390**
MFLX x MGTCOOR				-.343	.113	27.246***	-.242	.054	12.700***			

* significant at .05 (p <.05)
** significant at .01 (p <.01)
*** significant at .001 (p <.001)
β and F values have the same significance, except where indicated

As manufacturing flexibility increases with management coordination, each of the following performance measures decreases: setup times (-.308), WIP inventory (-.297), FG inventory (-.224), unit manufacturing cost (-.343), and purchased material cost (-.242). Management coordination as an independent variable had a significant relationship with machine utilization (.199), indicating a direct positive effect, but no interaction effect. In the model with scrap/rework cost as the dependent variable, manufacturing flexibility (-.167) remained significant with the addition of management coordination as an independent variable (-.268). This means that manufacturing flexibility and management coordination continued to have a significant direct effect, while the interaction was not significant. The larger variance explained (R^2) by these models, as compared to those in H2, indicates that the inclusion of management coordination strengthens the relationship between manufacturing flexibility and performance.

The aggregated manufacturing flexibility measure (MFLX) and information management (INFOMGT) were both significant when included in the models as independent variables with 7 of the 12 performance measures. Performance measures not significantly related to aggregated manufacturing flexibility and information management were throughput, scrap/rework cost, worker productivity, RM inventory, and on-time delivery. When the interaction term (MFLX x INFOMGT) was added, in a majority of the models with the remaining performance measures, both of the independent variables became insignificant while the interaction between the two variables was significant. This indicates the presence of a significant moderating effect by strategic integration on the relationship between manufacturing flexibility and performance. Only the significant models are included in Table 43.

As manufacturing flexibility and information management increase, each of the following performance measures decreases: WIP inventory (-.218), backorders (-.288), unit manufacturing cost (-.288), and purchased material cost (-.248). Information management as an independent variable had a significant relationship (.195) with utilization, indicating a direct positive effect but no interaction effect. In two models (setup times and FG inventory), information management remained significant when the interaction was included. This suggests that in those two models, information management continued to have a direct effect on performance when the interaction was included. As manufacturing flexibility increases with information management, setup times decrease (-.548) and FG inventory decreases (-.437).

Table 43 – Relationships between Manufacturing Flexibility and Information Management

Variable	Performance Measures											
	Setup Times			Throughput			Scrap/Rework Cost			Worker Productivity		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX												
INFOMGT	-.347*											
MFLX x INFOMGT	-.548	.073	9.056***									
	RM Inventory			WIP Inventory			FG Inventory			Backorders		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX												
INFOMGT							.322*					
MFLX x INFOMGT				-.218	.043	10.208**	-.437**	.034	4.648*	-.288	.079	18.482***
	On-Time Delivery			Unit Mfg Cost			Material Cost			Utilization		
	β	R^2	F	β	R^2	F	β	R^2	F	β	R^2	F
MFLX												
INFOMGT										.195	.033	8.087**
MFLX x INFOMGT				-.288	0.78	18.240***	-.248	.057	13.354***			

* significant at .05 ($p < .05$)
** significant at .01 ($p < .01$)
*** significant at .001 ($p < .001$)
β and F values have the same significance, except where indicated

In two models, the variance explained was larger than for models tested in H2. The larger variance explained (R^2) by these models indicate that the inclusion of information management strengthens the relationship between manufacturing flexibility and performance. In the model with utilization, information management explains the same amount of variance as when manufacturing flexibility is considered individually in the model. For the models with WIP inventory and backorders, the variance explained was lower than when these performance measures were regressed with manufacturing flexibility.

Therefore, Hypothesis 4 was supported in 5 of 12 models where Management Coordination strengthened the relationship between manufacturing flexibility and performance. Additionally, Hypothesis 4 also was supported in 5 of 12 models where Information Management strengthened the relationship between manufacturing flexibility and performance.

Summary

All of the tested hypotheses were supported in multiple models. As manufacturing flexibility increases, whether measured individually or aggregated, performance increases or decreases as hypothesized. Individually, labor flexibility explains a larger portion of variance than any other individual component. Additionally, with six performance measures (setup times, throughput time, scrap/rework cost, worker productivity, WIP inventory, and material cost) labor flexibility explains more of the variance than aggregated manufacturing flexibility. When strategic integration is considered, the interaction between manufacturing flexibility and strategic integration is significant in 9 of the 12 models supporting the hypothesized moderating effect. When organizational infrastructure, as measured by management coordination and information management, is also considered, the interaction between manufacturing flexibility and each sub-dimension is significant in 5 of 12 models, supporting the hypothesized moderating effect. A summary of the hypotheses and results of the hypothesis testing is in Table 44.

Table 44 – Summary of Hypothesis Testing

	Hypotheses	Result
H1	Individual flexibility components contribute to organizational performance.	Supported
H1a	Product-mix flexibility contributes to organizational performance.	Supported 5 of 12
H1b	Routing flexibility contributes to organizational performance.	Supported 6 of 12
H1c	Equipment flexibility contributes to organizational performance.	Not tested
H1d	Volume flexibility contributes to organizational performance.	Supported 9 of 12
H1e	Labor flexibility contributes to organizational performance.	Supported 9 of 12
H1f	Supply management flexibility contributes to organizational performance.	Supported 6 of 12
H2	Manufacturing flexibility contributes to organizational performance.	Supported 11 of 12
H3	Strategic integration strengthens the relationship between manufacturing flexibility and organizational performance.	Supported 9 of 12
H4	Organizational infrastructure strengthens the relationship between manufacturing flexibility and organizational performance.	Supported 5 of 12 for MGTCOOR 5 of 12 for INFOMGT

Additional Analysis

One of the main objectives of this study was to investigate manufacturing flexibility within a systems perspective. As such, further analysis of the performance measures based on the initial results of correlation and reliability analysis was pursued to determine if the individual performance measures could be combined into practical factors. Factor analysis on the performance measures followed the same process as used previously for the manufacturing flexibility components and the moderating variables.

The initial step of scale analysis (Alpha and CITC analysis) resulted in the following scale changes. The performance scale consisted of 12 items. Four items (PER15D, PER15I, PER15K, PER15L) were removed and the alpha value increased from .798 to .812. After initial item deletions from the scale, eight items representing organizational performance remained. Principal components factor analysis was used to analyze the structure of patterns in the data. In the second stage, two factors had eigenvalues greater than 1.0. Scree plot analysis and parallel analysis (Table 45) for the performance measures (N = 206) also indicated a two factor solution.

Table 45 – Parallel Analysis for Organizational Performance (8 items)

Factor	Study Eigenvalues	Simulated Eigenvalues
1	3.490	1.3033
2	1.190	1.1875
3	0.819	1.1006

Next, factor analysis with varimax rotation was used to determine the items for each performance factor. Performance Factor 1 retained five items, while Performance Factor 2 retained three items (Table 46).

Table 46 – Organizational Performance Rotated Factor Matrix (8 items)

Survey Item	Factor	
	1	2
PER15B	.820	
PER15A	.775	
PER15C	.594	
PER15J	.575	
PER15H	.503	
PER15E		.864
PER15F		.816
PER15G		.787
Alpha Values	.729	.821

Performance Factor 1 included: PER15A, PER15B, PER15C, PER15H, and PER15J. (Table 47 and Table 48). The alpha for Factor 1 is .729, which exceeds the acceptable cutoff of .60 for new scales. This value was not compared to an existing scale, as the items were taken from multiple sources, and were not originally hypothesized to form a factor.

Table 47 – Traditional Manufacturing Performance Scale

	Survey Item	Alpha	Orig Alpha
PER15A	Setup times	.729	N/A
PER15B	Throughput time (from order release to completion)		
PER15C	Scrap and rework cost		
PER15H	Number of backorders		
PER15J	Unit manufacturing costs (excluding purch. materials)		

Table 48 – Traditional Manufacturing Performance Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
PER15A	16.782	14.556	.523	.343	.659
PER15B	16.672	13.487	.576	.397	.635
PER15C	16.422	15.160	.496	.315	.671
PER15H	16.162	15.116	.375	.151	.724
PER15J	15.984	16.634	.473	.279	.685

Performance Factor 2 included the following items: PER15E, PER15F, and PER15G (Table 49 and Table 50). The alpha for Factor 2 is .821, which exceeds the acceptable cutoff of .60 for new scales. This value was not compared to an existing scale, as the items were taken from multiple sources, and were not originally hypothesized to form a factor.

