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AN EMPIRICAL INVESTIGATION OF THE CONTRIBUTION OF STRATEGIC SOURCING TO MANUFACTURING FLEXIBILITIES

by

Ajay Das

A DISSERTATION

Submitted to
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ABSTRACT

AN EMPIRICAL INVESTIGATION OF THE CONTRIBUTION OF STRATEGIC SOURCING TO MANUFACTURING FLEXIBILITIES

By

Ajay Das

Companies are increasingly turning to flexibility as a competitive strategy in uncertain market environments. Empirical studies of manufacturing flexibility have centered around the uses and advantages of advanced technology. Few studies have examined alternative ways of attaining flexibility objectives. This dissertation examined the role of strategic sourcing in achieving manufacturing flexibilities in an enterprise. Specifically, this research:

- *Investigated the impact of strategic sourcing on different dimensions of manufacturing flexibility*

- *Investigated the inter-relationships among different types of manufacturing flexibilities*

- *Investigated the impact of manufacturing flexibilities on different dimensions of manufacturing performance*

A conceptual framework of manufacturing flexibility, and its antecedents and outcomes, was proposed and tested, using empirical data. The data were analyzed using structural equation modeling. The results of the data analysis suggest that strategic sourcing can be a viable route to the development of mix and new product flexibilities. The findings also indicated synergies among different manufacturing flexibilities. Mix flexibility was observed to have a positive impact on modification flexibility, while

modification flexibility was found to have a positive effect on new product flexibility. The data also indicated significant relationships between manufacturing flexibilities and manufacturing performance. Mix flexibility was found to positively influence cost reduction, manufacturing cycle time reduction, and delivery performance. New product flexibility was found to have a positive impact on new product introduction time and customization responsiveness performance.

The identification of a positive relationship between strategic sourcing and manufacturing flexibility makes a new and significant contribution to theory development in the sourcing and flexibility literature. The exploration of manufacturing flexibility inter-relationships addresses another gap in the flexibility literature. This research also clarifies the role of manufacturing flexibility in manufacturing and corporate strategy.

For the practitioner, the research results provide direction on targeting specific manufacturing flexibilities with suitable supply base strategies. Finally, by examining definite relationships between manufacturing flexibilities and manufacturing performance(s), this research provides managerial insights on leveraging supply chain strategies for competitive advantage.

DEDICATED TO MY DEPARTED PARENTS, ALOKA DAS AND DR. SHAILENDRA MOHAN DAS, PROFESSOR EMERITUS, D.Sc., FRZS, FCS.

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I gratefully acknowledge the guidance and advice provided by my Chair, Professor Ram Narasimhan, in the development and completion of this dissertation. This research would not have been possible without his direction and tutelage.

I also record my deep appreciation for the time and efforts contributed by the other members of my dissertation committee, Dr. Gary Ragatz, Dr. Robert B. Handfield, and Dr. Daniel Krause. Their quick feedback on my dissertation drafts helped immensely in keeping this research on schedule.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Worldwide, highly successful companies have reduced product development, manufacturing and ramp-up times significantly. The ability to respond quickly, correctly and profitably to individual customer and market demands is a highly prized competitive advantage. A recent study by the Center for Advanced Purchasing Studies (Carter and Narasimhan, 1995) has highlighted the impact of customization and flexibility demands on sourcing strategies. The results of the manufacturing futures survey have also clearly indicated the emphasis that manufacturing firms place on the competitive value of manufacturing and design flexibility, customization and product variety (Miller 1992). The shift to these corporate priorities is supported by industry data. For example, the largest selling car in America in 1969 was the Chevy Impala with annual sales of 1.5 million. In 1989, it was the Honda Accord with annual sales of 380,000 units. In the auto industry, the volume per model has dropped dramatically, while model variety has proliferated to over 600 models (Wheelwright and Clark, 1992 - a). In the consumer electronics industry, Sony has introduced in excess of 200 variations of its original Walkman in the space of a few years, while reducing prices concurrently (Wheelwright and Clark, 1992 - b).

Product proliferation presents serious challenges to manufacturing firms under pressure to compete on quality and delivery. With product life cycles being reduced to a matter of months in some cases, the need for constant renewal compels firms to be more agile and flexible in their responses and initiatives (Bessant, J.R., 1989). These trends have led to the emergence of manufacturing flexibility as a key competitive strategy.

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Strategic sourcing has been identified as among the top five-most significant trends in sourcing and supply management by the 1994 North American Executive Purchasing Roundtable (Carter and Narasimhan, CAPS, 1995). The increasing strategic reach of sourcing, its evolving role in developing sustainable competitive advantages and its emergence as a core competence of firms is illustrated by the increasing dependence of firms on strategic supply management capabilities for attaining differentiation advantages (Fortune, 1995). The make/design/buy decision has never been of greater consequence. A year long international study in 1995 by Arthur Andersen and The Economist Intelligence Unit found that 93% of corporations plan to outsource in the next three years and that fully 31% of such buy decisions will be in the area of production/manufacturing (Outsourcing Institute, 1996). The study also documents a clear trend towards the use of suppliers as a competitive tool rather than a means of cost control.

The need for sourcing to be supportive of corporate competitive priorities has been stressed by Watts, Kim and Hahn (1992) in their framework linking strategic sourcing to corporate competitive priorities. Given the strategic importance of flexibility as a source of sustainable competitive advantage for the firm, it follows that sourcing must provide appropriate strategies and action programs aimed at achieving flexibility goals. There is evidence that manufacturing firms are increasingly obtaining volume, design and technology flexibilities through strategic supply base management (Tully, 1994).

However, the contributions of sourcing to the achievement of manufacturing flexibilities have not been investigated much in the literature. Empirical studies have centered on the use and advantages of advanced technology for enhancing/achieving manufacturing flexibility

(Groover, 1980; Gerwin, 1982; Ranky, 1983;; Hayes and Jaikumar, 1988; Kaplan, 1986). A recent report by Maruca (1993), points out that technology expenditures may in fact, have had the opposite effect of making firms less flexible. There is a paucity of empirical studies that go beyond a cursory examination of the potential impact of sourcing on flexibility (Carter and Narasimhan, 1990; Johnson and Johnson, 1991; Takac, 1993). More recently, Suarez et al. (1996) reported a positive relationship between the degree and relational quality of outsourcing, and achievement of certain flexibilities in the semi-conductor industry. The linkage was however, not explored in any detail.

This research investigates the relationship between strategic sourcing and manufacturing flexibility, explicates the buyer-supplier interface in such relationships and examines the impact of manufacturing flexibilities on manufacturing performance.

1.1 Background

What is flexibility? Webster (1990) defines flexibility as the capacity to adjust to change. Others have characterized flexibility as "doing things fast" and "being responsive to the market" (Bower and Hout, 1988; Stalk, 1988). Cybernetic theory defines flexibility as the capacity of a control system to change its system state in response to environmental variety (Kickert, 1985). Strategic perspectives of flexibility have been developed, defining flexibility as the capability to manage "capricious settings" and as the organizational ability to adapt to "substantial, uncertain, and fast-occurring" environmental changes impacting firm performance (Aaker and Mascarenhas, 1984; Evans, 1991). A common theme in all these treatments of flexibility is the notion of adaptability and recognition of the fact that flexibility is as num poten

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much potential as realized.

Flexibility capabilities, as defined above, may be attained in different and cumulative ways. Companies may target employee flexibility, organization structure and processes, and international value chain portfolio balancing (Kogut and Kutalika, 1994; Das and Elango, 1995). Investments in manufacturing encompassing structural and infrastructural areas, such as plant and machinery, product modularization and component standardization, and supply-base management and development are also representative of flexibility enhancing actions. Such investments may be broadly grouped under the rubric of manufacturing flexibility. Investments in manufacturing flexibility alone may not be enough to ensure enterprise flexibility in response to market volatility without complementary activities in human relations, marketing, and performance measurement and reward systems. However, manufacturing is a key competency for most manufacturing companies and flexibility research has converged on this aspect of firm operations (Gerwin, 1987, 1993; Slack, 1990).

Manufacturing flexibility is defined as the ability of a manufacturing system to cope with changing circumstances (Buzacott & Mandelbaum, 1985) or environmental uncertainties (Mascarenhas, 1981; Barad & Sipper, 1988). Flexibility is a multi-dimensional concept. Its dimensions include sourcing flexibility, machine flexibility, material handling flexibility, operation flexibility, process flexibility, mix flexibility, routing flexibility, volume flexibility, expansion flexibility, program flexibility, production flexibility and demand flexibility (Sethi and Sethi, 1990; Browne, Dubois, Rathmill, Sethi and Stecke, 1984; Gupta and Goyal, 1989). There exists appreciable fragmentation on definitions and unit of analysis in conceptualizing the

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construct of flexibility. Additionally, literature subsumes different levels of flexibility in its discussions of the construct. For instance, production flexibility can be a combination of machine, process and volume flexibilities. Similarly, routing flexibility could be a building block for process flexibility. Time and cost are two important elements in assessing flexibility (Slack, 1983). Various quantitative and qualitative measures have been devised to assess the different flexibility types. Gupta and Goyal(1989) provide a fairly comprehensive discussion of various manufacturing flexibility concepts and measures suggested by different researchers in the past. An empirically tested multi-dimensional measure of flexibility has been recently constructed and validated by Gupta & Somers (1996).

1.2 Routes to Manufacturing Flexibility

1.2.1 *The Role of Advanced Manufacturing Technology*

In contrast to the paucity of research in the area of sourcing-flexibility relationships, there are several studies on the impact of advanced manufacturing technology on the acquisition of manufacturing flexibilities are abundant in the literature. Although the gains to be obtained from advanced technologies may be notably curtailed by lack of organizational integration (Jaikumar, 1986; Upton, 1995) or by conditions of firm size, capital inaccessibility or unavailability of technical expertise (Flynn et al, 1994), enough evidence remains to sustain findings of positive associations between advanced technologies and attainment of manufacturing goals in terms of cost, quality, volume and productivity (Dodgson, 1987; Farley, Lehman and Moore, 1987; Hayes and Jaikumar, 1991). The central argument seems to revolve around the nature of *intended vs. realized* manufacturing gains pertinent to the use of such technologies. Research has shown that many adopters of advanced manufacturing systems suffer from an ambiguity or mis-direction of goals for such systems. Although flexibility has been highlighted as the natural goal of such advanced systems (Parthasarthy and Sethi, 1992), cost is often cited as the primary (achieved) manufacturing objective (Adler, 1988). Benefits in labor and product cost reductions to the tune of 25-88% have been reported in the literature (Hayes and Jaikumar, 1991). Such perspectives fail to recognize and/or elicit the additional gains of variety, customization and reduced new product introduction response times due to advanced manufacturing technology (Dodgson, 1987; Alvarez and Gill, 1994).

An emerging school of thought provides a middle-ground perspective, in that advanced manufacturing technology is considered to enlarge the scope of differentiation capabilities and simultaneously reduce the costs of doing so, perhaps even below conventional plant minimum economic scale cost levels (Schlie and Goldhar, 1989, 1995). The flexibility framework of Goldhar and Lei(1995) envisages plants evolving from using advanced manufacturing technology for cost and modification purposes to ultimately obtaining new product flexibility capabilities at a competitive cost.

Conventionally, research has addressed the issue of manufacturing flexibility achievement as essentially one of obtaining and successfully implementing advanced flexible manufacturing systems (Sethi and Sethi, 1990). Divergent opinions have been expressed about the key success factors of implementation of such manufacturing systems, mainly involving appropriate strategic and organizational changes that should accompany the new technologies (Goldhar, Jelinek and Schlie, 1991, Upton, 1995). Integration of technology, human resources, marketing and top management support is considered vital to successful implementation of advanced techno

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Gerwin (1993) suggests that advanced manufacturing technology represents just one way of delivering flexibility. Subcontracting is mentioned as an alternative strategy for coping with demand uncertainties. Other coping strategies include demand management through effective manufacturing - marketing schedule sharing, maintenance of slack in the form of inventory and excess capacity, forecasting efficiencies, and marketing strategies such as sales promotions and other demand-pattern influencing programs (McCutheon, Raturi and Meredith, 1994).

In summary, researchers have recently begun to look beyond advanced manufacturing systems, to alternative methods of delivering flexibilities. Sourcing is one of the relatively less investigated areas in this regard.

1.2.2 *The Role of Strategic Sourcing*

Limited literature exists on the role of sourcing in obtaining manufacturing flexibilities. Recent studies have found significant associations between sourcing and mix, volume and new product flexibilities (Suarez, Cusumano and Fine, 1996; Olhager 1993). These studies show a lack of detail in their investigation of sourcing-flexibility relationships.

The objective of strategic sourcing is essentially uncertainty reduction, when faced with supply, competitive, response and demand uncertainties (Wernerfelt and Karnani, 1987; Milliken, 1987). Strategic sourcing has been characterized as a corporate response to mitigate uncertainty by securing improved flexibilities (Johnson and Johnson, 1991). Carter & Narasimhan (1990) describe strategic sourcing as an indus

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initiative to build competitive advantage through early supplier involvement in simultaneous engineering teams, sharing of supplier technology and supplier assistance in developing product and process improvements. Strategic sourcing is a way to achieve manufacturing capacities without incurring investments in capital equipment. Strategic sourcing has been stated to be an important influence on manufacturing strategy (Rohlwink, 1988) with positive implications for manufacturing flexibility (Gupta and Somers, 1996; Takac, 1993; Quinn et al., 1990).

None of this research focuses on the dynamics of the sourcing-manufacturing flexibility relationship. Clearly, supplier capabilities can generate competitive advantages of time (Handfield and Pannesi, 1995) and cost. How exactly such advantages are related to the competitive priority of manufacturing flexibility is not very well known.

1.3 Research Question and Objectives

This research study addressed the question: what is the relationship between strategic sourcing and manufacturing flexibility?

The research objectives of this dissertation were to:

- *Investigate the impact of strategic sourcing on the achievement of manufacturing flexibilities*
- *Investigate the inter-relationships among the different types of manufacturing flexibility*
- *Investigate the impact of manufacturing flexibilities on different aspects of manufacturing performance*

These research issues were investigated by examining hypotheses:

- relating strategic sourcing to different aspects of manufacturing flexibility
- relating advanced manufacturing technology to different aspects of manufacturing flexibility. This hypothesis was introduced for control purposes. The objective was to demonstrate the distinct impact of strategic sourcing on manufacturing flexibility, separate from the

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- relating different dimensions of manufacturing flexibility to various aspects of manufacturing performance.

1.4 Significance of the Study

The primary research objective was to explore the relationship between strategic sourcing and manufacturing flexibilities. Another goal was to gain an understanding of the synergies among different types of manufacturing flexibilities. A final research objective was to understand the key influences of manufacturing flexibility on different aspects of manufacturing performance.

This study advances the flexibility literature in several ways. Empirical relationships were proposed and tested among sourcing, manufacturing flexibility and firm performance, filling a gap in existing sourcing and flexibility literature. The exploration of manufacturing flexibility interactions addresses another gap in the flexibility literature. Finally, very few studies have specifically looked at relationships between manufacturing flexibilities and individual dimensions of manufacturing performance. These research objectives add to the body of knowledge on manufacturing flexibility.

From a practical standpoint, the significance of identifying a potential relationship between sourcing and manufacturing flexibilities is apparent, given the increasing importance of customization and flexibility as key competitive criteria. The basic premise of this research is that strategic sourcing can be a key strategic lever for accomplishing manufacturing flexibilities. Supply-base strategies would focus on the selection, development and certification of suppliers with the requisite competencies to fulfill specific manufacturing flexibility

targets. Manufacturers can create and support competitive order-winning competencies by targeting specific manufacturing flexibilities with appropriate sourcing strategies.

Current views of manufacturing suggest near simultaneous realization of multiple competencies (Hayes et al., 1994; Roth et al. 1993). The flexibility interactions examined in this study may be particularly informative for a plant that faces the challenge of rapidly developing different types of manufacturing flexibilities. Managers should be aware of the potential complementarities among targeted flexibilities and factor these into their action plans.

From a strategic perspective, the study involves three distinct levels. At the corporate level, management drives the choice of competitive priorities to meet market and technology imperatives. At the business processes level, these corporate priorities are translated into cost, time, quality and variety goals. At the functional level, manufacturing establishes its own objectives in consonance with firm priorities, and sets appropriate manufacturing goals. Sourcing implements supply-base strategies designed to fulfill manufacturing and business priorities. To illustrate, a business strategy of cost reduction would require reductions in manufacturing costs. Modification flexibility could enable such cost reductions, by reducing the cost of making minor product design changes. In turn, modification flexibility may be achieved through several ways: an effective sourcing strategy consisting of actions aimed at developing and interfacing a responsive and technologically adept supply base; the adoption of advanced manufacturing technology; or through a combination of actions in both areas. Similarly, plants could attain volume flexibilities by obtaining supplier generated capacity and quick-response competencies, and/or appropriately configuring and

utilizing advanced manufacturing technology in their production and design processes. *For the manager, each flexibility can have different drivers and understanding the relevant relationships may be critical to successful implementation of manufacturing flexibility programs.*

1.5 Scope Of The Dissertation

Literature informs that flexibility can be a function of multiple influences. Besides suppliers and advanced technologies, other likely variables impacting flexibility are human resource practices, product modularization and postponement strategies (Das and Elango, 1995; Slack, 1993). Marketing techniques such as discount pricing, sales promotions and other dampening techniques are also employed to counter environmental fluctuations, mitigating the need for flexibility investments (Pine, 1993; Upton, 1995). The current model does not take such factors into account, and is therefore, somewhat truncated in content and scope. Admittedly, a expanded nomological network would complicate interpretation in addition to requiring more research resources. A series of cumulative studies, manageable and focusing on different causal relationships at a time, would perhaps be a more feasible alternative. The research also does not extend its scope to an examination of firm level performance, for reasons of time and questionnaire length restrictions.