Table 49 – Inventory Performance Scale

	Survey Item	Alpha	Orig Alpha
PER15E	Raw materials (RM) inventory levels	.821	N/A
PER15F	Work-in-Process (WIP) inventory levels		
PER15G	Finished Goods (FG) inventory levels		

Table 50 – Inventory Performance Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
PER15E	8.951	7.484	.702	.517	.726
PER15F	9.122	7.037	.718	.535	.707
PER15G	8.907	7.885	.607	.370	.819

After analyzing the items comprising Factor 1 for performance, it was decided that the label of Manufacturing Performance (MFGPER) was appropriate. The items represented traditional performance measures that are commonly measured in manufacturing organizations. Factor 2 for performance was labeled Inventory Performance (INVPER). All of the items related to types of inventory (RM, WIP, FG). These performance factors are referred to using these new labels for the remainder of the discussion.

Due to the small, but statistically significant R^2 values, additional analyses were performed using the new organizational performance factors – manufacturing performance and inventory performance – to better understand the relationship between manufacturing flexibility and performance. All of the hypotheses were tested with manufacturing performance and inventory performance as the dependent variable rather than the individual performance measures to better understand the relationships from a systems perspective. The significant models are summarized in Table 51.

When organizational performance is aggregated to better represent the performance of a manufacturing system, these results generally indicate that the independent variables and moderators explain more of the variance than for individual performance measures. The aggregated manufacturing flexibility component explains more of the variance in manufacturing performance than the individual manufacturing flexibility components with the exception of labor flexibility. Labor flexibility explains the largest percentage of variance (.216) in manufacturing performance of any of the alternate models. The model with manufacturing flexibility and strategic integration as well as the model with manufacturing flexibility and management coordination explain the next largest percentage of variance (.204 and .203, respectively) when an interaction is included.

Table 51 – Additional Analysis – Flexibility, Moderators, and Performance

Variable	MFGPER			INVPER		
	β	R^2	F	β	R^2	F
PMX	-.193	.032	7.856^{**}	-.199	.035	8.428^{**}
RTG	-.247	.056	13.228^{***}			
VOL	-.318	.097	22.918^{***}	-.183	.029	7.099^{**}
LBR	-.469	.216	57.605^{***}	-.227	.047	11.094^{**}
SPM	-.188	.031	7.496^{**}	-.177	.027	6.610^{*}
MFLX	-.412	.166	41.702^{***}	-.253	.059	13.935^{***}
MFLX x STR	-.456	.204	53.467^{***}	-.256	.061	14.277^{***}
MFLX x MGTCOOR	-.455	.203	53.224^{***}	-.287	.078	18.271^{***}
INFOMGT	$.367^{*}$			$.335^{*}$		
MFLX x INFOMGT	$-.709^{***}$	.166	21.352^{***}	$-.505^{**}$	.056	7.119^{**}

* significant at .05 ($p < .05$)
** significant at .01 ($p < .01$)
*** significant at .001 ($p < .001$)
β and F values have the same significance, except as noted

Based on these results, an additional analysis was conducted. This analysis involved using regression with backward selection on the individual manufacturing flexibility components to determine if a more parsimonious aggregated component explained the same or more variance. With manufacturing performance, labor and volume flexibility were the best combination of components. These two components together explained 23.5% of the variance at a significance level of .001. For inventory performance, labor and product-mix flexibility were the best combination, explaining 6.2% of the variance at a significance level of .01. These results explain more variance than those using the aggregated manufacturing flexibility factor comprised of all five components. Thus, a synergy is still created, but it does not require the use of all five flexibility components to generate the greatest benefit.

Labor flexibility and these new aggregated components (LBR-VOL and LBR-PMX) were used in regression analysis with the moderating variables to find the best overall model fit for each performance factor (MFGPER and INVPER). The results are discussed in chapter 5.

Summary

The primary purpose of this study was to determine the relationships between the manufacturing flexibility components and performance. This chapter contained the results of the data analysis. The business unit characteristics showed that the sample contained a diverse group of organizations representing the diversity of U.S. manufacturing. In addition, the respondent characteristics indicated their experience and knowledge within their organizations. Correlation and factor analyses were used to validate the scales in this study. The application of the instrument in a more diverse sample is of particular value.

The results of the hypothesis testing and additional analysis indicate that the components of manufacturing flexibility contribute in different ways to changes in organizational performance. When the components are combined into an aggregate measure of manufacturing flexibility, the variance explained (R^2) is higher than for individual components with the exception of labor flexibility. All of the hypotheses tested were supported to some extent. Chapter 5 contains a discussion of these results.

CHAPTER 5

DISCUSSION OF RESULTS

In addition to a discussion of the consistencies and inconsistencies in the study findings, this chapter includes an explanation of the study's limitations, theoretical and managerial implications, and avenues for future research.

Consistencies and Inconsistencies in the Findings

The consistencies and inconsistencies in the findings are below. The first section contains explanations of the differences between the new instrument and those used for its development. The next section contains a discussion of the results of each hypothesis test and the results from the additional analysis section of chapter 4.

Instrument Development

Several issues emerged with the development of the measurement instrument for this study in comparison with previous survey studies of manufacturing flexibility. These include the development of a generalizable instrument for more diverse manufacturing environments, the removal of the equipment flexibility component, a comparison of the questionnaire elements, performance measures used, and the analysis of results.

One goal of this study was to create an instrument that measured manufacturing flexibility outside the specific context of flexible manufacturing system (FMS) environments. Numerous studies suggest that manufacturing flexibility should be applicable in more diverse manufacturing situations, but little empirical evidence is available. Although the alpha values for this study are not as high as those for the original scales (Table 52), this result can be explained.

By focusing on Sethi and Sethi's (1990) definitions, the scales Zhang et al. (2003) were developed to measure manufacturing environments using more automated systems (e.g. FMS). Thus, in a non-FMS environment different results are likely. Zhang et al. (2003) limited their population to discrete manufacturing organizations in five SIC codes (34-38), thus, respondents in Zhang et al.'s sample and population were more homogeneous than those in the current study. This is a differentiating issue between the two studies, as the population in the current study was only restricted to organizations generating 70% or more of their annual sales from manufacturing. Additionally, Zhang et al. drew their sample from the Society of Manufacturing Engineers (SME). Using respondents who likely have similar engineering backgrounds further increased the homogeneity of their sample. The sample in the current study had representation from a broad set of functions including purchasing, materials/inventory management, supply chain management, engineering, and plant management.

Table 52 – Comparison of Instrument Structure

Component	Final Number of Items	Alpha	Number of Items Zhang et al.	Alpha
Product-Mix	5	0.72	6	0.92
Routing	5	0.85	6	0.92
Equipment	0	n/a	5	0.83
Volume	4	0.78	6	0.90
Labor	7	0.83	5	0.91

The poor performance of the equipment flexibility scale in the current study is also of interest with regard to instrument development. Organizations in Zhang et al.'s (2003) sample were not just in similar industries, but most were small organizations (less than 250 employees) primarily in two industries, fabricated metal products and industrial/commercial machinery. This type of organization is more likely to use automated manufacturing technologies such as FMS or CNC machinery, thus increasing the likelihood that the equipment flexibility items were highly applicable in those organizations. In the current study, the organizations may use less automated equipment, which would explain the poor performance and ultimate exclusion of the equipment flexibility scale. The current study had a larger variety of industries represented as well as the majority having over 250 employees. Although the definition included with the survey instrument defined equipment to include other alternatives such as hand tools or computers, some respondents may have answered with regard to whether they use “large industrial machines” rather than other types of equipment. For example, one respondent wrote on the survey form “Not applicable. We use hand tools only.” Previous research indicates that adding more sophisticated technology (e.g. FMS) does not necessarily increase an organization’s flexibility, thus the results of the current study may provide some support for that premise.

Zhang et al. (2003) have several other differences related to their questionnaire elements and scales that differentiate it from the current study. First, the Likert scale Zhang et al. used asked respondents whether they agree or disagree about each statement with regard to their organization as compared to competitors. It could be difficult for respondents to gauge these issues within their own organization much less when compared to competitors. Organizations tend to guard information about their competitive capabilities, so this comparison may be difficult unless a respondent worked recently for another organization. Generally, middle and upper managers have worked for the same organization for multiple years and would not have recent experience with another organization. Zhang et al. did not report the average time with the organization. In the current sample, the respondent’s average time with their companies was 11.9 years. Thus, the Likert scale in the current study (Never to Always) was specifically selected to overcome that issue and was expected to yield different results. Respondents were not asked to compare their organization to their competitors, but rather how frequently the statement applied to their business unit. Additionally, many of the items in Zhang et al.'s instrument included "can" in the wording. The goal in the current study was not to measure potential flexibility, but rather the actual flexibility the organization uses, thus "can" was removed from several items. For example, in labor flexibility they asked "A typical worker can use many different tools effectively." This item was modified in the current study to read "A typical worker uses different tools effectively." Lastly, Zhang et al.'s performance measure was customer satisfaction. Their items do not necessarily reflect whether customers were satisfied, but rather they can be only interpreted as to whether customers buy from the organization more than once. This may imply that there were no comparable options in the market rather than customer satisfaction. Zhang et al. did not survey the organizations' customers to determine if they were satisfied. The performance measures in the current study were common manufacturing and organizational performance measures commonly tracked, especially when implementing new practices, processes, or equipment. Additionally, the current study's performance measures were more internally focused versus an external focus on whether customers were satisfied, as surveying both the organizations and their customers would be problematic.

The final instrument development issue and differences with Zhang et al. (2003) relates to their data analysis. First, it appears that the same data were used for both exploratory and confirmatory factor analysis. If this was the case, this would explain the high fit indices in the structure equation models. Second, in their model, they define volume and product-mix flexibility as mediators between their other manufacturing flexibility components (routing, material handling, labor, equipment) and performance. Zhang et al.'s discussion implied they analyzed the other flexibility components (routing, material handling, labor, equipment) individually against volume and product-mix, although those results were not reported. Within the development of their SEM model, aggregated scales were created for the first four components, but not the other two. The reason for this difference was not discussed. Lastly, Zhang et al. do not report whether there were any direct effects between the first four components and performance. In the current study, all of the components were considered independent variables that predict changes in performance, thus with a different model the results would differ. In general, the differences between the results with the instrument developed in the current study compared to the results reported by Zhang et al. were logical.

Hypothesis Testing

With regard to the hypothesis testing, most of the relationships were significant and in the direction hypothesized. The results for each are discussed below and include possible reasons for the items deleted from each scale.

Hypothesis 1

H1a - Product-Mix Flexibility. Beginning with H1a, product-mix flexibility had significant negative relationships with RM inventory, WIP inventory, FG inventory, and number of backorders and a significant positive relationship with on-time delivery. Increasing product-mix flexibility would decrease these performance measures, which in all cases is considered an improvement. For example, an organization that is unable to switch easily between product mixes to respond to changes in demand would need to hold larger quantities of RM, WIP, and FG inventories as a contingency to prevent backorders and improve on-time delivery. Additionally, the presence of large inventories would prevent an organization from being able to respond quickly to market changes, as the existing inventory must be used first. The relationship with on-time delivery was positive, indicating that as product-mix flexibility increases on-time delivery increases. Product-mix flexibility was the only individual component having a significant relationship with on-time delivery. If an organization is able to easily changeover the product mix, then they can produce smaller batches to decrease throughput time while also improving the probability of on-time deliveries.

Items PMX11F and PMX11G were removed during analysis which may reflect that design and modification of products is still considered a separate task from the manufacturing of the products. Item PMX11I was also removed and could be perceived as an infrastructure characteristic, as it may convey a meaning more related to the product design process rather than to the manufacture of the product. Lastly, items PMX11H and PMX11J were removed which related to systems that control the manufacturing process. Again this may relate to coordinating the manufacturing process rather than enabling product-mix changeovers. One respondent commented that their information systems required creating manual workarounds to allow for manufacturing flexibility. Zhang et al. (2003) had six items, two of which overlapped. Additionally, they used “can” in every item which allows a respondent to “agree” with a statement that the organization has the potential to do, but does not reflect whether they actually do any of these activities to be more flexible. Thus, “can” was removed from these items resulting in a different scale from Zhang et al.

H1b - Routing Flexibility. Routing flexibility (H1b) had significant negative relationships with setup times, throughput time, scrap/rework cost, RM inventory, and backorders and a positive relationship with machine utilization. These relationships were in the direction hypothesized. Increased routing flexibility is reflected in the ability to setup machines faster, which in turn should help decrease throughput time. Scrap/rework cost should be reduced, as there are more options available for processing as well as to rework products. With increased routing capability, backorders would be expected to decrease while increasing machine utilization. The relationship to decreasing RM inventory, however, was interesting because there was no significant relationship with either WIP or FG inventory. As throughput increases and backorders decrease, all three types of inventory were expected to decrease. It may be, however, that organizations are becoming more efficient at producing more outputs, resulting in these two inventory types neither increasing nor decreasing. With higher routing flexibility, however, it is not intuitive that RM inventory would be reduced. This may indicate the ability to substitute different raw materials via alternate process plans or the ease of moving raw materials quickly to a new workstation or manufacturing cell. This may also indicate that it is easier to begin manufacturing products in the system because of alternate process plans; however, the products may not be finished or delivered any faster. Perhaps the manner in which the products are produced (make-to-order or make-to-stock) plays a role in this finding and should be investigated further.

Items RTG11F and RTG11G were originally added to this scale based on the literature related to material handling. Although intuitively logical that routing and material handling are too tightly coupled to be considered separately, the analysis did not support that expectation resulting in the deletion of these items. It may be that organizations have inflexible material handling systems that are made flexible through manual means that were not captured in those two items.

H1d - Volume Flexibility. Volume flexibility (H1d) had significant negative relationships with setup times, throughput time, scrap/rework cost, WIP inventory, FG inventory, backorders, and unit manufacturing cost. These relationships were as hypothesized. The positive relationships with both worker productivity and machine utilization were also as hypothesized. There was no significant relationship with RM inventory. Based on the literature it was expected that volume fluctuations would affect RM inventory. Therefore, organizations must manage this inventory issue via another mechanism such as routing flexibility or manufacturing control systems. Zhang et al.'s (2003) scale for volume flexibility had similar issues as those for product-mix. Every statement began with "We can" and respondents were asked to compare their organization's abilities to their competitors' capabilities. For this study, "can" was removed from the items.

Items VOL11A and VOL11B were deleted from the scale. This result was interesting, as they related to the ability to increase and decrease volume efficiently and profitably. It may be that increasing and decreasing volume was of less importance in the more diverse sample versus the industries studied by Zhang et al. (2003). Items VOL11G and VOL11H were also deleted. These items may be interpreted as tools that organizations use to increase volume, but some respondents may not consider that using temporary employees and outsourcing as a way to increase the organization's overall output volume, either temporarily or permanently. The resulting scale was, however, more parsimonious while maintaining an acceptable level of reliability.

<u>H1e - Labor Flexibility.</u> Labor flexibility (H1e) had significant negative relationships with setup times, throughput time, scrap/rework cost, WIP inventory, FG inventory, backorders, unit manufacturing cost, and purchased material cost and a significant positive relationship with

worker productivity. These relationships were in the direction hypothesized. Labor flexibility had nine significant relationships with performance. Labor cost is often cited as a reason for organizations outsourcing or moving manufacturing facilities to other countries. Many organizations, however, have not attained the expected cost benefits with these outsourcing decisions. When looking at these relationships closer, they suggest a possible answer. The negative relationships between increasing labor flexibility and decreasing measures such as setup times and throughput may reflect existing labor skills and abilities that newer manufacturing facilities and employees in other countries lack.

Zhang et al.'s (2003) labor flexibility scale had several items that used "can," which was removed from the items for this study. Two items overlapped, so one was deleted and replaced. The revised scale also included two concepts not captured with Zhang et al.' scale – problem-solving skills and team reorganization to meet changing needs. No items were deleted from this scale.

H1f - Supply Management Flexibility. Supply management flexibility (H1f) had significant negative relationships with scrap/rework cost, RM inventory, WIP inventory, unit manufacturing cost, and purchased material cost. Supply management is one area of operations where an immediate bottom line effect can be seen when the purchasing and materials management processes are well managed. Additionally, there was a significant positive relationship with worker productivity. This relationship may imply that if the sources of supply are well managed, then the production workers receive materials that always meet specifications, thus saving time on the manufacturing floor and increasing productivity which is reflected in reduced scrap/rework. All of these relationships were in the hypothesized direction.

Supply management flexibility was a new scale derived from two studies by Narasimhan and Das (1999a, 1999b). An alpha value comparison is not feasible with this scale because Narasimhan and Das's scales differed in several ways from those in the current study. First, both scales had two sub-constructs, each comprised of three items. Second, the items from those studies (SPM11B, SPM11C, SPM11E, SPM11F, SPM11I, SPM11J) were modified to work with a different Likert scale. Lastly, the construct defined in this study was different, therefore, a comparison was not reasonable.