1.6 Organization of the Dissertation

Chapter 1 of the dissertation outlines the context, describes broad constructs, research questions and significance of the study. Chapter 2 describes the diverse research streams and literature surrounding the key constructs, their relationships and their operationalizations. Gaps in the literature are identified and analyzed in this chapter. Chapter 3 develops a conceptual model of the research questions and the rationale for the research hypotheses. Chapter 4 describes details research design, measurement, and sampling and data analysis methodology issues. Chapter 5 develops measurement and path models to examine the hypothesized relationships. Chapter 6 discusses the results of the data analysis, and their implications for theory and practice. Chapter 7 concludes the study with a discussion of the research contributions, study limitations, and directions for future research.

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CHAPTER 2

REVIEW OF THE LITERATURE

The preceding chapter introduced the concept of manufacturing flexibility and briefly discussed the antecedent roles of sourcing and advanced manufacturing technology. This chapter describes and analyses the manufacturing flexibility concept, and its antecedents and outcomes in more detail. First, the conceptual and empirical literature on manufacturing flexibility is presented. Key antecedents of manufacturing flexibility investigated in the literature, are identified and discussed. This is followed by a review of the manufacturing performance literature. The chapter concludes with a summary of key issues in the flexibility literature.

2.1 Manufacturing Flexibility

2.1.1 *Conceptualizations*

Various frameworks have been developed in the literature on manufacturing flexibility. Suarez et al. (1996) divide the empirical literature on manufacturing flexibility into four groups, covering studies dealing with taxonomies, performance, historical and economic perspectives and literature reviews. Gupta and Goyal (1989) use theoretical vs. non-theoretical and qualitative vs. quantitative differentiating criteria in their review of the manufacturing literature. This research separates manufacturing literature into three broad categories. The first category includes studies, which attempt to develop a context for manufacturing flexibility and construct nomological networks around the construct (Gerwin, 1993; Swamidass, 1987). The second category comprises research that frames manufacturing flexibility into system level typologies (Mandelbaum, 1978; Swamidass, 1988). The third the ma

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category covers studies that adopt a micro-level approach and taxonomize the manufacturing flexibility construct into hierarchical, constituent parts (Gerwin, 1983; Slack, 1990; Suarez et al., 1996). Table 2.1 presents salient research studies within these three classifications.

The *contextual* literature develops the logic for a relationship between environmental uncertainty and the need for manufacturing flexibility. Swamidass et al. (1987) incorporate manufacturing flexibility as part of manufacturing strategy. Flexibility is represented by the frequency of new product introduction and the range of product variety. The study finds significant positive relationships between uncertainty and strategy (flexibility) and between strategy and performance. Slack (1988) links the choice of manufacturing flexibilities to a-priori ranked strategic goals. His framework extends to the identification of resources necessary to achieve the selected manufacturing flexibilities. Suarez et al. (1991) present a framework integrating uncertainty and strategy as a combined influence on the type and degree of manufacturing flexibility appropriate for an organization. Methods of flexibility delivery are also discussed and performance is judged by the degree of flexibility attained relative to that required. Finally, Gerwin (1993) offers a framework that establishes a feedback relationship between environmental uncertainty and manufacturing strategy. Manufacturing flexibility is seen as a strategy to mitigate and re-define environmental uncertainty through effective use of manufacturing flexibilities. The majority of the *contextual* studies share a common perspective in treating environmental uncertainty as the primary reason for manufacturing flexibility. Manufacturing flexibility is envisaged as a response to uncertainty present in the internal and external environment. The need for manufacturing flexibility is driven by the pre

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the presence of upstream uncertainties such as supplier defaults on delivery and performance, machine breakdowns, rejects, variable task times as well downstream uncertainties such as changes in demand, product mix, price and competitive action (Buzacott and Mandelbaum, 1985; Garret, 1986; Gupta and Goyal, 1989; Zelenovic, 1982). The need for flexibility increases with increases in such uncertainties (Wharton and White, 1988). Manufacturing flexibility can be deployed to create uncertainties for the competition (Swamidass, 1988; Chung and Chen, 1990). Flexibility can also create competitive advantages for the firm by dampening demand volatility (Swamidass, 1985; Gupta and Goyal, 1989).

As Gerwin (1993) remarks, uncertainty can be tackled in a variety of ways. Uncertainties in aggregate demand can be offset by developing long-term contracts with markets. Product modularization, improved forecasting, layoffs and production schedule freezing were some other strategies employed in the face of demand or supply uncertainties (McCutheon, Raturi and Meredith, 1994). Consequently, manufacturing flexibility may not always be the strategy of choice when confronted with uncertainties.

The *typology* literature views manufacturing flexibility as a strategic position in several dimensions. Mandelbaum (1978) in his doctoral dissertation identified two broad classes of flexibility - 'action' flexibility and 'state' flexibility. Action flexibility refers to "the capacity for taking new action to meet new circumstances", while state flexibility refers to "the capacity to continue functioning effectively despite the change, with built-in absorbency, robustness or tolerance to change". Slack (1983) characterizes flexibility in terms of three dimensions - the range of states a system can adopt, the cost of transitioning among these states and the time required to do so. Slack and

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(1983) does not combine these dimensions into a structured typology. Typologies have been developed around the same time describing the short term and long-term aspects of manufacturing flexibility (Hutchinson and Holland, 1982; Warnecke and Vettin, 1982; Steinhilper, 1985). These classifications are elementary and uni-dimensional in nature.

Swamidass (1988) developed a three-state typology of manufacturing flexibility employing a combination of high/low volume-variety tradeoffs. The framework does not explicitly consider the possibility of movements along the volume-variety axis. Firms may to able to develop and make rapid switches between different kinds of manufacturing flexibilities, in dynamic environments. A high volume-high variety situation may change into an unanticipated low volume-high variety condition. Different kinds and combinations of flexibilities are required for each environment. It becomes important to recognize and understand the inter-relationships among different manufacturing flexibilities, to facilitate plant responsiveness to such transitions in the environment. The framework also fails to consider the possibility of the effect of other than volume/variety variables on the choice of manufacturing flexibility. For example, competition on the basis of new product introductions, might require more that just volume or product variety capabilities. The ability to quickly develop and manufacture new products, with existing plant resources, creates the need for new product flexibility. Upton (1994) added the dimensions of time, mobility and uniformity in Carlsson's (1989) classification of operational, tactical and strategic flexibilities. Frequent changes call for operational flexibility capabilities as in a flexible machining center. Tactical flexibility is required in situations where changes are intermittent and not so closely spaced as in operational flexibility. An example is the switch from cane sugar to corn syrup as a sweetener in response to price changes (Upton, 1994). Strategic flexibility relates to significant, permanent changes on a much broader time horizon, typically anticipating the introduction of new regulations or technology. GM or Ford gearing up for manufacturing electric cars in response to California's emission laws is a good example of strategic flexibility planning. Mobility, another dimension of flexibility, is interpreted as the degree of difficulty in transitioning between states, measured in terms of time and cost. Upton's (1994) framework also includes the dimension of "uniformity of manufacturing flexibility". Uniformity is defined as consistency of performance in quality, yield etc., within the flexibility 'range' of the system. Upton's analysis falls short of a complete typology in that the different dimensions of manufacturing flexibility were not integrated into a formal contingency framework.

While these typologies provide (or imply) system-level, generic frameworks for understanding flexibility, more fundamental analysis is required to gain a better understanding of the dynamics of manufacturing flexibility.

The *micro-taxonomies* describe flexibility in multidimensional terms. The literature contains many overlapping categorizations and dimensions of manufacturing flexibility. Among the seminal classifications is Browne et al.'s listing of 8 kinds of manufacturing flexibilities. They characterize manufacturing flexibility as:

1. *Machine flexibility*: The ability to change or replace tools and mount fixtures without excessive set-up times, facilitating the change process involved in the production of a parts families.

2. *Process flexibility*: The ability to vary the steps required to complete a job, allowing multiple tasks to be fulfilled with a variety of

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3. *Product flexibility*: The ability to change over parts/products, economically and efficiently.

4. *Routing flexibility*: The ability to vary machine visitation sequences, with the option of scheduling the same operation on alternative machines

5. *Volume flexibility*: The ability to operate economically at different production volumes.

6. *Expansion flexibility*: The ability to expand production system capacity.

7. *Process sequence flexibility*: The ability to interchange the ordering of several operations for each part type.

8. *Production flexibility*: The ability to vary part variety, efficiently and economically.

Browne et al.'s classification was preceded by other categorizations (Mandelbaum, 1978; Buzacott, 1982; Gerwin, 1982). Later studies adapted and refined these preliminary taxonomies. Gerwin (1987) description of mix flexibility coincides with the production flexibility of Browne et al. (1984). Gupta and Somers (1992) conceive manufacturing flexibility as a 9 dimensional construct and develop measures for each dimension. Other classifications developed hierarchies of flexibility dimensions (Taymaz, 1989; Sethi and Sethi, 1990; Suarez et al., 1996). Table 2.2 uses Browne's framework to look at the manufacturing flexibility nomenclature employed in the literature

The table illustrates the numerous differences and similarities in defining the various aspects of manufacturing flexibility. It is evident that identical terminology does not necessarily imply identical meaning. Some flexibilities are composites of others, and there is considerable overlap in the scope of the different definitions. Attempts have been made to

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made to reduce the confusion and reconcile the varied nomenclature (Sethi and Sethi, 1990). At the same time, additional dimensions of manufacturing flexibility have emerged in the literature;

1. *Delivery time flexibility* (Slack, 1983): The ability to deliver a given production order faster or increase production faster.

2. *New product flexibility* (Suarez et al. 1996): The ability to create new products, quickly and efficiently.

2. *Material handling flexibility* (Sethi and Sethi, 1990): The ability to move parts efficiently through the manufacturing facility and manufacturing process.

3. *Program flexibility* (Sethi and Sethi, 1990): The ability of the manufacturing system to run untended for long periods of time.

4. *Market flexibility* (Sethi and Sethi, 1990): The ability of the manufacturing system to adapt to a changing market environment.

5. *Modification flexibility* (Gerwin, 1987): The ability to implement minor design changes in a given product.

6. *Material flexibility* (Gerwin, 1993): The ability of the manufacturing system to tolerate unexpected variations in input quality.

Previous studies have proposed different hierarchical models of manufacturing flexibilities. Each dimension of manufacturing flexibility relates to a specific hierarchical level and is considered a contributor necessary to the next higher flexibility level (Taymaz, 1989; Sethi and Sethi, 1990; Suarez et al., 1996). The 'machine' or 'components' level comprises lower order, shop-floor flexibilities such as machine, material handling and routing flexibilities. The next level builds on the lower order flexibilities to include volume, mix, process, product and expansion flexibilities. The highest order of flexibilities consist of program, market and production flexibility capabilities. The highest

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level reflects the responsiveness of the plant to supply chain vagaries. Flexibility is thus a function of the unit of analysis - firm, plant, system or machine, each level building up to the next in sequence and in complexity, analogous to the 'general systems theory' framework (Boulding, 1956). The hierarchical approach to manufacturing flexibility has resulted in a proliferation of flexibility dimensions (Chung and Chen, 1990). Empirical research is needed to gain parsimony and clarity in this area.

A notable shortcoming of the flexibility literature is the failure to adequately address the interactions *among* flexibilities at the same level. For example, a plant with high mix flexibility could foster organizational learning and enhance new product flexibility capabilities. On the other hand, high levels of mix flexibility may conflict with volume flexibility (Gupta and Goyal, 1989). Similarly, products in the initial stages of their product life cycle could require volume flexibility capabilities to meet unforeseen market fluctuations.

Table 2.3 presents a multi-level taxonomy of manufacturing flexibilities. Based on the literature, the taxonomy improves upon its predecessors by a) reducing the complexity of the flexibility construct by accumulating and collapsing overlapping descriptions b) providing updated literature support and c) enabling analysis of both cross-level and within-level relationships among different levels of manufacturing flexibilities.

At the most basic level are the components of operational flexibility - equipment, material, routing, material handling and program flexibilities - manifested in machine or shop-floor operations. These operational abilities cumulatively impact the development of tactical flexibilities - mix, volume, expansion and modification flexibilities -

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plant level competencies which are formally recognized, understood and utilized in medium-term tactical responses to change. The highest order flexibilities are the most abstract - new product and market flexibilities - long-term strategic capabilities that integrate directly with marketing and corporate strategies. These capabilities can help redefine business environments and change the very basis of competition in an industry (Chung and Chen, 1990).

It is important to recognize that operational flexibilities may be just one of several sets of drivers for higher order flexibilities. Gerwin (1993) cautions against an excessive focus on advanced manufacturing technology versus other methods of delivering flexibility. Literature reports that infrastructural, organizational and information technology factors are critical for the attainment of tactical or strategic level flexibilities (Sethi and Sethi, 1990).

Operational Flexibilities

Equipment Flexibility is an attribute typical of flexible machining systems. It is defined as the capability of the equipment to perform different operations within stringent time and cost constraints. Low set-ups, tool magazines, automated material handling and integrated control systems enhance equipment flexibility. The term is used synonymously with the *machine flexibility* of Browne et al. (1984) and Sethi and Sethi (1990).

Equipment flexibility permits reductions in lot-size, machine idle and inventory, and improves lead times and product quality (Gupta and Somers, 1996). Multi-axis, multi-purpose CNC machining centers represent the state-of-the-art in machine flexibility.

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parts or operations the machine is capable of handling. The temporal aspect refers to the time needed to transition from one set of operations to the next, an optimal situation being one of zero set-up time. The cost aspect refers to the cost changing between the manufacturing of one part another, or of changing from one set of operations to another. It should not be confused with the cost of implementing the machining system.

Material Flexibility refers the capability of the equipment to tolerate deviations in input quality specifications. A power plant with a boiler designed to handle extremes in coal sulfur content would be intrinsically more flexible than one which has more narrow tolerances. The former would likely be more expensive to install but may pay for itself in the long run through cheaper inputs, lower maintenance and fewer breakdowns. Material flexibility is to be distinguished from the capacity of a piece of equipment to handle a variety of inputs.

Range, in this context, refers to the number and magnitude of variations from specifications capable of being accommodated. Time refers to the time it takes to make adjustments to such variations. Cost refers to the expense involved in accommodating input variations.

Routing Flexibility can be potential or actual (Browne et al., 1984). Part routes may be fixed with the potential of automatic detours in the event of breakdowns. Parts may also be actually routed differently as standard operating procedure, independent of breakdowns. Alternative routes may consist of different but similar purpose equipment (e.g. lathes and milling machines), different operations or different sequences of operations. This interpretation is generally consistent with Browne et al's (1984) *machine flexibility* and Buzacott's (1982) *scheduling flexibility*.

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scheduling efficiencies (Gupta and Somers, 1996). It also mitigates the effects of machine downtime and breakdowns on production output.

Range here refers to the variety of parts capable of being re-routed and the average number of re-routing options available for a part. Time refers to the time penalties associated with a re-routing, including both time to re-route and the extra time taken by the alternative process to manufacture the part. Cost refers the cost to effect the re-routing and the incremental cost involved in the alternative process.

Routing flexibility subsumes operation flexibility which allows a part to be made using alternative operations (e.g., ultrasonic cleaning instead of compressed air blasting) or enables alternative sequencing of operations in a specific process (e.g. punching --- machining , or machining --- punching).

Operation flexibility derives from parts design considerations of modularization and standardization (Gustavsson, 1984; Sethi and Sethi, 1990). Designs providing similar access to parts surfaces would enable similar gripping, turning, movement and other basic operational performance across different machines. Operation flexibility is thus primarily an attribute of the part and is a component of routing flexibility. Routing flexibility differs from operation flexibility, in that a part limited to just one operating sequence could still be processed using alternative routes that operate different machines performing the same process. Both equipment and material flexibility can contribute to routing flexibility.

Material Handling Flexibility is defined as the capacity of the material handling system to transport, position, store and unload different parts and raw materials throughout the manufacturing system. The scope does not extend to logistics systems external to the plant.

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This definition is consistent with the descriptions of Stecke and Browne (1985), Sethi and Sethi (1990) and Gupta and Somers (1996).

The range aspect of material handling flexibility is the proportion of material movement paths supported by the handling system relative to the total number of possible paths. Time refers to the time required to switch from one handling process to another in the event of breakdowns or rush jobs. Cost refers to the cost of making such changes.

Material handling flexibility increases machine utilization and reduces manufacturing cycle times (Sethi and Sethi, 1990). Conveyors, monorails, towlines, automated guided vehicles, robots, general purpose pallet fixtures, automatic tool changers, cellular manufacturing, parts standardization, JIT production systems and layout designs enhance material handling flexibility in the plant. Material handling flexibility contributes to routing flexibility.

Program Flexibility may be defined as the capability of the equipment to operate virtually unattended for a long enough period. It has been similarly described by Jaikumar (1986) and Gupta and Somers (1992).

What constitutes a 'long enough period' is specific to the equipment and operation schedule. Jaikumar (1986) chooses the second and third shifts as critical periods in his study of US and Japanese flexible manufacturing systems.

Range, for program flexibility, is the proportion of equipment in the plant able to run without human attention for a long enough period of time. Time pertains to the average untended time for all such equipment in the plant. Cost relates to the incremental cost of maintenance and organizational re-structuring (worker monotony, motivation and reward, lay-off costs etc.) required to operate such equipment. It does not

include the cost of the equipment and associated monitoring and control software.