Hypothesis 2

The only relationship not supported between manufacturing flexibility and performance (H2) was with on-time delivery. This was not unexpected, since only one individual component was significantly associated with it – product-mix flexibility. As manufacturing flexibility increases, 9 of the 12 performance measures decrease (setup times, throughput time, scrap/rework cost, RM inventory, WIP inventory, FG inventory, backorders, unit manufacturing cost, and purchased material cost). As manufacturing flexibility increases, worker productivity and machine utilization also increase. All of these relationships were in the direction hypothesized.

These results imply that a synergy was created when more than one manufacturing flexibility component was present. Additional analysis of the five components indicated that a combination of labor and volume flexibility to predict manufacturing performance was a more parsimonious model that explained more variance (23.5%) than the aggregated manufacturing flexibility measure (16.6%) that included all five components. For inventory performance, a combination of labor and product-mix was a more parsimonious model that explained more variance (6.2%) than the aggregated manufacturing flexibility measure (5.9%) that included all five components. This result supports previous findings that partial flexibility can yield similar results to full flexibility. In this case, the partial flexibility measures were better than full flexibility.

Hypothesis 3

Hypothesis 3 was supported in 9 of 12 models. The interaction between manufacturing flexibility and strategic integration had significant negative relationships with eight performance measures (setup times, throughput time, scrap/rework cost, WIP inventory, FG inventory, backorders, unit manufacturing cost, and material cost) indicating that as manufacturing flexibility increases in the presence of strategic integration, the performance benefits were greater than if strategic integration was not present. Strategic integration had a significant direct effect on machine utilization. The models with the combinations of labor with volume and labor with product-mix also indicated a slightly stronger relationship to performance with the interaction of strategic integration than without, as well as creating more parsimonious models.

All of the models with strategic integration had larger beta values and explained more variance than the models with manufacturing flexibility alone. This not only further supports the concept of synergistic benefits for systems, but also of the importance of integrating manufacturing strategy with both other functional strategies and organizational strategy.

Hypothesis 4

Hypothesis 4 was supported in 5 of 12 models for each sub-dimension (management coordination and information management). The negative relationships of the interaction between manufacturing flexibility and management coordination was significant with five performance measures (setup times, WIP inventory, FG inventory, unit manufacturing cost, and material cost) indicating that the performance benefits were greater than if management coordination was not present. With setup time, the results were basically the same, however, in the other four models, the beta values were larger as was the variance explained. In two models, management coordination as an independent variable was significant. The positive relationship between management coordination and utilization indicates that as management coordination increases machine utilization also increases. The negative relationship with scrap/rework cost indicates that both manufacturing flexibility and management coordination have a direct effect on reducing scrap/rework cost.

The interaction term with information management had a significant negative relationship in four models (WIP inventory, backorders, unit manufacturing cost, and material cost) indicating that the performance benefits were greater than if management coordination was not present. In two models, management coordination as an independent variable was significant with the interaction. The negative relationship with setup times indicated that as manufacturing flexibility increases, information management had a direct effect on reducing setup times, but the relationship between manufacturing flexibility and reduced setup times was strengthened by information management. As manufacturing flexibility increases, FG inventory decreases and the relationship between manufacturing flexibility was strengthened by including information management, however, information management has an opposite direct effect on FG inventory. Thus, information management's direct effect on FG inventory will reduce the beneficial effect of the interaction between manufacturing flexibility and information management. With utilization, information management had a significant positive relationship indicating that as information management increases machine utilization also increases.

Through additional analysis, the combination of labor with volume flexibility also indicated a stronger relationship to manufacturing performance, with both management coordination and information management than without. The combination of labor with product-mix flexibility also indicated a stronger relationship to inventory performance, with either management coordination and information management than without. These models are more parsimonious than those using the aggregated manufacturing flexibility measure with management coordination and information management as moderating variables.

Limitations

There are several limitations for this study. The first is the use of a cross-sectional design. Causality can not be determined with such a design, so the results of this study are not prescriptive, but rather they explain variations in performance at a single point in time. Longitudinal research related to these constructs would be very interesting, as it would indicate whether organizations are able to sustain or continue performance improvements the longer they use manufacturing flexibility.

A second limitation is the use of self-reported measures from a single respondent in a business unit. This was addressed through validation of the survey instrument as well as selecting appropriate respondents who have access to the information relevant to answering the questionnaire. There is always a possibility for bias with self-report measures. It is assumed, however, that respondents were interested in receiving a summary report for the study with valid results, so they would answer each question as accurately and objectively as possible. In one instance, a respondent apologized for his late return of the survey stating that he went to others for clarification on sections where he lacked full knowledge. The additional resources required to collect a second set of responses for the 206 respondents was not justified.

A third limitation is the selection of a survey methodology over other research methods. A survey was selected for several reasons. First, a survey allowed collection of a large volume of data from various organizations thus facilitating comparisons. The use of primarily close-ended questions reduced the richness and detail of the data gathered; however, interpretation of a large number of open-ended responses from over 200 respondents would be problematic. Second, the time to administer a survey versus observing or interviewing the same number of respondents was significantly less. Additionally, the cost of observing or interviewing the same number of respondents was cost prohibitive. Third, an experimental design was not feasible, as a full manufacturing system within an organizational context could not be manipulated. The purpose of the study was not to understand whether flexibility could be achieved, but rather how organizations were already using it. Lastly, the type of information needed was not available within archival data sources. Thus, a survey methodology was the appropriate data collection method for the purpose of this study.

There may be additional limitations related to generalizability, as the survey does not cover every possible aspect within a manufacturing organization. Manufacturing organizations were the only type of organization surveyed, and the survey is usable with other manufacturing organizations but not service organizations without extensive modification. It is also unknown if the results would remain the same if the unit of analysis were other than the business unit. As with the three types of interdependencies (Thompson, 1967), organizations may have flexibility in some areas and not others, thus the unit of analysis may not capture all of this variation. There is no a priori evidence, however, to suggest that these findings are not generalizable.

Research Implications

This research is an attempt to clarify the proposed theory that manufacturing flexibility is a multi-dimensional concept that requires a systems perspective. The current study builds on previous studies that identified components of manufacturing flexibility and interrelationships among those components. This study uses a heterogeneous sample of organizations in diverse industries to illustrate the implementation of manufacturing flexibility in more varied manufacturing environments than previously studied. Existing research also provided evidence of a relationship between manufacturing flexibility and organizational performance, which is supported by this study. In past research, there was a focus on particular industries that were expected to use manufacturing flexibility to a greater extent. Although often suggested, the application of flexibility in other industries was not previously investigated. Thus, the current study took a broader view of manufacturing flexibility to determine whether it was beneficial in less obvious manufacturing environments. Therefore, the results of this study are relevant from both a theoretical and a managerial perspective.

Theoretical Implications

This study provides empirical support for the manufacturing flexibility components both individually and as an aggregated measure. This study is one of a few that is a large-scale, cross-industry effort to characterize the composition of manufacturing flexibility. Five components represented the domain of manufacturing flexibility for the business unit. These components have a valid and reliable set of measures which are usable in future research related to manufacturing flexibility. Additionally, the lack of support for equipment flexibility implies that this scale must be further revised for use in a broader context.

The multi-dimensional nature of manufacturing flexibility is frequently proposed in the literature by both academics and practitioners. Additionally, several past studies proposed that partial flexibility can be as beneficial as full flexibility because synergies are created. These concepts have been more thoroughly explored in this study. The empirical evidence validates both its multi-dimensional characteristics as well as the benefits of partial manufacturing flexibility. This study found that the manufacturing flexibility components each contribute to explaining changes in performance. Since manufacturing organizations are systems of interdependencies, the results indicate that a synergy is created when multiple components are included in the model. In particular, this study shows that labor flexibility may be more important than previously proposed. This result is likely more obvious due to the larger variety of industries in this study. These organizations may focus less on implementing complex, flexible automation and more on human resources that are highly adaptable to new situations. The significance of the relationships between labor flexibility and performance, an often ignored issue in operations management research, is of particular value to future studies. Flexibility with regard to suppliers is often studied separately from the flexibility of the buying organization. This study investigates the management of those supplier relationships to understand the effect on the buying organization's performance. This is a controllable aspect of the buyer-supplier relationship and supports the relevance of reciprocal interdependence with suppliers.

The inclusion of two moderating variables – strategic integration and organizational infrastructure – in addition to the manufacturing flexibility components previously investigated, provide additional insight into the interactions within complex manufacturing systems. The results emphasize the benefits of integrating manufacturing strategy with organizational strategy. Each significant relationship strengthened with the addition of strategic integration. Although this makes practical sense, empirical confirmation of this in real organizations is useful in further refining the manufacturing flexibility concept and those factors that influence its practical outcomes.

The development of two new infrastructure scales (management coordination and information management) that are valid and reliable are of particular value to future research. Again, these characteristics of successful organizations appear frequently in anecdotal accounts and make practical sense; however, the empirical evidence supporting them is a contribution of this research. Management support is often studied in the context of other areas such as JIT/Lean and TQM. This study used that research as a foundation and found that coordination with management support is important when implementing manufacturing flexibility. Additionally, the management of information further enables that coordination by increasing communication within an organization and with members of the supply chain. These two sub-constructs support the concept of reciprocal interdependence in the theoretical development of the model for this study. To facilitate, reciprocal interdependence, organizations can use real-time information for faster decision-making at lower levels within the organization. Due to the importance of labor in manufacturing systems, those interdependent workers can make adjustments based on real-time feedback within the process. Reciprocal interdependence requires more coordination and frequent communication which is supported by the results of this study.

This study supports the multi-dimensionality of manufacturing flexibility and finds the best combination of components and other variables that translate into changes in performance.

In addition, it provides further evidence of relationships with multiple organizational performance measures. Although there were significant relationships with most of the individual performance measures, when they were combined into two factors the patterns in the relationships were more obvious. The development of the two performance factors in the additional analysis section was not hypothesized. Both factors are of practical use in that they included common measures that manufacturing organizations track. This combination of performance measures has not been done in any previous study. With both having high reliability, these scales are of value to future research not only in manufacturing flexibility but in other related areas such as quality, mass customization, JIT/Lean, and manufacturing effectiveness.

The two new performance scales are both valid and reliable and applicable in a variety of manufacturing environments. Combining performance measures into a factor has not been done in previous studies. In particular, the manufacturing performance scale is of particular value to future research, while the inventory performance scale needs further consideration. The inventory scale may have high reliability, but these items individually may better reflect organizational capabilities. Each type of inventory represents a different part of the manufacturing process in the theoretical framework. WIP inventory relates to the internal performance of the transformation process. RM inventory reflects performance related to externally acquiring inputs from suppliers, while FG inventory reflects performance related to interacting with buyers. Additionally, reducing inventory has been a focus of many organizations since the 1970s and with the application of JIT/Lean manufacturing practices, thus there are likely other factors relevant to changes in performance related to each type of inventory. With both factors exhibiting high reliability, they should be useful not only for research related to manufacturing flexibility, but also for researching topics such as mass customization and JIT/Lean.

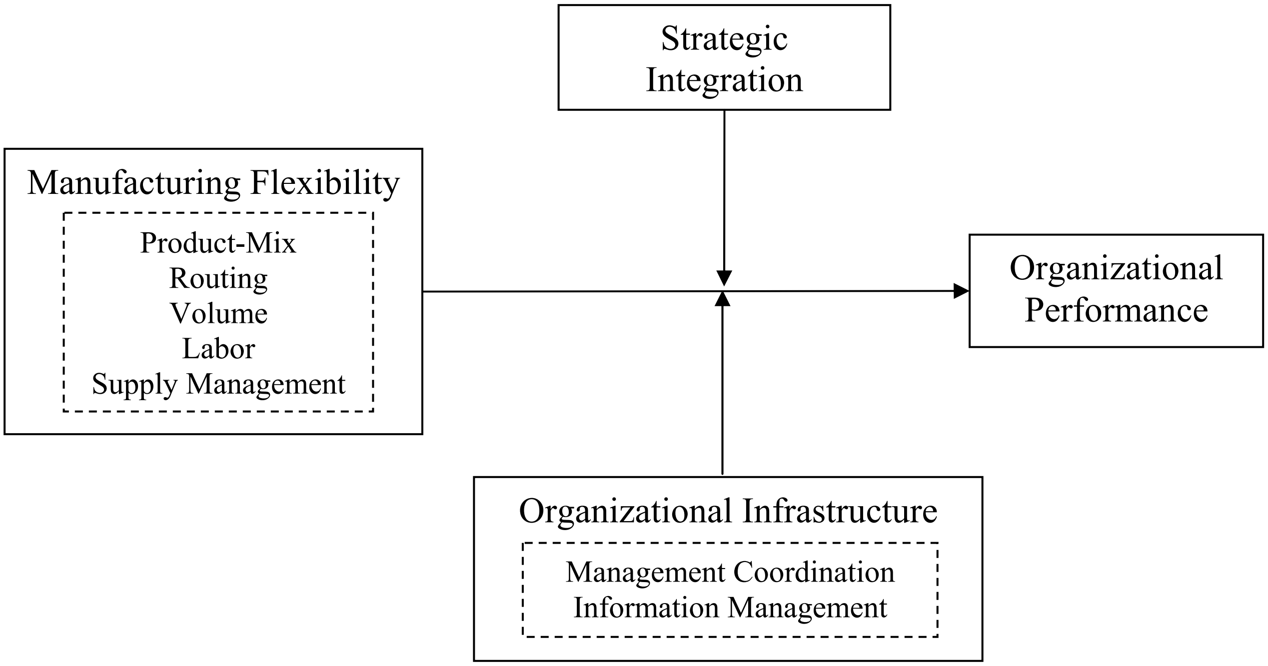


Figure 8 – Revised Research Model

The significance of the relationships between labor flexibility and multiple performance measures, an often ignored issue in operations management research, is of particular value to the theoretical development of manufacturing flexibility. The study results increase the theoretical understanding of manufacturing flexibility, its structure, and its relationship to performance. Figure 8 represents the revised model based on the results of this study.

Managerial Implications

The current research results have important implications for managers. Organizations that are planning to pursue manufacturing flexibility must understand the synergistic characteristics of the components to achieve maximum benefits. Manufacturing flexibility must be considered as part of a system rather than in isolation. Implementing one component or an inappropriate combination of components may result in less than desired benefits or may be detrimental to performance. Additionally, important interrelationships exist with other system factors related to strategic integration and organizational infrastructure. The relevant results are discussed below.

This study provides a better understanding of manufacturing flexibility in organizations and its relationship to performance. It gives managers a better understanding of which flexibility components affect performance in particular ways. As a manager, the information can be used to implement those manufacturing flexibility components that affect specific performance outcomes. For example, if an organization wants to improve on-time delivery, then their focus should be on increasing product-mix flexibility as it was the only component with a significant relationship to on-time delivery. To improve the other 11 performance measures, organizations have two or more component options to choose between. For most organizations, if they choose only one component to implement it should be labor flexibility as it has the strongest relationship with a majority of the individual performance measures. To create a synergistic effect, organizations should implement labor and volume flexibility to improve manufacturing performance or labor and product-mix flexibility to improve inventory performance. Additionally, organizations should focus on strategic integration, management coordination, and information management to further improve the organization's performance.

Both of the performance factors are of practical use as they are comprised of common measures that manufacturing organizations track.

The results can also be used by upper management to expand manufacturing capabilities in an appropriate direction. For example, when trying to increase flexibility, it is important to make sure that initiative is linked to organizational goals and strategies. Additionally, constantly reviewing and monitoring for progress is necessary to determine if changes are needed. The interactions among the components are of particular value to help organizations implement those that will complement each other. Again the importance of labor in the success of an organization can not be emphasized enough.

Suggestions for Future Research

Future research suggestions include longitudinal studies related to manufacturing flexibility. By collecting respondents' contact information, there is a possibility to extend the results in this study across multiple time periods. Longitudinal data collection may capture whether organizations continue to increase flexibility, change strategic integration, or develop infrastructural characteristics to support manufacturing flexibility. That research could show whether there are delayed effects between implementation of manufacturing flexibility and changes in performance. The results of a longitudinal study could also indicate whether performance benefits are sustainable and/or continue to improve.

In addition to longitudinal studies, in-depth case analysis of some of the respondent firms may suggest the reasons for unexpected results (e.g. lack of support for equipment flexibility). Research should also be conducted to further develop measurement instruments not based on definitions related to FMS environments. This allows for studying the relationships between the components in other environments. Future research should also include archival data and multiple organizational respondents to support reliability and validity of the scales and results. Although reliability and validity were analyzed, future studies should include objective data and a cross-check between respondents to support these results. Future research should also include responses from external sources, such as suppliers, to further understand the implication of supply management flexibility on the buying organization and the supply chain.

With regard to the data specifically collected in this study, some additional relationships can be investigated, such as differences between large and small organizations as well as comparisons across process type or manner of production (make-to-order versus make-to-stock). Analysis of the data related to the implementation status of the components and the relationship to performance should be interesting as well. Data were also collected related to the leadtime required to make changes and cost avoidance. Analysis of these other factors will provide further understanding of complex manufacturing systems. Further evaluation of the equipment scale is needed as well as an analysis to see if it is a precursor to the other component, a mediator, or a moderator.