Program flexibility offers gains in throughput time performance, better quality and increased capacity (Sethi and Sethi, 1990). It depends on automation levels, integrated failure detection and control systems and preventive maintenance procedures. Equipment, material and material handling flexibilities can promote program flexibility.

Tactical Flexibilities

Mix Flexibility is designated as the ability of a manufacturing system to switch between different products in a product mix without major set-ups. Literature provides similar definitions in Gerwin's (1982) *mix flexibility*, Browne et al.'s (1984) *process flexibility* and Gupta and Somer's (1992) *process flexibility*.

Range in mix flexibility pertains to the variety of different products capable of being processed by the system. Time refers to the time needed to changeover from one product to another. Cost refers to the cost of such changeovers. Suarez et al. (1996) include the elements of product set heterogeneity and number of final market categories in their treatment of the mix flexibility concept.

Mix flexibility reduces inventories and aids customization through set-up minimization and lower batch size (Gupta and Somers, 1992). It can also reduce plant machine population and contribute to lay-out efficiencies. It is supported by equipment, material, material handling and routing flexibilities.

Volume Flexibility describes the ability of a manufacturing system to operate economically over a range of aggregate output volumes. Cyclical industries such as furniture and apparel exhibit such flexibility. From a survival perspective, volume flexibility denotes the minimum volume at which the plant can still turn a profit. It is also indicated in the sensitivity of the average cost curve to changes in production. Compatible definitions are found in the literature (Gerwin, 1982; Browne et al., 1984; Gupta and Somers, 1992).

The range dimension of volume flexibility represents the range of volume fluctuations capable of being handled by the system. The average time required to change between different volumes and the cost of doing so represent the time and cost aspects of volume flexibility.

Recessions and market booms highlight the need for volume flexibility. Marketing strategies such as discounting and promotions create volume fluctuations which demand a volume flexible system. Volume flexibility draws on operational flexibilities. Flexible manufacturing systems can permit wide variations in volume without significant penalties in manufacturing cost. In contrast, chasing demand with labor-fluctuation strategies or large inventories can lead to increased costs and morale problems. Subcontracting represents another strategy employed by industry to attain volume flexibility. Increasing volume by buying additional equipment was not considered an example of volume flexibility.

Expansion Flexibility contributes to, but remains distinct from, volume flexibility. It is defined as the capability of expanding the capacity of the manufacturing system without prohibitive effort. Gupta and Somer (1996) define expansion flexibility as the extent of overall effort needed to increase the capacity and capability of a manufacturing system. Expansion flexibility is manifested in the modular expansion potential of the system (Browne et al., 1984). Zelenovic's (1982) *design flexibility* is a related concept.

Range refers to the extent to which added capacity can be installed in the plant. Time refers to the speed with which such expansions can be unde

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undertaken while cost refers to the transitional costs involved. Typical change costs may include cost of interruptions in production, lay-out changes etc. The cost of additional machinery is not included in the definition.

Expansion flexibility differs from volume flexibility in that expansion connotes the potential for capacity enhancements while volume flexibility is bounded by existing capacity. Running overtime or a third shift is not an example of expansion flexibility, whereas designing a manufacturing system with built-in potential to expand is. Subcontracting is another way to achieve expansion flexibility assuming that it is done for reasons of capacity limitations. Volume flexibility is created through the realization of expansion flexibility. Once new equipment is installed, the capacity of the system increases and thereby impacts the volume flexibility of the plant. Material handling flexibility, routing and operation flexibility can assist in the quest for expansion flexibility. Expansion flexibility strengthens market growth abilities and reduces new product introduction costs (Gupta and Somers, 1996).

Modification Flexibility refers to the ease of producing minor alterations in product design to meet customization or differentiation requests. Such design modifications are often seen in response to new product beta tests and in efforts to resurrect declining product life cycles.

Range, in this context, means the variety of modifications possible while the time and cost aspects refers to the speed and economy of making such modifications.

Modification flexibility is useful for product and market differentiation efforts and overall market share growth. It builds substantially from equipment flexibility and material flexibility. It is different from mix flexibility in that modification flexibility focuses on minor design changes to parts/products within a product mix, while the latter describes the ease of changing production between different products in a product mix. Supplier assistance in process and product design and material may contribute to modification flexibility.

Strategic Flexibilities

New Product Flexibility refers to the capability of the manufacturing system to introduce and make new parts and products, using existing facilities. It enables the manufacturing system to stretch its product line and adopt pro-active competitive strategies. Close definitions can be found in Browne et al.'s (1984) and Sethi and Sethi's (1990) *production flexibility.*

The concept is defined through the aspects of design capabilities, design change time and design change cost. The time aspect refers to product introduction ramp-up time while cost refers to the cost of such preparations (design, prototyping, overtime, production interruptions, job rescheduling, facility layout rearrangements, orders delayed/lost etc.). New product flexibility includes design and engineering activities. It excludes the cost of new equipment and hires needed for the production launch. It is driven in part by the tactical flexibilities. Design for manufacturability and supplier involvement in product and process design may also add to this capability.

New product flexibility is a powerful core competence. It enables the firm to reduce product life cycles, increase market share and create uncertainty for the competition. However, concerns have been expressed about obtaining new product flexibility options through equipment investments, since future technology or market demands may outstrip machine capabilities (Gerwin, 1993). In other words, possessing equipment flex

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flexibility is useful for known technologies and markets, but the same flexibilities may become obsolete or redundant over a longer time horizon.

Market Flexibility may be defined as the ease with which the manufacturing system can adapt to (or drive) market changes. Comparable definitions are found in Sethi and Sethi's (1990) *market flexibility* and Gerwin's (1993) *flexibility responsiveness*. The acquisition of market flexibility equips manufacturing management with the credentials to participate in and shape corporate strategy. Companies such as Sony and Honda have demonstrated strong market flexibility with rapid-fire product launches and market responsiveness. Chrysler is another case in point, having redefined the US auto market with its innovative team structures, sourcing partnership strategies and new product offerings (Dyer, 1996).

In addition to being sustained by new product flexibility, market flexibility is contingent on achieving operational and tactical flexibilities. Range, time and cost performance will depend on the efficiency with which supporting flexibilities are implemented.

A question that arises in the context of the above taxonomy is: what dimensions of flexibility are important to managers? Slack (1990) notes that at the manufacturing system level, managers identify five types of flexibilities - new product flexibility, modification flexibility, mix flexibility, volume flexibility and delivery flexibility. The last, delivery flexibility or the ability to change assumed delivery dates has a degree of interchangeability with volume flexibility (Sethi and Sethi, 1990). Managers also focus more on response time than range availability in rating flexibility abilities. Function has been found to influence managerial perceptions of manufacturing flexibility. Process and industrial engineers focused on mix flexibility,

product engineers on new product and modification flexibilities, and production controllers on volume/delivery flexibility. Purchasing, marketing and plant level management were interested in all five types (Slack, 1990). Adler (1988) organizes machine, system and plant level flexibilities under the rubric of process flexibility while mix, modification and new product flexibilities are collectively described as product flexibilities. He suggests that although it may be more natural for engineers to pay more attention to process flexibility issues, the bigger challenges and opportunities derive from product flexibility.

2.1.2 *Inter-Relationships*

Figure 2.1 uses the above taxonomy to present potential inter-relationships among different manufacturing flexibilities.

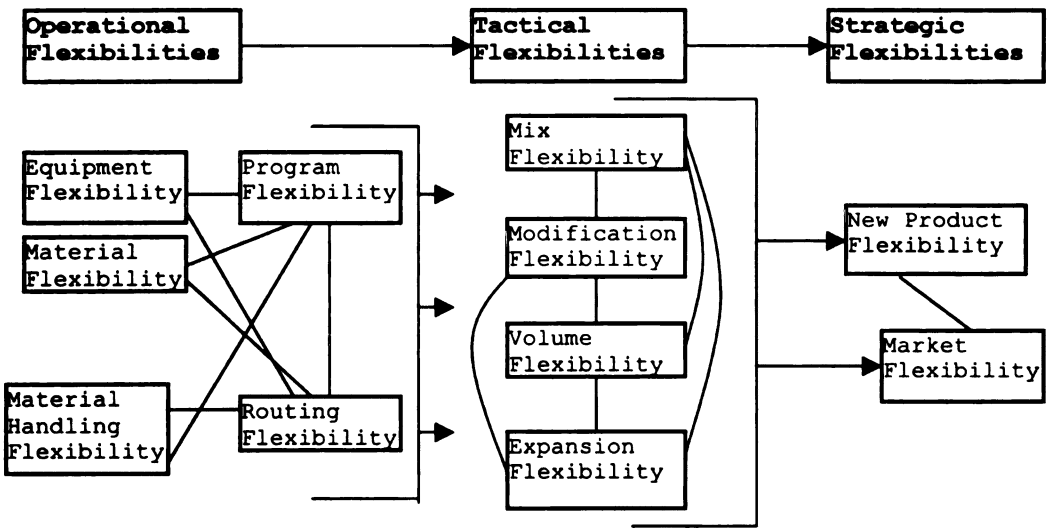

Figure 2.1

A Hierarchical Organization of Manufacturing Flexibilities

Suarez et al. (1996) in a preliminary analysis of flexibility interactions found that mix flexibility seems to add stability to overall

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production levels and consequently could have a negative relationship with volume flexibility. They also found a significant correlation between mix flexibility and new product flexibility. Their examination of the volume flexibility - new product flexibility link suggested a weak and non-significant relationship. Their results cannot be considered definitive because of the small sample size of the study (n = 31), the use of simple correlation analyses and the industry specific nature of the study. However, their study did indicate the potential for such interactions and trade-offs among different tactical flexibilities. Similar cursory discussions of inter-dimensional correlations among manufacturing flexibility factors can be found in Dixon (1992). Taymaz (1989) developed an elementary single machine model to determine how machine flexibility contributes to volume flexibility. He found complex interrelationships between various aspects of flexibility and production composition and characteristics. Gupta and Goyal (1992) also suggest the possibility of an inverse relationship between product flexibility and volume flexibility in their simulation study of flexibility tradeoffs in a flexible manufacturing system.

Although flexibility hierarchies have been developed earlier, the literature does not reveal any systematic attempt to empirically verify inter-relationships in manufacturing flexibility frameworks. Most measurement studies are concerned with the individual flexibility level and do not extend to in-depth interaction inquiries (Gupta and Somers, 1992; Dixon, 1992). Our study conceptualizes manufacturing flexibility as a multi-level, hierarchical set of operational and higher order aggregate flexibilities and focuses on the relationships among these higher order flexibilities. This research gap is a central focus of the dissertation and is addressed in greater detail during hypothesis form

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2.1.3 *Operationalizations*

"Operationalizing flexibility is ...... the single most important research objective" - Gerwin (1993). Literature shows that operationalizing the multiple perspectives on manufacturing flexibility remains a difficult task. Gerwin (1993) advances five major reasons for this. First, there is little agreement on the domain boundaries or content of the flexibility concept. Second, multidimensionality confounds scale development and validation. Third, the hierarchical approach to flexibility necessitates collection of different types of data from different sources. Fourth, while external validity demands cross-industry examinations, the intrinsic nature of the flexibility construct makes it difficult to develop meaningful measures for inter-industry comparisons. Single-industry studies are far easier to interpret and evaluate (Suarez et al., 1996; Dixon, 1992). Finally, Gerwin (1993) comments that work on flexibility measurement is hindered by a lack of communication between the conceptual and empirical research streams in manufacturing flexibility.

Despite such difficulties, scholars have endeavored to capture the various nuances of manufacturing flexibility in quantifiable form. Gupta and Goyal (1989) review these efforts and construct a typology of flexibility measures from the literature. They distinguish among measures based on economic consequences, measures based on performance criteria, measures employing a multi-dimensional approach, measures based on petri-net approaches, measures deriving from information theoretic perspectives and measures based on decision theoretic approaches. Each class of measures is further broken-down into quantitative and qualitative pri

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constituents. Table 2.4 adapts Gupta and Goyal's (1989) framework to provide an updated taxonomy of the manufacturing flexibility measurement literature.

A brief description of each class of measure follows. Measures based on economic consequences measure flexibility by evaluating the economic effects of a systems capability to meet change. For example, input quality variation may cause machine breakdowns leading to production downtime and losses. The consequences of a lack or paucity of material flexibility can thus be captured in an economic metric. Buzacott measured flexibility through the effectiveness (loss/gain) of the system when faced with changing operating environments. Son and Park (1987) propose four types of flexibility and measure each by relating it to a specific cost. For example, equipment flexibility is defined as the ratio of the physical output of the production system to the idle cost of the equipment. An aggregate measure of manufacturing flexibility is also developed in the form of the ratio of the physical output of the production system to the sum of the costs associated with each flexibility type.

Qualitative measures based on performance criteria are defined in terms of performance capabilities. Gerwin (1982, 1985) for instance, measures mix flexibility as the ability of the production system to simultaneously process a parts family. Frazelle (1986) and Carter (1986) measure routing flexibility as the ability to perform operations on alternative machines, in alternative sequences, dynamically and efficiently. Azzone and Bertele (1987) partition manufacturing flexibility into six types and measure each in different ways. Routing flexibility is measured by the ratio of the manufacturing systems expected production to the production of a fully operating system.

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Process flexibility is measured as the ability of the system to make product changes in a prescribed product range, as reflected in set-up times. Barad and Sipper (1988) segment flexibilities into short, medium and long-term categories. Long-term flexibilities are considered compound outcomes of the short to medium-term flexibilities. Measures are derived from system abilities. For example, operation flexibility is measured as the ability to interchange the ordering of multiple operations on individual parts. Machine set-up flexibility is defined as the ease of implementing machine changes in order to manufacture a given parts family. Rho, Hahm and Yu (1994) use the dimensions of mix and volume flexibility to develop a single factor measure of manufacturing flexibility.

Quantitative measures based on performance criteria have been developed in the literature. Chatterjee et al. (1984) develop a model of a manufacturing system consisting of interlinked module centers and create ratio scales for part mix and part specific flexibilities. Primrose and Leonard (1986) consider an FMS as a network with work centers as nodes and allowable parts movements as arcs, a network with saturated arc connections being considered as a fully flexible system. Routing flexibility is measured by the ratio of arcs for a particular FMS to the same number for an 'ideal' FMS with an identical number of work centers. Falkner (1986) proposed to measure machine flexibility by a plant-wide ratio of set-up time to processing time. Gustavsson (1984) took a different approach and advocated measuring flexibility in potential terms. Machine flexibility is thus measured as the ratio of the investment's residual value for the next product model to the initial investment. More recently, Taymaz (1989) developed an average cost function to quantify volume and machine flexibility in a single-machine production model.

The multi-dimensional approach to flexibility measurement is characterized by formal incorporation of the elements of range, time, and cost to different performance abilities. Slack (1983) examines individual flexibilities using these elements. To illustrate, delivery flexibility is measured as a function of minimum delivery time and the cost of making delivery changes. Minimum delivery time is given by the sum of the residual operations times. The cost of making delivery changes is determined by the stage of the production process the product happens to be at that time. Slack underscores the difficulty of assessing potential flexibility, though opportunity costing may provide some estimates. Gupta and Buzacott (1987) measure the flexibility domain thorough the sensitivity and stability of the manufacturing system. Sensitivity defines the amount of change tolerated prior to making corrections to the system. Stability relates to the range of variations accommodated by the system without compromising performance. Yilmaz and Davis (1987) also employ the time element to define different flexibility conditions. Dixon (1992) develops objective time and cost measures for mix, modification and new product flexibilities in his study of the manufacturing flexibility in the cloth industry. Gupta and Somers (1992, 1996) develop and validate a 21 item, nine factor instrument of manufacturing flexibility. Suarez et al. (1996) use the dimensions of range, time and cost in developing mix, volume and new product flexibilities for the printed circuit board industry.

The Petrinet stream of research models FMS systems rather than provide direct measures of manufacturing flexibility types. Petrinets portray a system through a stream of events. A flexible system will exhibit a different sequence of events from an inflexible system. System flexibility measurements are made by estimations of sequence durations and comparisons between durations of different sequences. Barad and Sipper (1988) employ this modeling tool to evaluate the operational flexibility of systems.

The information theoretic approach is characterized by studies based on entropy measures and information flow attributes of a system (Kumar, 1987; Yao, 1986). Entropy is defined as measure of randomness or uncertainty in a system. Kumar (1987) develops four entropic measures to quantify manufacturing flexibilities. Yao (1986) develops an information theoretic concept of routing entropy to assess routing flexibility and builds a principle of 'least reduction in entropy' for determining feasible parts routing choices. Gupta et al. (1989) develop production center availability based distribution models that provide load allocations and probabilities for job processing in a given cell.

The decision theoretic approach includes qualitative research which defines flexibility as a potential goal whose desirability depends on the managers uncertainty about the future (Mandelbaum and Buzacott, 1986). Quantitative measures assign economic values to production process choices (flexibility/cost trade-offs) link the value of flexibility to the presence of uncertainty (Hutchinson and Sinha, 1989). Flexibility has no value in the absence of uncertainty. Brill and Mandelbaum (1989) develop a framework for measuring flexibility using probability theory concepts. 'Task sets', machine groupings and task proportions are patterned after the probability concepts of sample space, set of events and random events. Measures are developed for individual machines and machine cells.

Table 2.5 furnishes flexibility specific measures from the empirical literature. Simulation/petrinet measures were not included, in

view of their specificity to individual models and the empirical nature of this research. The flexibility dimensions were based on the taxonomy of manufacturing flexibility (Table 2.3).

The literature substantiates Gerwin's (1993) observations on the complexity of measuring the manufacturing flexibility construct(s).

Diverse approaches were seen in the literature. Some studies measure manufacturing flexibility as a single factor, employing factor analysis or simple averaging to combine the different dimensions into one underlying variable (Swamidass and Newell, 1987; Fawcett et al., 1996). Others have chosen to use independent treatments of manufacturing flexibilities to model discrete effects in the manufacturing system (Suarez et al., 1996; Gupta and Somers, 1996). Research definitions and measures in the literature can be confusing. Some measures fail to take the time factor into account (Buzacott, 1982). Son and Park (1987) define equipment flexibility as the ratio of system output to the idle cost of the equipment. As Gupta and Goyal (1989) point out, high machine uptime does not necessarily imply output variety. A machine could achieve misleadingly high scores on equipment flexibility simply by continuous production of similar parts. Process (mix) flexibility is evaluated by Browne et al. (1984) in terms of the number of part types capable of being processed simultaneously. Different part families could be produced consecutively and still indicate a situation of high mix flexibility. Very few studies have accounted for item/product heterogeneity in developing measures of mix flexibility. The lack of sufficient attention to differences in parts characteristics is a common yet understandable drawback of flexibility measures. Dixon (1992) and Suarez et al. (1996) consider this issue in their development of mix flexibility scales - however, their task is facilitated by the single-industry, similar-product nature of their studies. Further confusion is created by the idiosyncratic combinations of flexibilities seen in some of the literature. Gupta and Somers (1996) treat market and expansion flexibility as a single construct and fail to distinguish between measures for each. Higher order flexibilities such as market and production flexibilities were often measured as composites of lower order flexibilities (Son and Park, 1987; Gupta and Somers, 1996). Common measure variance becomes an obstacle since strategic flexibilities are measured essentially through their operational/tactical drivers. Different perceptions of flexibility differences compound the problem. Dixon (1992) differentiates between new product and modification flexibility not in terms of new process requirements but in relation to customer perceptions of product characteristics. New product flexibility may be therefore be driven by different functional uses of the same product and not through any intrinsic design, parts or manufacturing process differences. Marketing could develop different user segments and the manufacturing system still get credit for achieving new product flexibility. Mathematical and modeling approaches to measuring flexibilities have also been critiqued for their intractability with problems of any real size (Gupta and Goyal, 1989).

In general, deficiencies in flexibility measures can be attributed to the following reasons:

a) Computational Complexity - an example is Sethi and Sethi's (1990) description of Jaikumar's use of shadow prices to compute product flexibility through a stochastic mathematical formulation.

b) Difficult to apply across plants - equipment flexibility is assessed by (Carter, 1986) by the range of tasks, changeover times and changeover costs. Task difficulty differences were not considered. A truly comparable measure would have to focus on similar plants with a similar range of manufacturing tasks.

c) Difficult to measure - many measures require data that are not collected routinely. Gupta and Somer's (1992) measure of material handling flexibility calls for a quantifiable value for the number of paths supported by the handling system to the potential number of possible handling paths in the system. It is difficult to think of a manufacturing position with ready access to such data.

d) Costly to measure - as data needs become more esoteric and complex, the cost of collection increases commensurably. Monitoring routing flexibility would be much more expensive than counting the number of part types produced in an FMS.

e) Confidentiality of information - a common research problem, featured again in Suarez et al.'s rationale for selecting the printed circuit board industry (and not, say the computer industry) for their study. Apparently, intermediate product manufacturers were less concerned about confidentiality issues than manufacturers of final products.

f) Not known to management - measures which are difficult to understand or interpret are likely to be unreliable, even if managers are willing to part with the information. Estimates of 'potential' flexibilities such as expansion flexibility may be more of optimistic opinion than based on technological and system attributes.

g) Static vs. dynamic - measures that do not capture the time dimension of change are static snapshots of flexibility. For example, product line breadth may indicate mix flexibility at a point in time. A more dynamic measure would additionally elicit information on the magnitude and direction of changes in product line breadth over a period of time. This would, of course, aggravate data collection difficulties.

h) Long-term vs. short-term - while information on operational and tactical flexibility measures may be available on a fairly regular basis, strategic flexibilities such as 'market flexibility' are rarely formally measured. As one manager put it, abstractions do not get the money - details do.

i) Decline in variance explained - the variance explained in each flexibility construct by its constituent manufacturing related item measures may decrease as the level of abstraction increases. Tactical and strategic flexibilities antecedents could enfold human resource policies, evaluation systems, supply base competencies etc., in addition to operational flexibilities (Sethi and Sethi, 1990; Das and Elango, 1995). Consequently, the impact of unobserved variables may detract substantially from the overall variance explained in the latent construct.

j) Multiple respondent requirements - not all the information needed may be present at one level. Different levels in the organization have access to information on different levels of flexibility. For example, operators and supervisors may be more reliable sources for data on operational flexibilities while manufacturing management may have a better understanding of tactical/strategic flexibilities. Similarly, senior executive management may have a much richer appreciation of the strategic nuances of flexibility competencies.

In terms of statistical rigor and comprehensiveness, the cross-industry scale of Gupta and Somers (1992) represents perhaps, the state-of-the-art for measuring different manufacturing flexibilities. They factor analyze the classification of manufacturing flexibilities by Sethi and Sethi (1990), into nine distinct factors and develop cross-industry measures for each. The scales are cross-validated using a separate sample for criterion, convergent and discriminant validity. The scales find re-use in Gupta and Somers's 1996 study on strategy, flexibility and performance relationships. The measures developed by Dixon (1992) and Suarez et al. (1996) also deserve mention. These studies incorporate differences in parts/product characteristics in their measures of flexibility, but are handicapped in being restricted to single industries.

Notwithstanding the best efforts of empirical researchers, the issue of how to include parts or process complexity differences in manufacturing flexibility measures, remains. Single industry studies enable equivalence in measures and data analysis and facilitate comparisons of results. Cross-industry research generally cannot go beyond broad estimates of the degree of difference in parts/products handled by the manufacturing system. Such differences incrementally impact the difficulty of change. Measures such as the proportion of new parts/processes used in new product and modification changeovers and the degree of product line parts/process commonality for assessing mix flexibility, may be able to capture a part of the detail necessary to make plausible comparisons. Trade-offs have to be made between the loss of comparability and detail in expanded studies, and the external validity advantages of such studies. A series of case-studies, conducted with carefully adjusted measures over a range of industries, may provide more credible comparisons. However, time constraints do not permit such initiatives within the scope of this research.

2.2 Antecedents of Manufacturing Flexibility

Literature makes a distinction between structural and infrastructural factors in discussing the antecedents of manufacturing

flexibility. Slack (1990) offers a framework for analyzing flexibility which distinguishes between structural and infra-structural resources. Included in the framework are structural factors of technology and labor and infrastructural factors of supply base and production control. Slack (1990) considers both structural and infrastructural resources as fundamental to the realization of manufacturing flexibility. The key enabling roles played by organizational structure and information technology is also stressed by Sethi and Sethi (1990) in developing their framework of manufacturing flexibilities.

Organizational studies have discussed innovative forms such as group technology cells, plants within plants and networks that go 'with the grain' of new technologies (Sethi and Sethi, 1990). Lim (1987) identifies labor flexibility as a infra-structural artifact of flexibility. Labor flexibility refers to the capability of workers to perform different tasks and the adjustability of the number of operators. Swamidass (1988) identifies specific infrastructural factors such as personnel, training, JIT, data collection and quality control as important contributors to aggregate manufacturing flexibility. Gerwin (1993) suggests the use of subcontracting and cross-functional design teams as alternatives to manufacturing technology in attaining flexibility in an organization.

The role of structural factors in acquiring manufacturing flexibilities has been well researched in the literature. Within the ambit of structural factors are process and product design systems (Swamidass, 1988). Investigations of the use of advanced manufacturing technology to attain manufacturing flexibilities have been an integral feature of the flexibility literature. The seminal analysis by Browne et al. (1984), of FMS types and their effects on manufacturing flexibilities are challenged by Jaikumar's (1986) well known explication of FMS failures in the U.S. Swamidass (1988) considers both process (FMS, CNCs, AGVs, CAM) and product design factors (CAD, CAE) integral to manufacturing flexibility goals. Can organizational reshaping lead to manufacturing flexibility enhancements on its own? It is feasible to increase manufacturing flexibility capabilities by reconfiguring work processes and layouts. For example, cellular layouts have been shown to promote worker flexibility and versatility. Conversely, the failure to change organizational structure and process in line with advanced manufacturing technology demands has also been shown to retard successful implementation of such technology systems. Theoretically, the maximum payoff will occur when both technology and organization structure are in alignment. In fact, some operationalizations of advanced manufacturing technology subsume organizational re-engineering in their measures (Das and Khumawalla, 1989; Tranfield et al., 1991; Dean and Snell, 1996).

In brief, three broad conclusions can be drawn from the literature on the structural and infrastructural environment of manufacturing flexibility. First, manufacturing flexibility is shaped by a diversity of structural and infrastructural factors, encompassing technology, design, sourcing, labor and organizational structure. Second, advanced manufacturing technology such as FMS have historically been the primary means for targeting flexibility capabilities. Third, among infrastructural influences, there is a growing recognition of the potential role of sourcing in developing manufacturing flexibility capabilities.

This research integrates the literature on flexibility antecedents into three generic components - sourcing, advanced manufacturing technology (inclusive of process and design elements), and organizational supp

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factors of labor and configuration (Figure 2.2). The next sections review each antecedent relationship in detail.

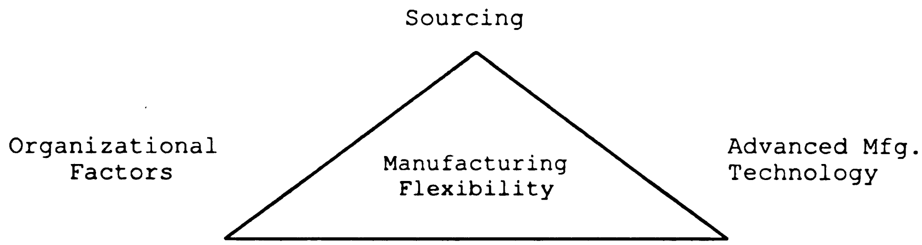

Figure 2.2

The Flexibility Triangle

2.2.1 *Sourcing*

Faulhaber, as far back as 1967, had discussed the benefits of supplier design assistance, technology and process expertise in developing design and manufacturing flexibility. Studies have identified links between technology and sourcing and between product complexity and sourcing strategies. High levels of technology, product complexity and increasing international competition drive sourcing strategies (Baxter, 1986; Hill, 1994). The sourcing patterns of auto companies support conventional thinking on the issue (Koshiro, 1987).

Sourcing strategies can generate multi-level consortia with built-in flexibility benefits for member firms. New technologies can be obtained from new members, underperformers can be dropped/replaced, drops in demand do not necessarily lead to idle capacity or inventory, lower overheads and administrative costs afford financial flexibility and internal resources are freed to focus on core capabilities through the strategic sourcing process itself (Venkatesan, 1992). Time (response time) and cost (range over which firm can accommodate changes in market price) flexibilities are enhanced through best-in-class supplier capabilities which can enable a firm to reduce uncertainties and cushion shocks from unanticipated environmental shifts. Olhager (1993) suggests that supplier responsiveness can support mix flexibility by maintaining a dependable material flow of inputs for the product line. For example, Samsung Electronics derived significant gains in manufacturing responsiveness from their supplier flexibility program (Park, 1994). Information sharing with the supply base and investments in supplier development to reduce cycle times and inventories are key elements of Samsung's supplier flexibility strategy. Handfield and Pannesi (1995) in their study of make-to-order manufacturers reported positive relationships between JIT purchasing, early supplier involvement in design, supplier on-time and quality performance, and manufacturing lead time reduction. Topfer (1995) considers early integration of suppliers in design and the reduction of internal manufacturing content critical to product cycle-time reduction strategies. Other studies report consistent findings of supply base contributions to buyer cycle time reduction and new product introduction strategies. Mendez and Pearson (1994) advocate that supplier certification, strategic alliances, supplier involvement in design, parts standardization and value analysis be included as key elements in product development programs. Gold (1987) argues that product development can be accelerated by accessing external sources of technology - supplier technological capabilities are thus harnessed by the buyer to reduce cycle time. A reduced supply base, lower number of purchasing transactions, less material handling, sharing of forecast and scheduling data and the development of supplier partnerships can aid buyer responsiveness in high velocity environments. Clark (1989) in his extensive study of the automobile industry, highlights the role of the supply base in Japan's success in this industry. Supplier involvement (and strong supplier partnerships) according to Clark (1989), account for almost 33% of the man-hours advantage and the 4-5 months of lead time advantage enjoyed by the Japanese auto companies over US automakers. Nishiguchi (1994) takes a different approach and examines mix, design, new product flexibility, volume and human resource flexibilities at the supplier end at fifty-four automotive component suppliers spread across the US, Japan and Europe. Japanese suppliers demonstrated significantly superior flexibility capabilities than their US or European counterparts. Besides being better in such production tasks as die-exchanges, the Japanese suppliers showed much more manpower flexibility and buyer-supplier production synchronization and leveling than non-Japanese firms elsewhere. These supply base strengths enable Japanese auto makers to use more unique parts, obtain more manufacturing flexibilities and increase product variety. US industry has taken a cue from the Japanese and developed kereitsus of American design (Dyer, 1996). For example, Cadillac has supplier representatives in 75% of its simultaneous engineering cross-functional teams, while Honeywell co-located its engineers in Boeing's work site for the B777 airplane development (O'Neal, 1993).

Despite this impressive body of conceptual, anecdotal and case-based research on the significance of sourcing to manufacturing and business goals, few studies relate specifically to the manufacturing strategy level. Beyond directly impacting manufacturing cost and quality through component cost reduction and quality improvements, sourcing may also fulfill a larger role in achieving less visible, yet equally important strategic manufacturing priorities. Manufacturing flexibility is a strategic priority in many industries today and sourcing presents a potential way to obtain it. One research objective is to understand the impact of sourcing on the capability of the plant to change with

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efficiency - change between manufacture of customized products, change by introducing new products or change between different production volumes - and not on supplier price reduction contributions to manufacturing cost reduction. It is the ability of the supply base to respond to the demands made by changes in the buyer's plant that contributes to the effectiveness with which the buyer's plant makes these changes. To illustrate, consider the case where a supplier "value engineers" a design simplification and reduces the price of a component of a specific product in the buyer's product mix. The cost impact of the change can be usually quantified without much difficulty and related to overall buyer manufacturing cost. Another supplier offers a wider variety of design changes for other components but does so without offering price reductions. In a customization driven market, the latter supplier would be more valuable to the buyer, because of the supplier's contribution to the buyer's ability to customize product offerings. The former contributes primarily to manufacturing cost reduction performance - the latter contributes to manufacturing flexibility capabilities. Sourcing's contribution to manufacturing flexibilities thus may be distinct and separate from its impact on direct manufacturing metrics such as cost or component quality. This research examines sourcing's impact on a plant's ability and cost of being able to effect and sustain rapid change to market and consumer demands. In doing so, manufacturing flexibility is abstracted as a plant level strategic manufacturing capability that captures the impact of sourcing (and technology) on a plant's cost time, and range of change. The basic premise of this dissertation is that careful selection, development and integration of suppliers will contribute to the manufacturing ability to make increased changes, without incurring significant time or cost penalties.

While studies have discussed the importance of strategic supplier involvement and management (Monczka and Morgan, 1992; Bhote, 1989), the linkage between sourcing and manufacturing flexibility has been typically considered only peripherally, as part of a larger research schema (Carter and Narasimhan, 1990; Rohlwink, 1988). Slack (1983) suggests that the ability of the materials management function to ensure material supplies in new product or high volume-flux environments was critical to the realization of product, mix and volume flexibilities. More recently, Gupta and Somers (1996) mention supplier alliances as a means for acquiring manufacturing flexibility but do not develop the topic further. In another study conducted by Suarez et al. (1996), the level of assembly outsourcing is positively linked to volume, mix and new product flexibilities. However, the empirical framework of the study does not explicate the nuances of these associations.

The literature thus lacks studies that investigate the relationships between sourcing strategies and manufacturing flexibilities in any detail. Very little is known about the characteristics, enablers and key success factors of such relationships, beyond an acknowledgement of their probable existence.

2.2.2 *Advanced Manufacturing Technology*

The term "advanced manufacturing technology" includes a wide variety of computer controlled systems used for design and manufacture. The key feature of such systems is their capability to link individual machines and manufacturing processes together through local area networks. Advanced manufacturing technology can be viewed as a continuum of integrated automated process technologies, anchored by standalone ma

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numerical controlled (NC) machines and computer integrated manufacturing systems, respectively. A computer integrated manufacturing system is also called a flexible manufacturing system, integrating automated material handling systems, robotics, NC and CNC machines and group technology through a hierarchical network of computers (Sharit and Salvendy, 1987).