Summary

This study further develops the concept of manufacturing flexibility by providing empirical evidence of its relationship to organizational performance. Previous research was identified and synthesized to identify the components of manufacturing flexibility to develop a reliable and valid measurement instrument. The results indicate that each manufacturing flexibility component contributes individually and synergistically to changes in performance. Of particular interest is the consistent positive effect of labor flexibility on performance.

This study provides a foundation for further understanding and explanation of the multi-dimensionality of manufacturing flexibility and the relationships between the manufacturing flexibility components and performance. Additionally, the importance of other organizational factors to manufacturing flexibility is important to further development of the manufacturing flexibility concept. The findings suggest that future research should address the variety in manufacturing environments to develop more generalizable definitions and measures.

APPENDIX A

INITIAL MAILING COVER LETTER

UNT
UNIVERSITY OF
NORTH TEXAS

<<Date>>

<<First Name>> <<Last Name>>
<<Company>>
<<Address1>>
<<City>>, <<State>> <<Zip>>

Dear <<First Name>>,

We are conducting research in the area of manufacturing flexibility and its effects on organizational performance. The need to be flexible has become increasingly important for U.S. manufacturers. There is still confusion as to what comprises manufacturing flexibility and whether every organization should try to increase flexibility. The purpose of this research is to collect information related to manufacturing flexibility within different process types and industries.

Your organization may or may not have adopted any specific flexibility components, however, it is important for you to participate in this research. For the results to truly represent manufacturing systems and those components that comprise flexible production systems, we need information from as many organizations as possible.

This questionnaire was developed through a rigorous process to specifically collect the necessary information and to minimize the time required for completion. The responses generally include circling or checking your responses and in a few cases providing a numerical answer. The questionnaire should take about 25 minutes or less to complete. Individual instructions are with each set of questions. You are encouraged to write any comments you have about the questionnaire in the space provided at the end of the survey. We have included a prepaid reply envelope for you convenience in returning the questionnaire as soon as possible.

This project has been reviewed and approved by the University of North Texas Institutional Review Board as acceptable for use with human subjects. You may be assured that your responses will remain completely confidential and all data will be reported in an aggregated form with no distinguishable characteristics revealed for you or your organization. Your name will never be written on the questionnaire. If you wish to receive a copy of the summary results from this study, please include you business card in the envelope with your survey. By providing your business card with the completed questionnaire, we can remove your name from the mailing list. This reduces duplicate follow-up mailings.

Please return the questionnaire within the next two weeks so we can complete this phase of the study. Thank you for your cooperation and participation in this research.

Sincerely,

Pamela Rogers
Project Manager

APPENDIX B

POSTCARD REMINDER

Just a reminder…

Recently you received a questionnaire seeking information about manufacturing flexibility. The questionnaire is a significant part of a research study about manufacturing flexibility.

If you have already completed and returned the survey to us, please accept our sincerest thanks. If not, please complete it and return it to us as soon as possible.

Because the survey was only sent to a select group of manufacturing professionals, it is important that your responses be included in our analysis so the results accurately represent flexibility in manufacturing systems.

If you did not receive the questionnaire, or it was misplaced, please email or call and we will send you another copy today.

We truly need and appreciate your participation in this research study.

Thank you,
Pamela Rogers, Project Manager
Email: RogersP@unt.edu Phone: (940) 565-2236

APPENDIX C

SECOND MAILING COVER LETTER

UNT
UNIVERSITY OF
NORTH•TEXAS

<<Date>>

<<First Name>> <<Last Name>>
<<Company>>
<<Address1>>
<<City>>, <<State>> <<Zip>>

Dear <<First Name>>,

About four weeks ago, I wrote seeking information about manufacturing flexibility. IF YOU HAVE RETURNED THE COMPLETED QUESTIONNAIRE FROM THE PREVIOUS MAILING, I WOULD LIKE TO THANK YOU FOR YOUR HELP AND ASK THAT YOU DISREGARD THIS LETTER. If you have not yet returned a completed questionnaire, please use this opportunity to do so. In the event your original questionnaire was misplaced, a replacement is enclosed along with a self addressed, pre-paid envelope.

This research study was undertaken to examine the relationships between various components of manufacturing flexibility and different types of manufacturing processes. The results of this study should extend the present knowledge of manufacturing flexibility by evaluating its applicability and contributions to performance of manufacturing organizations.

I am writing to you again because of the significance your questionnaire has to the success of this study. For the results to truly reflect how organizations implement and use manufacturing flexibility, it is imperative that each manufacturing professional in the sample return the enclosed questionnaire.

Your assistance is greatly appreciated.

Sincerely,

Pamela Rogers
Project Manager

APPENDIX D

INSTRUCTIONS AND DEFINITIONS

Research Project on Manufacturing Flexibility
General Instructions

1. This questionnaire asks for your assessment of the manufacturing flexibility in your business unit and its potential benefits. You may have little or a great deal of direct experience with efforts to improve manufacturing flexibility, but either way your input is valuable. Most of the questionnaire is in a standard format allowing you to provide answers in a short period of time (25 minutes or less to complete).

2. Completion of the survey involves no foreseeable risks. Participation is voluntary, and you give consent for inclusion of your responses by completing the survey. All of your answers will be kept strictly confidential. Hard copy data will be stored in locked cabinets with limited access and electronic data will be stored on a password protected computer. Only aggregate statistics from the answers of many respondents from different organizations will be published.

3. Some questions ask you to check or circle a response and others ask for specific information. There are no “right” or “wrong” answers. Different firms may respond in different ways to the same situation. Our purpose is to understand these differences.

4. Please answer all questions as accurately as you can. Keep in mind that an approximate answer is better than no answer as incomplete questionnaires may not be usable for analysis.

5. <u>There is a page of flexibility component definitions attached to these instructions.</u> These definitions are separate from the questionnaire for your convenience and may be placed next to the survey booklet as you answer the questions. In particular, please refer to these definitions when answering the manufacturing flexibility components section of the survey (page 6).

6. Please return the completed questionnaire booklet in the enclosed prepaid return envelope – in the next two weeks if possible. **If you would like to receive a summary of the study results, please enclose your business card in the return envelope.**

7. This project has been reviewed and approved by the University of North Texas Institutional Review Board (940-565-3940). You may keep this page of the survey as your record of this informed consent notice.

8. Please feel free to contact us about this project. We are happy to answer any questions you may have.

Pamela Rogers, Project Manager	RogersP@unt.edu	940-636-1698 (voice mail)
Richard E. White, Program Coordinator	White@unt.edu	940-565-3036

Department of Management
College of Business Administration
University of North Texas
P.O. Box 305429
Denton, TX 76203-5429

Thank you for taking time to complete this questionnaire.
Your cooperation and input is greatly appreciated.

Flexibility Component Definitions

Product-Mix Flexibility	The ability to offer a broad product line by switching quickly/easily between products. Changeovers may be between existing products, modification of existing products, or newly designed products. Modular design is used to reduce product development time and to increase design options using standardized modules. Production schedules and design specifications should be easy and quick to update.
Routing Flexibility	The ability to move different parts between machines/processing centers. Parts can be rerouted quickly and easily for better workload balance or to cope with disturbances. Routes can be added or removed quickly and easily to accommodate new equipment or new products/processes.
Equipment Flexibility	The ability of equipment to perform multiple operations to produce different parts. These operations may be manual or automated. As new products or product lines are created, the shop floor layout can change as needed. Reducing setup times is an ongoing goal.
Volume Flexibility	The ability to operate profitably at different output volumes. Output volume can be increased or decreased quickly and easily within the current layout. Production capacity can be increased quickly and easily.
Labor Flexibility	The ability of workers to perform multiple tasks effectively. Cross-trained workers are given increased responsibility beyond “production tasks” and may work in diverse parts of the organization. Cross-functional teams are used for production, design, and other functions within the organization.
Supply Management Flexibility	Suppliers’ ability to respond to buyer requests to adjust order quantities without significantly increasing leadtime or unit cost. Suppliers are able to deliver on-time and frequently as well as expediting orders without significantly increasing unit cost. Suppliers assist with product modifications, new product design, and leadtime improvements. Long-term relationships are established with a small number of quality suppliers.