Previous research has found inconsistent relationships between advanced manufacturing technology and manufacturing flexibilities. Kochan (1984) found that lead times were reduced an average of 50% after FMS were installed. Swamidass (1988) identified flexible manufacturing systems, computer aided manufacturing and computer aided design as key enablers of manufacturing flexibility goals. Flexibility has been emphasized as the objective of advanced manufacturing technology in the works of Browne et al. (1984), Meredith, (1988) and Lei and Goldhar (1990). Similar opinions were advanced by Parthasarthy and Sethi (1992) who consider advanced manufacturing technology to be best suited to strategies emphasizing flexibility. In contrast, Dean (1987) found that cost reduction is frequently the dominant reason for implementing such systems. In fact, Dean and Snell's (1996) failure to find a statistically significant relationship between advanced manufacturing technology and flexibility strategy performance, lends support to claims about the inappropriate utilization of such systems. Another practice is to overorder and then under-utilize new technologies, mirroring a lack of strategic clarity on the part of management (Adler, 1988). Ettlie (1988) examined much of the empirical research on the capabilities of advanced manufacturing technology components and found documented positive effects of robotics performance in the areas of costs, productivity and payback. CAD technologies were found to typically result in significant productivity gains. CIM technology performance was reported primarily in en

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terms of inventory reduction and decreases in scrap and re-work. These conclusions lend support to claims that advanced manufacturing technology is seen as a collection of labor saving mass production techniques employed primarily for cost-cutting, not revenue generating purposes (Jaikumar, 1986; Zuboff, 1988; Susman and Dean, 1989). It is thus important to realize that advanced manufacturing technology may be adopted for other than flexibility reasons. Upton (1995) mentions information monitoring capabilities and quality gains as some non-flexibility targets of these systems.

Even where flexibility is the touted aim of advanced manufacturing investments, required accompaniments in human and organizational factors are not implemented, leading to what Upton (1995) calls the "unfulfilled promise of CIM". Unanticipated pay-offs result in the form of cost and productivity improvements while the intended flexibility goals remain unrealized. Realized results could therefore be used to create a post-hoc rationale for technology expenditures - a distinct possibility in short-term performance evaluation environments. Longitudinal studies are required to better understand such subtleties between intended and realized advanced technology applications.

There is another stream of research which takes a less contentious view of the rationale for adopting advanced manufacturing technology. Lim (1987) studied flexible manufacturing systems in the U.K. and found that reduction in labor costs was only one of several reasons for investments in such systems. External stimuli in the form of customer or competitor demands triggered these investments in the majority of cases. Flexibility was considered a system objective but managers were unclear on the precise nature of their flexibility needs and the extent to which existing advanced manufacturing technology satisfies those needs. Lim pu

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(1987) found moderate to high levels of product and process flexibilities but low levels of routing flexibility among the plants in his study. Dodgson (1987) reported multiple gains from implementing advanced manufacturing technology in small manufacturing companies, including improved product flexibility, faster response times, reduced manufacturing cycle times and lowered costs. Case studies such as O'Toole's (1985) analysis of Deere and Company and Goldstein and Klein's (1987) report on Allen-Bradley offer evidence of flexibility and productivity gains. Ayres and Butcher (1993) suggest that advanced manufacturing systems offer major gains in terms of greater flexibility, lower cost and higher quality. Corbett and Van Wassenhive (1993) argue that reducing manufacturing fixed costs should be a goal of advanced manufacturing systems in addition to flexibility missions. Indeed, the case for combined cost-flexibility advantages underlies Goldhar and Jelinek's (1983) "economies of scope" justification for flexible manufacturing plans.

A certain amount of trade-off between variety and volume is always present in the choice of advanced manufacturing technology. Some relatively dedicated flexible manufacturing systems may make four different part types while more general purpose systems can turn out upto 500 parts per part family (Blumenthal and Dray, 1985). Advanced manufacturing technology is well suited for batch manufacturing environments, particularly for batch sizes of 100 or below, but are generally limited in the variety of shapes and input materials each system is capable of handling (Handfield and Pagell, 1995). Hence, advanced manufacturing technology typically represents an economically acceptable middle ground between dedicated equipment with high volume/low cost attributes, and general purpose job shop arrangements with low volume/high cost features. High velocity operating environments requiring flexibilities of volume, mix or product suit the use of such advanced manufacturing technology. The benefit of a relatively flat average cost curve across multiple volumes and varieties is important only when market fluctuations are present or induced. In summary, the literature on advanced manufacturing technology's relationship with manufacturing flexibilities displays consensus on three issues:

1. Flexibility is a natural objective of advanced manufacturing technology, but companies may have alternative/additional non-flexibility goals.
2. The full potential of advanced manufacturing technology may not be realized without concurrent adjustments in other organizational areas.
3. Advanced manufacturing technology has definite domains of volume and variety flexibilities. The choice of technology should reflect a good fit between range and response needs and the nature of flexibilities required.

2.2.3 *Organizational Factors*

Literature documents failures to obtain clear benefits from advanced manufacturing technology. Fleck (1984) reported that a significant proportion of sampled Australian manufacturers abandoned robotics technology because of implementation problems. Similarly, in a survey undertaken by Deloitte and Touche, only 29 percent of American manufacturing executives perceived significant benefits from advanced manufacturing technology (Sheridan, 1990). At the same time, industries rank flexibility as a priority goal and are concerned about successful implementation of advanced manufacturing technology (DeMeyer et al., 1989). There is a growing consensus that flexible organization structures org

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are required to obtain the benefits of advanced manufacturing technology (Bessant and Buckingham, 1989; Ettlie, 1988; Walton, 1989; Zammuto and O'Conner, 1992). Previous research has examined the implications of organizational form and structure and process for the achievement of manufacturing flexibilities.

Zammuto and O'Conner (1992) describe two key structural strategies through which organizations attempt to address the complexities of advanced manufacturing technology implementation. They suggest that organizations choose between "control-oriented design" vs. "flexibility-oriented design" strategies. Control oriented designs centralize decision-making power at the managerial level, routinize operations for the worker and reduce the need for high operator skill levels. Highly "mechanistic" organizational structures develop consequently with expertise and information theoretically located in the upper hierarchies of the organization (Burns and Stalker, 1961). Although productivity gains may be possible in such an organizational system, because of lower training needs and negligible turnover effects, centralization of responsibilities retards organizational learning. Problems may accumulate at the machine level, causing production delays and deterioration, before being funneled up to the concerned decision authority. Little initiative or opportunity remains for the worker to acquire or apply decision making capabilities, even in routine situations. Almost no contribution can be expected at the operator level when faced with non-routine situations created by operational uncertainties. Therefore, the mechanistic structures created by control design strategies are not likely to be compatible with the flexibility requirements of an uncertain business environment.

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alternative in the form of "flexibility oriented" strategies, that decentralizes decision making at the problem site level. Worker learning is encouraged and developed thorough information sharing, cross-training and process teaming in the enterprise. Thus the overall effect of empowering lower hierarchical levels accelerates organizational learning and enhances response time capabilities (Hirschhorn, 1984; Zuboff, 1988). Companies have been experimenting with different organizational arrangements such as group technology, parallel assembly cells, network teams etc. to acquire fast response capabilities. Sethi and Sethi (1990) call these "experiments in product-focused forms", organized around processes not functions. Jaikumar's (1986) study of 95 FMS systems advocated small, technologically proficient cross-functional teams for successful flexible manufacturing system design and operation. Similar organizational designs have been advocated elsewhere in the literature for high velocity, high uncertainty environments (Mintzberg, 1979; Meredith, 1987; Parthasarthy and Sethi, 1992). The development of such integrating mechanisms gives rise to what Burns and Stalker (1961) called "the organic" organization. An organizational configuration that nurtures lateral communication, openness and cross-functional teaming engenders speed and efficiency in incorporating successively more sophisticated technologies (Goldhar and Lei, 1995). Flexibility oriented designs can catalyze the success of advanced manufacturing technology in responding to market and product flux. Indeed, as Krafcik (1988) reports, companies with organic production management structures were found to outperform firms with more advanced manufacturing technology but more rigid organizations. Gyan-Baffour's (1994) study of 268 manufacturing companies found that firms with high levels of advanced manufacturing technology tend to have high levels of employee involvement in strategic decision

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making, training and information sharing. However, evidence exists to indicate that operator skill requirements for advanced manufacturing technology range from a downskilling approach at one end of the spectrum to job-enrichment at the other. Many systems use entry-level workers for loading/unloading, cleaning and low-level maintenance tasks but rely on highly skilled, multi-functional system attendants/supervisors to monitor and attend to machine needs (Graham and Rosenthal, 1986). Often, one supervisor/attendant may be in charge of more than one advanced manufacturing machine system. Flatter hierarchies, multi-skilling/de-skilling (no need to set-up, tool change manually etc.), lesser direct supervision and increased coordination mechanisms are some specific characteristics of the new organizational model formed by Tranfield et al. (1991) in their case study of advanced manufacturing technology implementers in the U.K.

Organizational structures can thus moderate the impact of advanced manufacturing technology on flexibility goals (Gerwin and Tarondeau, 1989). Such structures though can be difficult and expensive to build, involving substantial employee re-training, manager re-education and re-orientation of organizational values (Zammuto and O'Conner, 1992). The potential gains from reorganization have to be considered against the estimated costs. Operator re-training can be an important mechanism for generating flexibility, building confidence, esprit de corps and new vision in workers. Equally important can be the alignment of employee measurement and motivation systems with manufacturing goals and top management commitment to deal with the organizational requirements for technology implementations(Upton, 1995; Goldhar and Lei, 1995).

Two key conclusions can be drawn from the organizational literature in the context of this research:

1. Companies should not expect to develop manufacturing flexibility advantages through the use of advanced manufacturing technology alone - complementary actions need to be taken in organizational design and human resource policies to enable successful implementation of these technologies

2. Organizational designers should recognize the manufacturing flexibility implications of positioning themselves at a point on the Burns and Stalker (1961) bi-polar "mechanistic - organic" continuum.

2.3 Sourcing

2.3.1 *Strategic Sourcing*

Strategic sourcing can be defined as the integration of specific sourcing strategies with the business goals of an enterprise. Carter and Narasimhan (1995) draw a useful distinction between "sourcing strategies" and "strategic sourcing". While strategic sourcing will involve the use of sourcing strategies, not all sourcing strategies qualify to be included in the domain of strategic sourcing. Sourcing strategies comprise sourcing practices, the sourcing function engages in, to achieve its own objectives. For instance, sourcing might pursue a strategy of supply-base rationalization or supplier certification. While this might be an integral part of overall sourcing plans, it may not necessarily mean that sourcing is contributing to the strategic goals of the organization. As Carter and Narasimhan (1995) point out, only those activities and strategies that fundamentally support the business priorities of the firm qualify to be included under the rubric of "strategic sourcing". Strategic sourcing establishes a visible and strong link between sourcing plans and actions, and the fulfillment of business goals. It becomes possible when sourcing becomes a participant in the stra

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strategic planning processes of a firm and impacts key policies at both corporate and functional levels. It is accomplished by the careful selection of specific sourcing strategies which can be directly related to the achievement of business level goals. Much of the conceptual literature shares this perspective on 'strategic sourcing', variously described as "worldclass purchasing", "integrative purchasing", and "strategic management" (Bhote, 1989; Reck and Long, 1988; Freeman and Cavinato, 1990). Frameworks in the literature suggest an evolutionary process in the development of strategic sourcing in a firm. The process reaches culmination with the full integration of sourcing strategies in a firm's competitive strategic processes - the 'phase IV' strategic management stage of Freeman and Cavinato (1990) and the 'integrative' phase of Reck and Long (1988).

Two questions emerge from this discussion. One, what are the sourcing strategies and practices that might be included in strategic sourcing; and two, what role does integration play in strategic sourcing? Within the rubric of strategic sourcing lie a portfolio of sourcing strategies and practices. Such strategies span an entire gamut of activities from supply-base optimization to early supplier design involvement to worldwide sourcing (Monczka and Trent, 1991). This research considers four fundamental, distinct, sourcing strategies which might be found in many purchasing environments - *supply-base optimization, buyer-supplier relationship development practices, supplier capability audit, and purchasing integration*. While other sourcing practices such as global sourcing and total quality management exist, past research has distinguished these four sourcing strategies in a variety of sourcing situations.

Robertson (1995), in an in-depth study of the strategic evolution

of the sourcing function at Rover Motors, U.K., observed that supply-base rationalization formed the first step in their strategic sourcing initiative. Rover than engaged in information sharing and other several buyer-supplier relationship development activities with its rationalized supply-base. This was followed by systematic and regular assessments of supplier performance, in areas of importance to Rover Ltd.. These actions were undertaken in an integrated manner, through cross-functional teams involving manufacturing, engineering and finance members. Purchasing integration played a key role in convincing management of the strategic value of sourcing actions. The tangible value-added to business goals led management to recognize the strategic importance of sourcing and invest in its development. Other studies have documented the fundamental nature of these four sourcing strategies in the sourcing plans of companies (Morgan, 1987; Monczka and Trent, 1991; Gadde and Hakansson, 1994). These strategies often support and sub-sume other, more dis-aggregate, sourcing strategies and practices. For example, companies engaged in buyer-supplier relationship development employ supplier quality and technical assistance programs, build long-term supplier relationships, form buyer-supplier councils, and deploy a total cost focus. Such practices have been clustered and labeled differently, as supplier development, total quality management, and total cost of ownership sourcing strategies (Monczka and Trent, 1991), all of which can be included within the larger domain of buyer-supplier relationship development.

Supply-base optimization and volume leveraging are perceived as pre-requisites for other sourcing initiatives (Monczka and Trent, 1991; Bhote, 1987) and constitute a distinct strategic issue, that generally precedes other sourcing activities (Gadde and Hakansson, 1994). Supplybas

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base optimization consists of supplier reduction, re-organization and volume leveraging actions, that prepare the ground for more sophisticated relationship building and supplier involvement strategies.

Supplier capability audits are associated with supplier performance expectations. Purchasing contributes to strategic objectives by selecting, developing and monitoring a capable supply-base (Fitzpatrick, 1996). The increased reliance on the supply-base for obtaining current and future competitive success has focused management attention on supplier performance. Such attention has increased in recent years particularly since buyers perceive supplier performance as less than satisfactory - escalating management expectations of purchasing have created similar sourcing expectations of supplier performance (Monczka and Trent, 1995). Supplier performance evaluation and capability audits have become a critical part of sourcing strategies in supply chains in the US and abroad (Hahn, Watts and Kim, 1990).

Purchasing integration constitutes the fourth sourcing strategy examined in this research, and underlies the strategic impact of the other three sourcing strategies. Purchasing integration enables fit and alignment between sourcing strategies and the business objectives of a firm. It links sourcing plans, policies and actions to corporate and cross-functional priorities and is a key influence on top management perceptions of the strategic value of purchasing. These reasons have shifted the focus of much of purchasing research during the 1990's towards integration and purchasing participation in the business goals of an enterprise (Ellram and Carr, 1994; Fitzpatrick, 1996). Purchasing integration requires the active involvement of sourcing in the business of a firm, achieved through mechanisms such as cross-functional teaming, participation in strategy formulation and a focus on activities that are per

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perceived as adding value to strategic business goals (Gadde and Hakansson, 1994; Robertson, 1995).

Collectively, these four basic sourcing strategies of supply-base optimization, buyer-supplier relationship development, supplier capability auditing, and purchasing integration provide a platform for the evolution of strategic sourcing in a firm. The next section discusses these four components of strategic sourcing in more detail.

2.3.1.1 *Supply-Base Optimization*

Supply base optimization is a major decision in strategic sourcing. Three decisions are subsumed in this strategy. The first is the choice between single sourcing or multiple sourcing and by implication, a limit on the total number of suppliers. The second concerns the choice of arrangement of suppliers within the supply base in terms of responsibilities, investments, accountability and reliance. The third relates to the extent of parts bundling and volume consolidation undertaken in a firm.

Single sourcing can be defined as the deliberate decision to procure all requirements for a specific item/family of items from one supplier. Further refinements in terms of designating sourcing from particular plants and locations within a single supplier are possible (Treleven and Schweikhart, 1988). Multiple sourcing envisages supply from more than one supplier for an item/family of items. The capability to procure from two sources may be called dual or parallel sourcing (Richardson, 1993). Conventional purchasing wisdom dictated the need for multiple sourcing, chiefly for reasons of cost control and risk diversification. Nevertheless, the trend towards single sourcing appears to be firmly entrenched in industry (Newman, 1988; Helper, 1991; Offodile ne

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and Arrington, 1992). Single sourcing also finds prominence in the early conceptual literature (Deming, 1982; Schonberger, 1982; Hall, 1983). The reasons for this are manifold. The technology strategy of the firm may need specialist technologies from the supply-base. Clearly, such capabilities will not be distributed equally among all suppliers. Further, resource limitations permit investments in the development of such supplier capabilities to just a few promising firms in the supply base. Volume leverage considerations also prompt consolidation of orders on one supplier - considerable savings in material and administrative costs have been recorded by industry (Tully, 1995). Initial price criteria have been replaced by the total cost perspective which forces buyers to evaluate life-cycle, relationship and technology compatibility costs. Handfield (1993a) reported significantly lower supplier numbers in JIT production environments of reduced set-up times and reduced lot-sizes as compared to non-JIT environments. Handfield (1993b) also found that supply base reduction is a valid response to demand uncertainty. A reduced supply base provides lower coordination costs and enhanced value creation through the production process (Han, Wilson and Dant, 1993). A smaller supplier base also offers dedicated capacity, lower transaction times and costs and reduced logistics complexity, all of which help sourcing to respond effectively to production variations of design or volume. Single sourcing is anticipated to reduce inventories through greater schedule sharing, increased delivery performance and more stable schedules.

However, single sourcing is not without its detractors. Trevelen and Scheikhart (1992) categorize single sourcing risks into five classes - disruption of supply, price escalation, inventory and schedule, technology access and quality. The first two are classic manifestations

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of buyer apprehensions in single sourcing situations. Research has shown that such risks can be mitigated through scrupulous supplier selection, on-going monitoring of key indicators and the development of contingency on-hand alternative sources of supply. Improved information sharing has been shown to precede and accompany supply base rationalization (Handfield, 1993b). The probability of early detection of supply failures would increase with the availability of advance information from the supplier. Cost sharing is a recognized feature of focused relationships with a reduced supply base. Fears of supplier 'price-gouging' may prove unfounded with the exchange of cost information and the supplier economies derived from level schedules and volume guarantees. Literature also refers to the use of 'parallel' sourcing to inject an element of competition in the buyer-supplier relationship (Richardson, 1993).

Technology access strategies influence the choice between single and multiple sourcing. Extremely volatile technological environments may be more appropriate to multiple sourcing, such that buyers can access the latest technology and avoid getting 'locked in' with an obsolete supplier. A good example of this is the bio-genetics industry where technology frontiers are in a state of extreme flux. More stable conditions would encourage joint technology development and early supplier involvement with a consolidated supply group. Such examples are seen in the auto industry where suppliers can work with buyers at the concept car stage. Trevelen and Schweikhart (1988) cite quality as the prime reason for adopting single sourcing strategies. The elimination of underperformers during the supplier screening process automatically improves quality levels to a point. Single sourcing also naturally reduces variability in inputs since the buyer deals with a single/similar manufacturing process. The paring of the supply base also allows a

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resources to be concentrated on a few select supply points to improve supplier performance. Additionally, volume contracts permit learning curve effects to take effect with order of magnitude improvements in cost and quality.

The risk-reward dilemma in single sourcing led to efforts to find acceptable alternatives which would alleviate the risks of single sourcing while maintaining much of its benefits. Dual or parallel sourcing emerged as a feasible answer to the problem. Parallel sourcing involves the development of single supply sources for similar components, thus offering comparison opportunities in terms of costs and technologies. The Japanese experience showed the feasibility of single sourcing while maintaining the presence of a technologically competent alternative source of supply (McMillan, 1990; Smitka, 1991; Richardson, 1993). The presence of a credible threat combined with relationship specific investments functioned as an effective deterrent to supplier opportunistic behavior. The added set-up and coordination costs in parallel sourcing are offset by the incentives offered by such a system for supplier performance. Switching and set-up costs can be traded off against reductions of supplier power. The difficulty with this approach is in treading the fine line between developing asset-specific supplier relationships and the maintenance of believable strike-back capabilities. Given sufficient volume and variety, parallel sourcing can be a powerful stick to accompany the partnership carrot in single supplier sourcing.

The second aspect of supply-base optimization concerns the organization of suppliers into tiers. Literature offers overwhelming support for the benefits secured in particular, by the auto industry through innovative supply-base tiering (McMillan, 1990; Nishiguchi, 1994). Tiering the supply-base affords the buyer scope to focus scarce e

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resources on the first tier suppliers. Management, quality and performance responsibilities cascade down the tiers, effectively making each supply layer accountable for the performance of the next layer. Most first tier deliver aggregate systems or sub-assemblies - of these, only a select few are involved in truly full service design and manufacture activities (Kamath and Liker, 1994). Supply base tiering has been adopted in quick measure by US industry (Tully, 1995). For example, the 'Contour' car development saw just 227 first tier suppliers, the result of a drastic pruning and re-structuring of the 700 or so first tier suppliers of the 'Tempo/Topaz' platform (Fleming, 1994). Chrysler manufactures the 'Neon' relying on 289 first tier suppliers, down from 425 for the earlier 'Sundance/Shadow' (Chappell, 1994). Long-term contracts and escalated volumes forced the first tier of the supply base to become more responsive to assembler schedules, quality and design issues. In turn, the first tier suppliers demand equivalent performance from the lower tiers, since their performance is inextricably linked with their own assembly and major parts suppliers (Choi and Hartley, 1996).

Strategic supplier typologies have been developed in the literature to obtain a richer understanding of the dynamics of the tier system. Merenda, Kaufman and Wood (1996) distinguish suppliers in terms of four technology-collaborativeness combinations (Figure 2.3), based on their study of 200 manufacturing companies in New Hampshire.

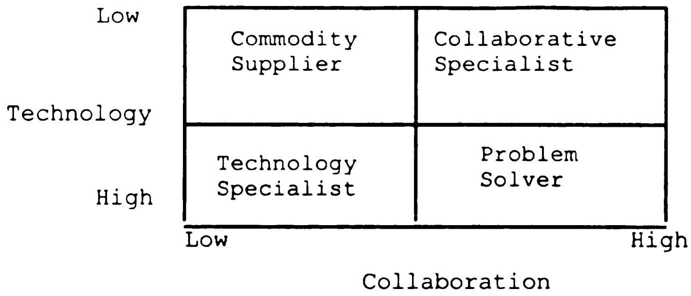

Figure 2.3

Strategic Supplier Typology

Source: Wood, Kaufman and Merenda, 1996.

Wood et al. (1996) equate problem solvers to the elite first tier of a Japanese *keiretsu*. Suppliers in this category position themselves as providers of options and solutions, and share certain characteristics. They have 'black-box' design capabilities, are quality certified, use advanced management practices such as employee empowerment and quality practices, certify their own supply-base and pursue differentiation strategies in a variety of markets. They run small batches and exhibit high process and labor flexibility. Commodity suppliers are spot-market producers, competing on price and manufacturing to OEM specifications and can be found in the third or fourth tier of the supply base structure. Collaborative specialists do not posses competitive design capabilities but differentiate themselves by forming close buyer relationships. They are representative of first or second tier suppliers in industries with stable and established product specifications. Technology specialists may be proprietary parts manufacturers, differentiating on the basis of product/process innovation. They differ from problem solvers in that they do not tend to work closely with customers or form collaborative relationships. Technology specialists can also be first or second tier suppliers in more technologically fluid buyer environments. The

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distinction between first tier problem-solving suppliers and first tier technology or collaborative specialists. made by Wood et al. (1996) is consistent with Kamath and Liker's (1994) report on partnership characteristics of the Japanese supplier system. Only a chosen dozen or so first tier suppliers were considered full partners among the more than 100 first tier suppliers typically encountered in Japanese auto companies. Partnerships, Kamath and Liker (1994) observe, are reserved for suppliers that have "outstanding technology, sophisticated management, and global reach". Suppliers also scan their customer base to determine partnership prospects, based on mutuality of strategic goals. Kamath and Liker (1994) conceptualize their investigation of supplier roles in the Japanese auto industry into a four level typology of supplier roles. The typology classifies supplier roles into 'partner', 'mature', 'child' and 'contractual' phylums. Partner suppliers employ their black box design technology and global reach to supply complete assemblies and systems to customers and enjoy equal status in their market relationships. Mature suppliers have gray box design capabilities /responsibilities for complex assemblies and are closely supported by their customers. They may alter and improve on customer designs and specifications. Child suppliers perform simple assembly tasks well and but have little influence over customer specifications. Contractual suppliers manufacture standard parts or commodities, with no product development responsibilities. Long-term contracts are possible with contractual and child suppliers too, based on manufacturing process capabilities such as flexible automation or JIT supply abilities. The roles described in Kamath and Liker's (1994) typology correspond well with Wood et al.'s description of supplier types. The 'partner' class translates into the 'problem-solver' category, the 'mature' class into the '

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the 'technology specialist' category and the 'child/contractual' classes into the 'collaborative specialist/commodity' categories. Both perspectives endorse the feasibility of concluding long-term contractual relationships without supplier involvement in product design. However, full service partnerships with asset concentration and design exchanges are limited to the 'partner/problem-solver' class of suppliers.

Are close buyer-supplier relations necessary for strategic sourcing? From a flexibility standpoint, both supplier product and process technology could contribute to manufacturing flexibilities. For example, volume flexibility could be achieved by contracting with suppliers with flexible manufacturing processes but little design prowess. Similarly, new product and modification flexibilities could be augmented by sourcing technology from capable firms. However spot-market sourcing is not likely to produce consistent results. Helper and Sako (1995) salience the role of long-term 'voice' supplier relationships in obtaining production and delivery lot size reductions. Extended contracts are essential to obtain strategic gains. Collaboration prospects and product and process technology availability can be considered the governing criteria for strategic flexibility sourcing. Strategic sourcing may support other manufacturing and business goals, in addition to flexibility goals. A manufacturer may elect to compete on a cost-based strategy. Sourcing may respond with target costing, value-engineering and other cost elimination techniques. However, the successful implementation of such methods needs the active and sustained participation of the supply base (Monden and Hamada, 1991). Effective relationship management therefore seems integral to the realization of strategic objectives. Viewed as a continuum, buyer-supplier relationships can range from the pure transactions approach to full blown partnerships. Under this view, With e

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Wood et al.'s (1996) 'technology specialist' and 'commodity supplier' would be unlikely candidates for strategic sourcing because of the lack of the long-term ingredient in their customer transactions. Compatibility and sustainability across the supply chain are critical in building barriers to entry for competitors (Choi and Hartley, 1996) - effective supply base management is essential for this purpose.

The third aspect of supply-base optimization involves the practice of parts bundling and volume consolidation by purchasing, in order to generate buying leverage and obtain cost, quality, delivery, and supplier capacity and technology dedication advantages. Parts bundling refers to the practice of grouping parts of similar specifications/ attributes/manufacturing technology into part families, which are then sourced as combined 'bundles' to one or more supplier. Such an approach reduces administrative sourcing costs, facilitates order tracking and warranty claims, increases volume rebates, reduces supplier manufacturing costs, and improves parts quality (less variance), among other benefits. Conceivably, supplier familiarity with a broader range of parts could also improve opportunities for value engineering, and parts re-design and standardization. Volume consolidation is the practice of grouping identical parts across different divisions of the same company. Gains from this practice stem primarily from supplier economies of scale. Other benefits may include lower variance and decreased supply-base administration costs. Both practices are in wide use in companies today (Tully, 1995). The Industry Week survey of best practices and performance in the US manufacturing industry reported extensive use of supplier rationalization and leveraged buying strategies, with associated median productivity gains of $200,000 per employee (Taninecz, 1997).

Monczka, Trent and Callahan (1993) advocate the consolidation of cost-

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purchase volumes worldwide to maximize buying leverage. They report the cost-benefit ratio of volume consolidation as among the highest within industry. Allied-Signal Inc. is an exemplar, with forecasted savings of $100-$300 million in lower prices and reduced transaction costs from volume consolidation strategies. Motorola implemented a sourcing strategy of parts bundling and volume consolidation consistently during the 1980's, with tangible price and performance gains (Raia, 1991).

Volume consolidation and parts bundling can impact more than just product cost. With the knowledge of additional volume commitment, suppliers and buyers can focus resources on design and process improvements. Volume consolidation could thus be of strategic value to the business, by helping to increase supply-base performance in areas of strategic importance to a firm. Despite the evidence of such clear gains, research reports that volume consolidation is a sourcing strategy not exploited to its full potential in many firms (Monczka et al., 1993). Decentralization of the purchasing function has been attributed as a possible reason. Uncoordinated sourcing strategies can reduce the opportunities and incentives for parts bundling and volume consolidation initiatives. Responsiveness is often associated with decentralization. However, improvements in information technologies and communications, and organizational structural innovations such as global sourcing teams have made it possible for companies to coordinate sourcing strategies for leverage, and remain responsive to individual unit needs.

2.3.1.2 *Buyer-Supplier Relationship Development Practices*

Carter and Narasimhan (1995) identify management of supply-base relationships as a vital proposition for strategic sourcing in their study of future trends in purchasing and supply management. A contrary viewpoint might question the need for investing in supplier relationships at all - vertical integration offers full control and reduced uncertainty. While conventional economic and sociological theories (transaction costs and resource dependence) rationalize activity internalization as the ultimate form of control over uncertainties, the realities of global markets and competition have made it impossible for firms to have total supply chain ownership due to cost, technology, personnel, market and political reasons. One solution lies in quasi-integration, the inclusion of supplier competencies in product design and manufacturing through strategic sourcing (Stuckey and White, 1993). The natural hesitation in proceeding with such a strategy stems from concerns of confidentiality, loss of in-house technology and design architecture, loss of internal manufacturing skills, organizational disruptions, transitioning difficulties and possibly the biggest incubus of them all - the creation of a new competitor. Firms have developed specific legal, economic and social risk governance mechanisms to deal with these apprehensions. Patents and contracts, human/capital/location asset specificities, financial participation, cultural/industry norms and firm reputation and trust building practices being some of the more researched methods for achieving such buyer-supplier cooperation in reducing environmental uncertainties.

Close on the heels of the Japanese subcontracting experience (Smitka, 1991), came the awakening of US industry to the strategic potentialities of supply base management. The new paradigms of strategic sourcing created a body of literature on buyer-supplier relationships. There are several emerging insights from this literature - these broadly relate to the outcomes, operating characteristics and structural attributes of effective buyer-supplier relationship practices.

Ellram (1991a) synthesizes the literature on buyer-supplier relationship management into three dimensions - management issues, technological issues and financial issues. Management related gains stem from reduced transactions cost in dealing with an optimized supply base, greater stability, information sharing and strategic congruence, better lead times and greater supplier responsiveness. Supplier involvement in design, quality improvements and accelerated new product introduction cycle times are some of the technological spin-offs of supplier-buyer intimacy. Ellram (1991a) also identifies financial benefits in terms of more stable input prices, lower inventory levels, joint research and development and shared development risks. Suppliers profit from closer relationships with customers by achieving economies of scale, reduced capacity utilization risk, lower transaction costs associated with a reduced customer base, and longer investment and planning horizons (Ellram and Cooper, 1990). Several positive outcomes of buyer-supplier partnerships were also verified by Stuart (1993) in his survey of 240 purchasing executives in North America. Short-term benefits included reduced downtime and re-work, decreased throughput time and inventory reductions. Longer term gains were obtained through a reduced cost structure, product sales increases and improved product quality. These gains need to be equitably shared between firms to sustain long-term relationships (Gentry and Vellenga, 1996). Some researchers have addressed the central purpose of a long-term relationship. Day (1995) suggests that the strategic goal of such relationships is not just the cost or quality gains that accrue from long-term ties, but more importantly a competitive advantage over other companies. Negative outcomes of buyer-supplier cooperation include risks associated with dependency and loss of control and the opportunity costs of externalization (Ellram, 1991b). Ramsay (1996) emphasizes the difficulties and risks of partnership formation especially for smaller buyers and the need to use caution in transitioning to single-sourcing partnerships.

Behavioral and economic factors such as trust, satisfaction, and asset specificity have been identified as important enablers in external relationships (Ganesan, 1994; Gulati, 1995; Zaheer and Venkatraman, 1995; Aulakh, Kotabe and Sahay, 1996). Additionally, sourcing specific studies have identified commitment, joint problem solving, information exchanges, a reduced supply base, supplier proximity, asset specificity, relationship time, and formal supplier selection, evaluation and feedback systems as some key attributes and success factors in supply-base partnerships (Spekman, 1988; Landeros and Monczka, 1988; Ellram, 1992; Hendrick and Ellram, 1993; Nishiguchi, 1994; Dyer, 1994; Morgan and Hunt, 1994). Table 2.6 depicts key findings on the operating characteristics of collaborative buyer-supplier relationship arrangements.

An interesting situation arises when one juxtaposes the need for inter-firm cooperation against the high failure rate associated with such cooperative efforts (Bleeke and Ernst, 1991). To this point, little empirical effort has focused on the determinants of relationship failure or relationship development costs, although conceptual discussions can be found in the literature (Nevin, 1995). Confronted with a paucity of adequate explanations in the traditional neo-classical economic literature (Williamson, 1975, 1983), scholars have stressed the behavioral aspects of inter-firm collaborations as critical success factors of inter-organizational relationships (Aulakh, Kotabe and Sahay, 1996). The organizing principles of inter-firm relationships appear rooted in the relational aspects of firm behavior involving the notions of continuity, information sharing, interdependence and joint problem solving. The development of trust as an alternative governing mechanism (Smitka, 1991; Gulati, 1995) is another reflection of the departure from the discrete, transactional approach of black-box economics.

A more dynamic view of inter-organizational collaboration is offered by the process models developed in the literature. Dwyer et al. (1987) develop a five stage model, progressing through the stages of awareness, exploration, expansion, commitment and dissolution in a typical relationship. Increased communication, establishment of norms, mounting interdependence and the building of trust and satisfaction create conditions where the partners consciously choose to ignore opportunities to build alternative relationships. Ellram (1991a) traces the evolution of purchasing partnerships through a 5 phase sequence. Phase 1 begins with the identification of partnership benefits and appropriation of organizational resources and support. Phases 2 and 3 deal with the development and weighting of partner selection criteria, candidate shortlisting and detailed financial and compatibility evaluation. Phase 4 formalizes and implements the partnership, and establishes feedback and problem correction mechanisms. The final phase consists on on-line monitoring of the relationship and affords information for decisions on the future of the relationship. Generally speaking, partnerships are either maintained at their current level or escalated to greater levels of integration - termination options are seldom favored in view of the prohibitive switching costs involved. The model is validated and updated using a case study of successful partnership implementation (Ellram and Edis, 1996). A different perspective of inter-organizational dynamics is provided by the Europe based *IMP* network research school (Hakaansson, 1982). The *IMP* model depicts buyer-supplier relationships as a network of interlinked factors, involving partner attributes, interaction process specific elements and surrounding environmental and atmosphere conditions. Firm interactions occur within the network established by these factors and consist of episodic financial, product or social exchanges. Smith (1993) suggests that inter-firm interactions are shaped by both individual and organizational influences. Trust evolves as the system evolves. Previous research (Hallen and Johanson, 1984) has also shown that relationship dimensions such as information sharing, interfirm dependence and social exchanges are moderated by country of origin, market share and distance, demand concentration and product type and technology variables. Hallen, Mohamed and Johanson (1989) also found that interfirm information exchanges share a recursive relationship with the degree of product, process, delivery and inventory adaptation displayed by the partners in the relationship. Briefly, the network school advocates looking at relationships and not the firm in isolation and hold that the motivation for opportunistic behavior can be reduced because partners employ a long-term perspective in their relationships (Hakansson, 1982; Ford, 1984). The incentive to form long-term relationships derives from resource heterogeneity between firms.