APPENDIX E

QUESTIONNAIRE

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Manufacturing Flexibility Research Project

Please answer this questionnaire with respect to the part of the organization about which you are most familiar. From your position, you may be able to respond for the entire corporation, for only one plant, or for some business unit in between. Check the appropriate response below and **answer the questionnaire as it applies to that business unit.** Please complete all sections even if the organization is still in the process of increasing manufacturing flexibility. Base your answers on the current status and results to this point; do not try to anticipate future results. You may refer to the flexibility component definition sheet as you respond to the manufacturing flexibility component section of the survey (page 6).

Company Information

1. Business unit about which you are most familiar. (check one)

______________ 1 Total Corporation (all divisions and companies)
______________ 2 Group (several divisions)
______________ 3 Single Division or Company (in a multi-divisional corporation)
______________ 4 Individual Company (not in a multi-divisional corporation)
______________ 5 Manufacturing Plant
______________ 6 Other (specify) ______________________________________

Business Unit Information

2. Industry in which your products primarily compete. (check one)

______________ 1 Automotive
______________ 2 Aviation/Aerospace
______________ 3 Electrical
______________ 4 Electronics
______________ 5 Healthcare/Medical Devices
______________ 6 Food/Beverages
____________ 7 Transportation
____________ 8 Metal Fabrication
____________ 9 Pharmaceuticals/Chemicals
____________ 10 Plastics/Rubber
____________ 11 Software/Hardware
____________ 12 Other (specify) ___________________________

3. Business unit manufactures using make-to-order, make-to-stock, or some combination. (total should equal 100%)

____________% 1 Make-to-Order
____________% 2 Make-to-Stock

4. Business unit is unionized or non-unionized. (check one)

______________ 1 Unionized Production
______________ 2 Non-Unionized Production
______________ 3 Combination

5. Size of the business unit by number of employees. (check one)

______________ 1 Under 100
______________ 2 100 – 249
______________ 3 250 – 499
______________ 4 500 – 999
______________ 5 1000 or more

6. Size of the business unit in annual sales dollars. (check one)

______________ 1 Less than $5 million
______________ 2 $5 million to < $10 million
______________ 3 $10 million to < $20 million
______________ 4 $20 million to < $50 million
______________ 5 $50 million to < $100 million
______________ 6 $100 million or more

7. Percentage of business unit's annual sales generated from manufacturing and services, respectively. (total should equal 100%)

__________ % 1 Manufacturing

__________ % 2 Services

8. Percentage of business unit's annual sales produced by type of manufacturing process. (total should equal 100%)

__________ % 1 **Project:** Products/units are of such size and complexity that each requires special planning and control. The material flow pattern may be different for each product.

__________ % 2 **Job Shop:** Custom products/units are produced in small batches in production runs lasting a few hours or days. General purpose equipment performing same/similar functions is grouped in one area or department and equipment setup is required for each different batch. The material flow pattern may be different for each batch.

__________ % 3 **Batch:** Product/units are produced in moderately large batches in production runs lasting several days or weeks. Mostly similar general purpose equipment performing same/similar functions is grouped together and equipment setups are generally required between batches. The material flow pattern may be the same/similar for many of the products; often a dominant material flow pattern exists.

__________ % 4 **Repetitive/Mass Production:** Most products/units are mass produced. The products are very similar/standardized discrete units. The work stations are laid out sequentially (i.e. assembly line) and the material flow is basically the same for all products.

__________ % 5 **Continuous Flow:** Products are highly standardized. The processing is almost totally automated with highly specialized equipment. Production tasks take place over predetermined sequential steps. Material flow is continuous rather than in discrete units.

9. Strategic Integration

Please circle the appropriate response indicating the frequency of each of the following in your business unit. If a statement doesn't apply, then an appropriate response would be "never."

	Never	Seldom	Half the Time	Usually	Always
a. Manufacturing strategy supports corporate strategy.	1	2	3	4	5
b. We clearly define manufacturing strategies, goals, and objectives.	1	2	3	4	5
c. Our corporate strategy leverages existing capabilities.	1	2	3	4	5
d. Manufacturing strategy complements other functional strategies.	1	2	3	4	5
e. Manufacturing is involved in corporate strategy formulation.	1	2	3	4	5
f. Manufacturing strategy is frequently reviewed and revised.	1	2	3	4	5
g. Flexibility is a central element of manufacturing strategy.	1	2	3	4	5
h. Our manufacturing strategy makes the most of existing capabilities.	1	2	3	4	5
i. Manufacturing strategies and goals are clearly communicated to employees.	1	2	3	4	5

10. Organizational Infrastructure

Please circle the appropriate response indicating the frequency of each of the following in your business unit. If a statement doesn't apply, then an appropriate response would be "never."

	Never	Seldom	Half the Time	Usually	Always
a. Cross-functional teams have regular meetings.	1	2	3	4	5
b. Managers focus on continuous process improvement (kaizen).	1	2	3	4	5
c. Resources, ideas and information are shared among functions.	1	2	3	4	5
d. Our information system makes pertinent information available.	1	2	3	4	5
e. We work as a team with our supply chain members.	1	2	3	4	5
f. Managers have full access to information on supply chain needs.	1	2	3	4	5
g. Management emphasizes change and pursuing ''best practice."	1	2	3	4	5
h. Information exchange between our suppliers and us is timely.	1	2	3	4	5
i. We work to improve responsiveness to internal/external customers.	1	2	3	4	5
j. Managers provide personal guidance for improving flexibility.	1	2	3	4	5
k. Decision making is coordinated throughout the organization.	1	2	3	4	5
l. Information exchange between our suppliers and us is complete.	1	2	3	4	5
	Never	Seldom	Half the Time	Usually	Always
m. Planning for product changes involves a cross-functional team.	1	2	3	4	5
n. Management emphasizes information sharing.	1	2	3	4	5
o. Employees are rewarded for learning new skills.	1	2	3	4	5
p. Our supply chain is informed about changes that may affect them.	1	2	3	4	5
q. Management is evaluated on improving manufacturing flexibility.	1	2	3	4	5
r. Decisions are made and coordinated based on real time information.	1	2	3	4	5
s. Management is responsible for improving manufacturing flexibility.	1	2	3	4	5
t. Information exchange between our suppliers and us is accurate.	1	2	3	4	5
u. Production teams meet each shift.	1	2	3	4	5
v. Our supply chain has effective communication processes.	1	2	3	4	5
w. Business processes and supply chain functions are integrated.	1	2	3	4	5
x. Our information systems increase our manufacturing flexibility.	1	2	3	4	5
y. We have direct computer-to-computer links with suppliers.	1	2	3	4	5

11. Manufacturing Flexibility

Please circle the appropriate response indicating the frequency of each of the following in your business unit relative to your product-mix, routing, and equipment capabilities. If a statement doesn't apply, then an appropriate response would be "never."

Product-Mix	Never	Seldom	Half the Time	Usually	Always
a. We produce a wide variety of products in our plant(s).	1	2	3	4	5
b. We produce different product types without major changeovers.	1	2	3	4	5
c. We build different products in the same plant at the same time.	1	2	3	4	5
d. We vary the product mix from one period to the next.	1	2	3	4	5
e. We easily change from one product to another.	1	2	3	4	5
f. A large number of products are modified to customer specifications.	1	2	3	4	5
g. New products are extensions of existing product families.	1	2	3	4	5
h. Bills of material are easy to change in our production planning system.	1	2	3	4	5
i. Modular design is used to create a broader product offering.	1	2	3	4	5
j. Production schedules are easy to change in our production planning system.	1	2	3	4	5
k. We frequently introduce new products.	1	2	3	4	5

Routing	Never	Seldom	Half the Time	Usually	Always
a. A typical part can be routed to alternate machines.	1	2	3	4	5
b. A typical part can use many different routes.	1	2	3	4	5
c. The system has alternative routes in case machines break down.	1	2	3	4	5
d. The sequence for parts flow can be changed.	1	2	3	4	5
e. The processing sequence can be changed quickly.	1	2	3	4	5
f. Our material handling system handles different types of parts.	1	2	3	4	5
g. Our material handling system is easily reconfigured.	1	2	3	4	5

Equipment	Never	Seldom	Half the Time	Usually	Always
a. Machines/tooling can be set-up quickly.	1	2	3	4	5
b. Our typical machine performs many types of operations.	1	2	3	4	5
c. Machines become obsolete when new operations are required.	1	2	3	4	5
d. Machine set-ups are easy.	1	2	3	4	5
e. We use cellular manufacturing.	1	2	3	4	5
f. Plant layout is easily reconfigured for product or process changes.	1	2	3	4	5
g. Equipment is well maintained and ready for production.	1	2	3	4	5

11. Manufacturing Flexibility (cont.)

Please circle the appropriate response indicating the frequency of each of the following in your business unit relative to your labor, volume, and supply management capabilities. If a statement doesn't apply, then an appropriate response would be "never."