A deeper examination of these frameworks reveals some underlying commonalties. The successful development of inter-organizational relationships is found to be contingent on the presence of six key enablers - the elements of time, interdependence, asset commitment, information exchange, joint actions and trust. The causal relationships among these elements constitutes a body of research in itself, which lies beyond the scope of this research. However, there exists a general consensus on the importance of each of these six elements in achieving satisfactory inter-firm relationships.

The third aspect of buyer-supplier relationship relates to the range of governance and cooperative mechanisms employed in designing and implementing the relationship. Between Williamson's (1975) organizational extremes of pure markets and pure hierarchies lie a range of intermediate governance structures. These can take several forms, including joint ventures (Contractor, 1986; Kogut, 1988), technology licensing (Koh and Venkatraman, 1991) and strategic partnerships (Heide and John, 1990). This spectrum of organizational arrangements can also be classified in terms of degree of ownership and control, i.e, equity and non-equity relationships (Figure 2.4).

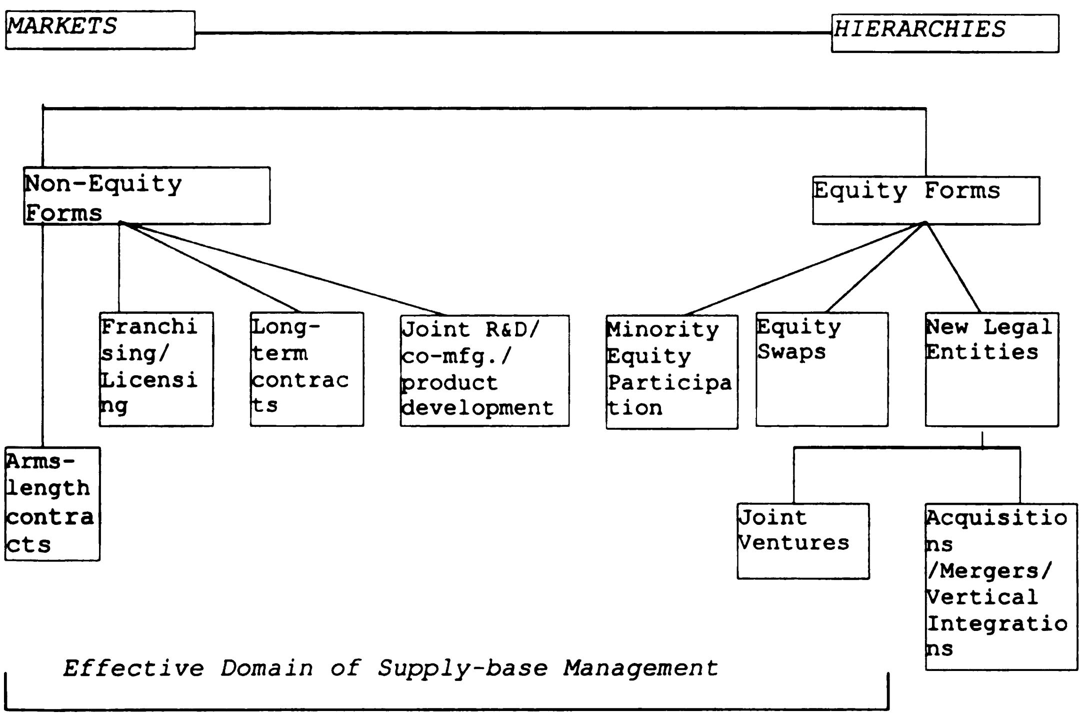

Figure 2.4

Inter-Organization Structures

Adapted from Yoshino and Rangan, 1995

Firms, especially large auto makers, are moving away from the pure market transaction paradigm implicit in traditional arms-length buyer-supplier dealings into more long-term synergistic associations (Helper and Sako, 1995) For example, Dyer (1996) describes the co-development of critical assemblies for Chrysler's new models of cars and trucks with first tier suppliers who then take the responsibility of prototyping, manufacture, cost, delivery and quality of these co-designed systems. He identifies three key factors behind Chrysler's successful buyer-supplier relationship strategy - building trust, reducing costs and improving communication. Trust is developed through long-term commitments, provided the supplier meets current *kaizan* cost targets and meets target costs for the next model. To improve communication, Chrysler employed resident supplier engineers, installed shared inter-active computer design, manufacture and information systems and constituted an advisory supplier council from its top 14 suppliers. To achieve cost targets, Chrysler first asked its primary suppliers to perform value engineering and analysis on lower levels of the bill of material owned by lower-tier suppliers. It also conducted in-house examinations of processes and products.

Japan's *keiretsus* are exemplars of cooperative inter-organizational arrangements involving marginal to medium equity participation. The *keiretsu* is an economic institution which networks in order to reduce costs, distribute risks, facilitate communication, develop trust and reliability and provides strategic advantages against external competitors to its members (Lincoln, Gerlach and Takahashi, 1992; Smitka, 1991). In fact, such institutional arrangements can cross international shores, witness the rapid recreation and extension of Japanese buyer-supplier links in Japanese transplants in North America (Martin, Mitchell and Swaminathan, 1995). Recent research has shown that North American firms are moving away from the arms-length transactions to more relational approaches in their buyer-supplier relationships (Helper and Sako, 1995). Interestingly enough, in Japan itself, buyer-supplier relationships are beginning to show exit patterns, perhaps in response to increased competition and a desire for flexibility in technology access (Helper and Sako, 1995). The overall proportion of long-term partnerships however, remains much larger in Japan than in North America. Joint ventures and equity participations are not frequently encountered in the North American domestic context. Internationalization often creates the necessity for such organizational arrangements, a case in point being the recent collaborative manufacturing agreements of GM and Ford with Indian partners in Asia.

The quintessential trade-off in the choice between various degrees of market and hierarchies lies between ownership control and risks. Full integration confers full control yet exposes the firm to fixed investment risks. Total outsourcing minimizes investment risks but carries potential penalties of loss of technology and subservience to supplier power. The current paradigm concerns itself with the intermediate range of non-ownership inter-organizational structures which essentially offset outsourcing risks by developing alternative governing mechanisms. Aulakh et al. (1996) cite trust as one such effective substitute for ownership control, achieved through repeated encounters, asset specific investments and top management commitment. Long-term relationships, and co-design or manufacturing efforts represent such non-equity relational arrangements.

2.3.1.3 *Supplier Capability Auditing*

More than three decades ago, Leenders (1966) related supplier capabilities to increased organizational profitability. Watts et al. (1992) showed the theoretical importance of acquiring supplier capabilities to complement manufacturing capabilities and support purchasing and business goals. The reliance on supplier capabilities has increased over the years (Burt, 1989; Monczka et al., 1993). Strategic sourcing requires a competent supply base (Tully, 1994). While effective buyer-supplier relationship may assist to develop and obtain positive sourcing outcomes, the supply-base itself should possess fundamental strengths in the areas of technology and agility. Nishiguchi (1994) found that the superior production and communication capabilities of Japanese suppliers enabled Japanese OEM's to achieve higher performance than their US or European competitors. The international movement of indigenous supply-bases with worldwide Japanese and US OEM transplants confirms the importance of the availability of supplier capabilities for competing effectively. Monczka et al. (1993) found that buying firms are increasingly relying on suppliers for developing critical product and process technologies. This dependence increases the need for supplier capability analysis. Hines (1996) identified supplier capability evaluation as a key responsibility for purchasing in a lean production agenda. Dyer, Cho and Chu (1998) note that supplier performance on non-controllables such as innovation and responsiveness is critical in strategic buyer-supplier relationships. Firms seek supplier capabilities in engineering, design, testing, manufacturing and tooling (Monczka and Trent, 1991). More recently, Monczka et al. (1993) found that purchasing executives prioritize technological, delivery and responsiveness capabilities in the supply-base and expect best-in-class performance in such areas.

Essentially, a firm needs to ask itself two questions: do we have the supply-base capabilities to match and support manufacturing and business strategic objectives; and are these supplier capabilities being realized in terms of supplier performance. For example, design and manufacturing may plan for new product introduction. Sourcing must find out if supplier capabilities in component and process design exist to support manufacturing and design objectives. It should then introduce relationship management practices to obtain supplier performance from these capabilities.

Research indicates a shift from traditional cost and quality emphasis, towards increasing technological reliance on supplier product and process design capabilities (Monczka et al., 1993; Watts and Hahn, 1993). Full service demands increase the strategic importance of maintaining a technologically capable supply-base. Purchasing managers pursuing strategic sourcing, would likely have a strong interest in monitoring supply base capability and performance in relation to their strategic needs.

In the context of a flexibility strategy, sourcing should be concerned with supplier capability and performance in the areas of supplier responsiveness to: order volume changes, delivery schedule changes and order 'mix' changes. Sourcing may also be attentive to supplier ability to accommodate minor design changes, provide assistance in product and process design, and design and manufacture new products to meet buyer product-based strategies. Such capabilities can relate directly to the achievement of volume, mix, modification and new product flexibilities in a firm (Olhager, 1993). These capabilities should be monitored and audited on a continual basis to ensure optimum supplier performance for achieving flexibility and other strategic business goals.

2.3.1.4 *Purchasing Integration*

Integration has become a new core competence for businesses. Dell Computer has achieved a 54% increase in returns, based on its assemble-to-order manufacturing strategy (Wall Street Journal, 1998). This manufacturing strategy is supported by a system that closely integrates suppliers, order-entry and customer monitoring, manufacturing and finance, using a mix of technology and business process re-engineering. A large part of the success of the 'Toyota production system' can be attributed to the significant role of purchasing integration in (understanding and formulating) Toyota's production philosophy and extending it to Toyota's primary supply-base (Hines, 1996). The challenge for purchasing lies in integrating its sourcing strategies with the strategic objectives of the rest of the business. The degree to which it does so, determines the degree of purchasing integration in a firm. In turn, the congruence and interaction among sourcing, manufacturing and business strategies influences the degree of 'strategic sourcing' achieved in a firm.

The literature views integration of purchasing goals and practices across inter-functional boundaries as a critical enabler of 'strategic sourcing' in a firm. Several conceptual frameworks discuss the integration of sourcing with manufacturing and corporate strategy. Watts, Kim and Hahn (1992) describe strategic sourcing as achieving congruence between purchasing objectives and action plans and manufacturing and business goals. A key feature of their framework is the need for purchasing to be able to link supplier capabilities of flexibility, cost, technology, quality and delivery to manufacturing objectives. The precise capabilities to be acquired is defined by the nature of manufacturing and business needs. In essence, Watts et al. (1992) define strategic sourcing as the sourcing actions involved in providing external capabilities to support internal manufacturing competencies and the competitive positioning of the firm. To do so, sourcing must be a full participant in corporate and manufacturing strategy formulation and implementation. Whether this is actually achieved is a debatable issue, despite the growing recognition of purchasing as a core competence area in the firm (Tully, 1995). Monczka and Trent (1991) in their study of *Fortune 500* firms conclude that strong linkages do not exist between sourcing strategy and business strategy. They attribute this to the absence of suitable interfacing mechanisms between sourcing and top management, although a certain amount of indirect coordination may be provided through manufacturing. Similarly, St. John and Young (1991) found inconsistencies in agreement on strategic issues between purchasing and production as well as a lack of consensus with overall business level priorities. Other strategic sourcing frameworks are built around sequential stages of sourcing development (Reck and Long, 1988; Bhote, 1989; Freeman and Cavinato, 1990). A common theme of these frameworks is the evolutionary description of the changes in purchasing activities and attitudes as the sourcing function matures into a strategic contributor in the company. The movement from routine, clerical purchasing activities to a pro-active, cross-functional, capability based role in the firm, is a key defining criteria in the progress from lower to higher order stages in all these frameworks. Cross-functional teaming, application of new measures of cycle-time and total cost, enhanced personnel skill-level requirements and pro-active attitudes are some of the other anticipated changes on the path to strategic sourcing. A common drawback of these frameworks is their descriptive foundation. Many draw on interviews, case studies or limited samples for their conclusions and lack large scale empirical validation and analytical rigor.

Narasimhan (1996) presents the evolution of supply chain management in terms of simultaneous, integrative transitions in four major dimensions - scope, focus, role and structure. Full integration is realized when sourcing employs a global scope, deploys an external focus, occupies a strategic position in the company and manages complete supply chains linking suppliers to end customer and markets. Sourcing creates and provides 'firm specific competitive advantages' for sustainable business growth. The framework is validated with examples from international industry.

Given the significance of purchasing integration in a strategic sourcing initiative, the question arises of how firms could achieve such integration? Previous research has emphasized that purchasing's involvement in a company's strategic decision-making process is the primary requirement for achieving purchasing integration. This can be undertaken in several ways: purchasing representation in top level management, integrated cross-functional teaming, separation of strategic and tactical purchasing responsibilities, and measurement and reward systems based on strategic contributions to competitive goals (Ellram and Carr, 1994; Gadde and Hakansson, 1994; Robertson, 1995; Fitzpatrick, 1996).

In summary, sourcing can pursue two different approaches in its strategies. It can seek functional excellence and develop supporting internal and supply-base competencies. Alternatively, it can pursue a strategic vision of supply-chain wide sourcing issues and develop competencies to support the strategic requirements for organizational success. The latter approach results in the strategic alignment of sourcing and enterprise objectives and actions, and the diffusion of sourcing influence throughout the organization and its supply chain. It are these conditions that can lead to management recognition of sourcing as a strategic contributor to firm competitive advantage.

In conclusion, strategic sourcing can be characterized as the careful selection, development and integration of sourcing strategies, aimed at the achievement of the manufacturing and business goals of an enterprise. Supply base optimization, buyer-supplier relationship practices and supplier capability auditing represent three common strategies in sourcing agendas. Purchasing integration links these sourcing strategies to the manufacturing and business priorities of a firm.

2.4 Advanced Manufacturing Technology

2.4.1 *Conceptualizations*

Table 2.7 offers a chronological view of the evolution of advanced manufacturing technology.

The advent of NC machines in the late 40's and early 50's was limited primarily to high-precision, high-complexity defense, because of their high capital costs, programming constraints and uncertain reliability (Romeo, 1975; Carlsson, 1992). Consequently, NC machines accounted for less than 20% of the total US investment in machine tool jobs till the 1960's. The introduction of computer control by the Japanese in the mid-70's led to the establishment of the CNC as a much more easily programmable and eventually less expensive machine during the 1980's. By 1984, NC/CNC's accounted for more than 40% of the total US machine tool market (Edquist and Jacobsson, 1988). Although the first computer integrated manufacturing system (FMS) in the US was installed at Caterpillar in 1970, the total number of FMS installations was limited to about 125 worldwide till 1984 (Handfield and Pagell, 1995; Pyoun, Choi and Park, 1995). The rate of adoption of computer integrated flexible manufacturing systems (FMS), while lagging that for robots and CNCs (Handfield and Pagell, 1995), showed a remarkable increase over the late 80s' and 90's. The average number of FMS installed globally in 1989-93 was around 100, a figure which is expected to rise to about 200 during 1994-2000 (Pyoun et al., 1995). Design, tooling, engineering and testing were also integrated into the scope of FMS following the development of CAD, CAE, CAM and CAT. Advances in information and design technology has enabled the interfacing of design, engineering and manufacturing across the supply chain for product development and production purposes. The total number of FMS installed globally as of 1993 was estimated as 1500, with another 1500 anticipated installations by the year 2000 (Pyoun et al., 1995).

The rapid development and transferability of technology have enabled many smaller companies and countries to leapfrog the intermediate stages of technology evolution. For instance, South Korea created its semi-conductor competency by accessing the best technology available in the world. The most striking feature in the growth and change of manufacturing technology has been in the area of computer integration. Innovative technologies such as CAD/CAM and computer-aided testing (CAT) have assimilated separate, sequential tasks into concurrent, inter-active, real-time design and manufacturing systems which have begun to extend across company boundaries (Dyer, 1996).

Flexibility however, is not a dictate of all manufacturing environments. The spectrum of manufacturing processes is bounded at one end by repetitive continuous/discrete manufacturing systems (e.g., oil refineries, automobile transfer lines) and by job-shop individual customized products (e.g., prototypes for aerospace/automobile industry), at the other. Intermediate manufacturing situations are created by limited volume, limited variety demands, largely met through batch production methods. While one time jobs can be handled by stand-alone CNC machines, such arrangements do not have the capacity to ramp up to multiple product, larger volume batch order requirements. It has been estimated that 25% of all US production is done in batch sizes of 50 or less, a figure which rises to 75% in such industries as metalworking (Hyer and Wemmerlov, 1982; Handfield and Pagell, 1995). Dysfunctional consequences are experienced when job shops are asked to efficiently fulfill batch manufacturing orders. Low machine utilization, high parts queue times, excessive material handling of large WIPs and manual tracking of different parts and products are some symptoms of the mis-match between manufacturing task and manufacturing process (Black, 1983; Hutchinson, 1984). Advanced manufacturing technology resolves the volume/variety dilemma to an extent through the deployment of flexible manufacturing systems (FMS), multi-machine, computer linked, CNCs attached to automated material handling and storage systems.