Volume	Never	Seldom	Half the Time	Usually	Always
a. We operate efficiently at different levels of output.	1	2	3	4	5
b. We operate profitably at different production volumes.	1	2	3	4	5
c. We economically run various batch sizes.	1	2	3	4	5
d. We quickly change the quantities of our products produced.	1	2	3	4	5
e. We vary total output from one period to the next.	1	2	3	4	5
f. We easily change the output volume of a manufacturing process.	1	2	3	4	5
g. Production capacity is increased with temporary employees.	1	2	3	4	5
h. Production capacity is increased by outsourcing.	1	2	3	4	5

Labor	Never	Seldom	Half the Time	Usually	Always
a. A typical worker uses different tools effectively.	1	2	3	4	5
b. Employees are cross-trained to perform a variety of activities.	1	2	3	4	5
c. Workers operate various types of machines.	1	2	3	4	5
d. Our employees have strong problem-solving abilities.	1	2	3	4	5
e. Workers are cross-trained in multiple cells/teams.	1	2	3	4	5
f. Workers are cross-trained in diverse departments in a plant.	1	2	3	4	5
g. Teams are reorganized in response to product or process changes.	1	2	3	4	5

Supply Management	Never	Seldom	Half the Time	Usually	Always
a. Our suppliers make frequent deliveries.	1	2	3	4	5
b. Suppliers adjust quantities without significantly increasing unit cost.	1	2	3	4	5
c. Suppliers adjust quantities without significantly increasing leadtime.	1	2	3	4	5
d. We provide technical assistance to our suppliers.	1	2	3	4	5
e. Suppliers modify products to meet our needs.	1	2	3	4	5
f. Our suppliers assist in product design and innovation.	1	2	3	4	5
g. We establish long-term relationships with suppliers.	1	2	3	4	5
h. We rely on a small number of high quality suppliers.	1	2	3	4	5
i. Our suppliers adjust delivery times to meet changing requirements.	1	2	3	4	5
j. Suppliers assist with reducing our overall customer leadtime.	1	2	3	4	5

12. Manufacturing Flexibility Components

Please refer to the flexibility components definitions page while you are answering the questions below.

N = No effort to improve this flexibility
0-1 = Effort to improve started within the last year
1-3 = Effort to improve started 1 year but < 3 years ago
3-5 = Effort to improve started 3 years but < 5 years ago
5+ = Effort to improve started 5 or more years ago

How long has your business unit worked to improve the following?					
a. Product-Mix Flexibility	N	0-1	1-3	3-5	5+
b. Routing Flexibility	N	0-1	1-3	3-5	5+
c. Equipment Flexibility	N	0-1	1-3	3-5	5+
d. Volume Flexibility	N	0-1	1-3	3-5	5+
e. Labor Flexibility	N	0-1	1-3	3-5	5+
f. Supply Management Flexibility	N	0-1	1-3	3-5	5+

13. Leadtime

Please circle the time required to make changes for each of the following regarding your business unit.

1 hr = Takes 1 hour or less
1 day = Takes more than 1 hour but less than 1 day
1 wk = Takes more than 1 day but less than 1 week
1 mo = Takes more than 1 week but less than 1 month
6 mo = Takes more than 1 month but less than 6 months
1 yr = Takes more than 6 months but less than 1 year
>1 yr = Takes more than 1 year

	1 hr	1 day	1 wk	1 mo	6 mo	1 yr	>1 yr
a. Change the product mix using current products	1	2	3	4	5	6	7
b. Change the product mix with modified products	1	2	3	4	5	6	7
c. Change the product mix to add new products	1	2	3	4	5	6	7
d. Route a product to an alternate machine	1	2	3	4	5	6	7
e. Add new material handling routes to the current layout	1	2	3	4	5	6	7
f. Change material handling routes when adding new machines	1	2	3	4	5	6	7
g. Change output volume by ± 10% (using existing resources)	1	2	3	4	5	6	7
h. Increase capacity by 10% (by adding new resources)	1	2	3	4	5	6	7
i. Set-up equipment to make a product in the same part family	1	2	3	4	5	6	7
j. Set-up equipment to make a product in a different part family	1	2	3	4	5	6	7
k. Set-up equipment to make a new product	1	2	3	4	5	6	7
l. Train a worker to make a modified product	1	2	3	4	5	6	7
m. Train a worker to make a new product	1	2	3	4	5	6	7
n. Suppliers to accommodate change requests	1	2	3	4	5	6	7
o. Suppliers to increase their output volume by 10%	1	2	3	4	5	6	7

14. Cost Avoidance

Please circle the appropriate response indicating the frequency of each of the following in your business unit. If a statement doesn't apply, then an appropriate response would be "never."

	Never	Seldom	Half the Time	Usually	Always
a. Employees modify existing equipment to make new products.	1	2	3	4	5
b. Our employees make minor equipment repairs.	1	2	3	4	5
c. Our employees make major equipment repairs.	1	2	3	4	5
d. Quality is affected when changing the product mix.	1	2	3	4	5
e. Average cost per unit is affected when changing the product mix.	1	2	3	4	5
f. Our new products require new tooling.	1	2	3	4	5
g. Product designers use standardized components/modules if possible.	1	2	3	4	5
h. Average cost per unit is affected by using alternate machines.	1	2	3	4	5
i. Our new products require new equipment/machines.	1	2	3	4	5
j. Prototyping is used to improve product designs.	1	2	3	4	5
k. We use delayed differentiation to reduce cost.	1	2	3	4	5

15. Business Unit Performance

Based on efforts to improve manufacturing flexibility, please indicate how much change there is for each performance measure.

	Decreased More than 50%	Decreased 31% to 50%	Decreased 11% to 30%	Decreased 1% to 10%	No Change	Increased 1% to 10%	Increased 11% to 30%	Increased 31% to 50%	Increased More than 50%
a. Setup times	1	2	3	4	5	6	7	8	9
b. Throughput time (from order release to completion)	1	2	3	4	5	6	7	8	9
c. Scrap and rework cost	1	2	3	4	5	6	7	8	9
d. Worker productivity	1	2	3	4	5	6	7	8	9
e. Raw materials (RM) inventory levels	1	2	3	4	5	6	7	8	9
f. Work-in-Process (WIP) inventory levels	1	2	3	4	5	6	7	8	9
g. Finished Goods (FG) inventory levels	1	2	3	4	5	6	7	8	9
h. Number of backorders	1	2	3	4	5	6	7	8	9
i. On-time delivery	1	2	3	4	5	6	7	8	9
j. Unit manufacturing costs (excluding purch. materials)	1	2	3	4	5	6	7	8	9
k. Cost of purchased materials	1	2	3	4	5	6	7	8	9
l. Machine utilization	1	2	3	4	5	6	7	8	9

General Information

12. Please indicate your years of experience in the following categories.

__________ yrs With this organization

__________ yrs Overall business experience

13. What is your level within the organization? (check one)

__________ 1 Production worker
__________ 2 Production management
__________ 3 Middle management
__________ 4 Top management
__________ 5 Support staff
__________ 6 Other (specify) ____________________________

14. What is your current department? (check one)

__________ 1 Production
__________ 2 Quality
__________ 3 Inventory/Materials
__________ 4 Purchasing
__________ 5 Engineering
__________ 6 Academic
__________ 7 Consultant
__________ 8 Other (specify) ____________________________

15. What is your current job title? (check one)

__________ 1 Production Supervisor
__________ 2 Manufacturing Manager
__________ 3 Inventory/Materials Manager
__________ 4 Purchasing Manager
__________ 5 Industrial Engineer
__________ 6 Product Design Engineer
__________ 7 Plant Manager
__________ 8 VP Manufacturing
__________ 9 Chief Operating Officer (COO)
__________ 10 CEO/President
__________ 11 Other (specify) ____________________________

16. What is the highest level of education you have completed? (check one)

__________ 1 Some high school
__________ 2 High school
__________ 3 Vocational school
__________ 4 Some college courses
__________ 5 Associate's degree
__________ 6 Bachelor's degree
__________ 7 Graduate degree
__________ 8 Other (specify) ____________________________

Thank you for taking the time to fill out this questionnaire. Your cooperation and input is appreciated. Please return the questionnaire booklet to the address on the front page using the prepaid envelope provided. **If you would like a summary of the study results, please enclose your business card in the return envelope.**

Comments (optional):____

____

____

____

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