One of the earliest conceptualizations of advanced manufacturing technology was made by Groover (1980) who divided flexible manufacturing systems into 'dedicated' and 'random' types. 'Dedicated' systems manufactured a fixed range of part types over a definite time horizon, whereas 'random' systems manufactured a greater variety of part types in random sequence. Flexible manufacturing systems target economies of scope by offering flexibility options, although in practice such options may seldom be exercised (Jaikumar, 1986).

A multi-dimensional view of advanced manufacturing technology was introduced by Browne et al. (1984). They expanded Groover's (1980) classification to include 'type 1', '2' ,'3' and '4' FMS and introduced the dimensions of material handling and on-line control systems. A 'type 1' FMS, also called a 'flexible machining cell'(FMC) would comprise one CNC, an automated inputs buffer and an automated pallet changer. A 'type 2' FMS (flexible machining system) would have several FMCs, more flexible material handling systems and on-line production controls. A 'type 3' FMS (flexible transfer line) would pre-assign processing tasks to specific machines and use a carousal or conveyor material handling system. Smaller set-up times and increased set-up frequency would distinguish it from a conventional dedicated transfer line. A 'type 4' FMS would consist of multiple inter-linked flexible transfer lines and provide more routing flexibility than a type 3 FMS.

Technological advances, especially in the area of computer integration, have broadened the domain of the early definitions of advanced manufacturing technology. Swamidass (1988) includes robotics, automated guided vehicles (AGV), FMS, numerically controlled and computer numerically controlled machines (NC/CNC), CAD/CAM and CIM as technology enablers of manufacturing flexibility. Lei, Hitt and Goldhar (1996) describe advanced manufacturing technology in terms of computer integrated manufacturing systems (CIM), flexible manufacturing systems (FMS) and computer aided design/manufacturing linkages (CAD/CAM). Others have defined it as the use of a variety of computer controlled, inter-linked systems of design and manufacture (Flynn et al. , 1994) and the extent of use of advanced technological, methodological and structural concepts and methods in a firm (Bessant, 1989; Bolk et.al, 1989). The definition provided by Tranfield, Smith, Ley, Bessant and Levy (1991) transcends automated machine typology to enfold CAD/CAM, information technology, configurational processes and the use of JIT/Kanban in their description of a complete and effective advanced manufacturing system. Similar system elements incorporating cellular manufacturing and flexible process design and the engagement of JIT production processes have been proposed in related literature (McCutcheon, Raturi and Meredith, 1994; Dean and Snell, 1996). Implicit in these understandings of advanced manufacturing technology is a systems perspective, integrating production machinery, accessory material handling, information technology and process related elements into an effective flexible manufacturing system. Similar observations have been made by Jaikumar's (1986) on the combined deployment of CNCs with robots, special material handling systems and automated storage and tool handling systems among successful users of advanced manufacturing technology in Japan. Another aspect of advanced manufacturing technology relates to the extent of use of group technology (Das and Khumawala, 1989). Grouping, classifying and coding parts on the basis of similarity of dimensions and/or processes simplifies tool magazine capacity constraint planning and offers reduced set-ups and improved control. Roth and Giffi (1995) distinguish between the 'hard' and 'soft' aspects of advanced manufacturing technology, but determine both to be necessary for world class manufacturing performance. Computer-aided testing (CAT), computer-aided engineering (CAE), robotics, local area networks (LANS), vision systems and flexible manufacturing centers are considered the 'hard' factors of advanced manufacturing technology. 'Softer' technology areas involve design for manufacturing (DFM), productive/preventive maintenance, JIT, Kanban, concurrent engineering, value analysis/ engineering and integration of manufacturing systems. Gaining excellence in both 'hard and 'soft' factors is a key way in which world class manufacturers differentiate themselves from other firms.

Another approach to classifying advanced manufacturing technology is represented by the continuum concept. Voss (1986) uses the twin criteria of integration and automation to create a continuum of advanced manufacturing technology, ranging from NC machines at one end to CIM at the other. Handfield and Pagell (1995) similarly describe integrated automated process technologies in terms of a continuum, bracketed at each end by stand-alone NC machines and CIMs, respectively. Continuums could also be defined using cost considerations. Ranta and Tchijov (1990) use the notion of cost to divide advanced manufacturing systems into a 'cheap - expensive' classification. A 'cheap' system employs limited technical complexity and elementary control architecture. In contrast, an 'expensive' system, typically affording more expandability and adaptability, would consist of multiple CNCs, with AGVs and automated storage and retrieval (ASR) systems, tied together by a local area network. The average cost distribution of such a system would be in the range of US$ 10-15 million with the following breakdown by expenditure head - CNCs (35-40%), material handling systems (15%), control and communication systems (25-30%) and planning and training (15-20%).

The literature suggests that advanced manufacturing technology can be classified under four complementary dimensions - manufacturing machinery, infrastructural support systems (material handling, production planning and control systems), computer systems in design and engineering, and human resource management practices. Figure 2.5 employs these dimensions to build a continuum of advanced manufacturing technology, using flexibility as a system variable.

	Low — Degree of Operational Flexibility	— High
Manufacturing Machinery	NC machines	Computer integrated manufacturing Integrated CNC machines FMS
Computer Systems in Design and Engineering	None	Computer aided design/ Computer aided
Infrastructural Support Systems	Use of Belt Conveyors	Use of Automated Guided Vehicle systems
	Traditional job shop/ transfer line process - large WIP, Inventories, Waiting time etc.	Low setups, use of JIT, Kanban, EDI, bar coding etc.
Human Resource Management Practices	Focus on functional skills, centralized decision-making	Use of manufacturing teams, de-centralized decision-making, operator cross-training

Figure 2.5

A Continuum of Advanced Manufacturing Technology

Manufacturing machinery can range from simple numerical controlled machine tools, to individual CNCs (islands of automation), to inter-linked CNCs and Flexible Manufacturing Systems. Infrastructural material handling systems can range from belt conveyors to powered roller conveyors, to power-and-free conveyors, to mono-tractors, to towline carts, to automated guided vehicle systems (Stecke and Brown, 1985).

Infrastructural production and control processes can range from conventional production processes with large inventories, safety stocks, sequential/job shop manufacturing, high set-up times and frequencies to the gradual introduction of 'lean' manufacturing elements such as JIT, preventive maintenance, Kanban, value analysis/engineering, real time control and in-plant EDI systems. Computer systems can range from none to completely integrated design and engineering systems. Human resource management practices in manufacturing, comprise operator team development and deployment, worker multi-skilling and related measures to increase decentralization and empowerment on the shop-floor.

Selected combinations of advanced manufacturing technology elements would be relevant for the particular industry and manufacturing environment under study. For example, a job shop environment will probably invest in what Browne et. al. (1984) call 'Type II FMS' , an interlinked system of flexible machining centers using carts, conveyors or towlines, capable of multi-product small-medium volume tasks. In contrast, a more dedicated "Type III" flexible transfer line equipped with carousals or conveyors may be more appropriate for larger volume, lower variety manufacturing environments.

One notable point is that the extent of manufacturing flexibility will depend on the extent of system integration of all the above factors of an advanced manufacturing technology system. For instance, installation of an inter-connected CNC system is not likely to optimize flexibility performance, if not accompanied by parallel improvements in production processes and human resource management practices. Advanced manufacturing technology is thus conceptualized as a composite of 'hard' and 'soft' investments which combine to generate manufacturing flexibilities for an enterprise.

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2.4.2 *Operationalizations*

Various empirical operationalizations of advanced manufacturing technology have been made in the literature. Notable among these are Roth and Giffi's (1995) identification of 'hard' and 'soft' technology factors that differentiate world class manufacturers, and Snell and Dean's (1992) 18 item scale of advanced manufacturing technology. Other studies have employed ratio measures including capital outlay on computer automation vs. capital outlay on fixed automation (Parthasarthy and Sethi, 1992) and the proportion of NC and CNC machines to non-programmable conventional machine tools (Gyan-Baffour, 1994).

Roth and Giffi (1995) surveyed 872 senior manufacturing executives as part of the 'global manufacturing technology and strategy vision project' at the University of North Carolina, and defined several key advanced technology world class practices. However, their operationalization of advanced manufacturing technology did not include statistical validation. Snell and Dean (1992) developed a statistically rigorous multiple item, multiple respondent measure of advanced manufacturing technology, using factor analysis. Their scale measured the extent to which a firm has integrated computer technologies for manufacturing objectives. However, JIT production practices are measured independently from advanced manufacturing technology. Parthasarthy and Sethi (1992) proposed two alternative ways to assess 'flexible automation'. They suggest the use of ratios to quantify the relative outlay on computerization in manufacturing and design, or the use of semantic differential scales to survey the extent of computerization and design integration in a manufacturing process. Again, these measures were not subjected to statistical validation. Other studies have attempted to gauge advanced manufacturing through item measures such as 'use of flexible

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flexible manufacturing systems' and 'use of robotics', the 'percent of machines linked by automated transfer systems' and the 'average machine value' (Suarez et al., 1996).

The measurement literature reveals a lack of statistically validated scales to evaluate and assess the advanced manufacturing technology concept. Ratio scales, while offering quantitative convenience, are not sufficiently comprehensive. Other efforts lack statistical rigor and also suffer from constrained domains. Snell and Dean's (1992) multi-dimensional measure of advanced manufacturing technology is statistically superior to the other measures. Its shortcoming is that the authors do not use second order factor analysis to confirm the presence of a higher order technology factor which might subsume both JIT production practices and manufacturing technology elements. Statistical rigor is also found in Ward, Leong and Boyer's (1994) development of uni-dimensional scales for structural and infrastructural capability building programs. The authors factor analyze technology elements such as CAD, CAM, FMS, CNC, DNC and vision control into a composite structural factor. Their infrastructural factor includes worker training, empowerment, and job-enrichment. More recently, Boyer, Ward and Leong (1996) develop and validate an advanced manufacturing technology scale with three factors - design, manufacturing and administration - across a range of high technology industries.

It is evident from the literature that advanced manufacturing technology contains multiple domains. This research distinguishes four such significant domains: manufacturing machinery, infrastructural (material handling systems) and production planning and control systems (planning, kanban, preventive maintenance etc.), computer systems in design and engineering, and human resource management practices (Figure

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2.5). Any reflective or formative scale of advanced manufacturing technology needs to employ enough breadth of coverage to include and specifically measure each of these domains. Additionally, the degree of simultaneity between the various domains also requires to be measured. A manufacturer using integrated CNCs without corresponding infrastructural or design processes would not be described as a strong user of advanced manufacturing technology.

2.5 Performance

2.5.1 *Manufacturing Performance*

Manufacturing performance is discussed here from two perspectives - the *content* of manufacturing performance and the *measures* of manufacturing performance.

The *content* of manufacturing performance has been characterized in terms of the fundamental competitive priorities of operations strategy - quality, time, cost and flexibility (Krajewski and Ritzman, 1990; Neely, Mills, Platts, Gregory and Richards, 1994). Flexibility targets economies of scope in the plant - achieving variety and speed at low cost (Goldhar, Jelinek and Schlie, 1994). As Schlie and Goldhar (1995) remark, manufacturing cost is the key differentiator, as rising consumer expectation thresholds force companies unable to charge a price premium, to compete on the basis of low price. Successful imitation of product features by competition is rendered difficult by the challenge of having to produce and sell the product at the low price set by the cost leader. A viable differentiation strategy can only survive in the long-term when accompanied by low cost manufacturing competencies (Schlie and Goldhar, 1995). Operating costs have been used before to measure manufacturing performance (Rho, Hahm and Yu, 1994), consistent with the business

priorities of current day manufacturers (Kim, 1994). Inasmuch as cost harmonizes and underlies other manufacturing differentiators such as quality and variety, it needs be considered as a fundamental performance objective of competitive manufacturing situations. Total manufacturing cost reduction is expected to remain an important barometer of manufacturing performance (Roth and Giffi, 1995).

In addition to manufacturing cost, manufacturing performance indicators in such areas as facility output, employee and machine productivity, quality, scrap rate, and delivery reliability and speed have been traditionally employed by firms (Arthur, 1994; Lawrence and Hottenstein, 1995; Banker, Field, Schroeder and Sinha, 1996). Similar measures find mention in the product life cycle tailored list of manufacturing performance areas developed by Richardson and Gordon as early as 1980. Macduffie et al. (1996) employed productivity and quality to measure plant performance in their international study of the impact of product variety on manufacturing performance in the auto industry. However, departures from convention in the form of measures of new product or process innovation or flexibility are still infrequent, even when required by the demands of the product(s) life cycle stage(s) the firm happens to be in.

Customer linked performance measures have been highlighted in the recent literature. Kaplan and Norton's (1992) 'balanced scorecard' proposes internal business process measures tied to customer satisfaction. Internal factors that affect customer perceptions of deliverables range from cycle time to quality and productivity. Roth and Giffi (1995) found that world class manufacturers place a premium on customer driven manufacturing performance targets including improvements in perceived quality, responsiveness, on-time delivery and customer

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One way to structure the content of manufacturing performance is to decompose higher level performance goals into local levels. Decomposition enables identification of tangible performance areas for focusing employee effort. Figure 2.6 organizes manufacturing performance content in order of different levels of abstraction. The representation of performance areas is illustrative, not exhaustive.

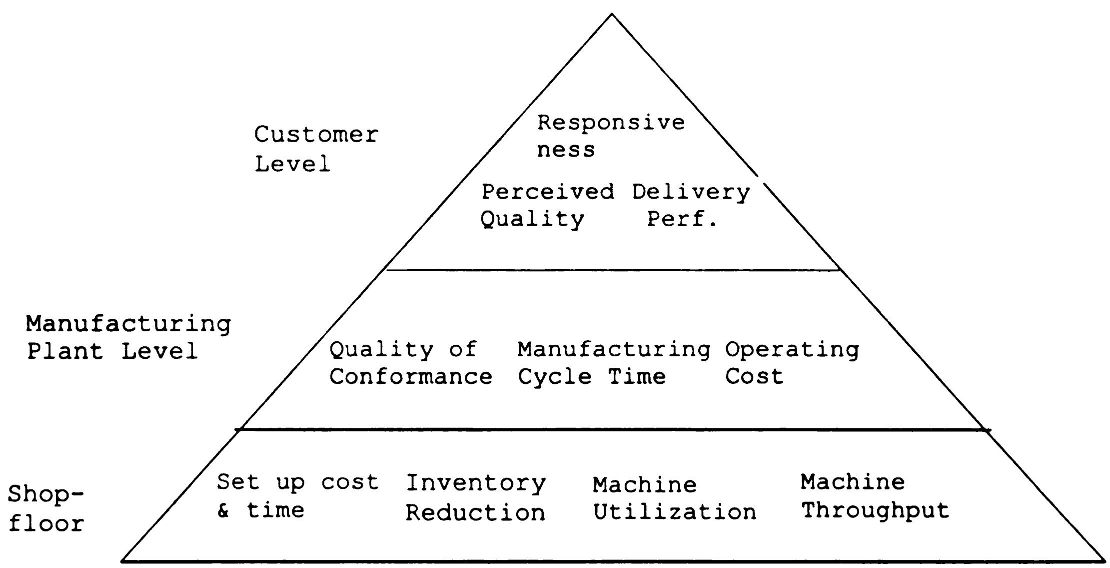

Figure 2.6

Different Levels of Manufacturing Performance

Each level in Figure 2.6 builds on the other - the top layer interfaces directly with customer satisfaction attributes. A detailed description of the interactions within and between different levels of manufacturing performance is not attempted here. The intent is to show the potentially cumulative impact of lower level performance factors on successively higher levels of performance parameters. The logic could be easily extended to make forward, backward and internal linkages between manufacturing performance, firm performance and supply chain performance.

The multi-dimensionality and tiering characteristics of manufacturing performance calls for measures which a) capture all performance dimensions relevant to the study and b) do not compare or combine lower levels of performance with higher levels (although each can be measured independently). The unit of analysis needs to be clearly defined in any performance study.

Different *measures* of manufacturing performance have been described in the literature. Roth and Miller (1990) used principal components analysis to reduce eleven critical manufacturing capabilities into five independent dimensions of manufacturing performance. These are quality, delivery, flexibility, price and market scope. Seven point Likert scales were used to measure each dimension of performance, relative to competitor performance. Quality consists of items measuring consistency of quality and high performance products. Delivery consists of items measuring dependability and lead time. Flexibility consists of items measuring design changes, introduction of new parts and rapid volume changes. Price is measured by the capability to offer low prices. Market scope consists of items measuring distribution, advertising, product line breadth and after-sales service competencies. Cronbach's alpha ranges from 0.77 to 0.53. Strong factor loadings testify to the presence of convergent validity - however, no formal attempt was made to ascertain the discriminant validity of the scale. The use of perceptual measures alone, without some cross-validation from other organizational sources or objective measures, also detracts from the validity of the scale.

Dean and Snell (1991) develop an 8 item (a=0.75) uni-dimensional scale, comparing current manufacturing performance to the industry average, in terms of product quality, employee morale, on-time delivery, inventory management, employee productivity, equipment utilization, producti

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production lead time and scrap minimization. The same scale finds application in a second study carried out by the authors in 1996 (Dean and Snell, 1996). Rho et al. (1994) measure manufacturing performance through top management perceptions of product quality, new product development, operating cost and delivery, relative to competitor performance, on a 5 point Likert scale. However, these dimensions are used independently as dependent variables in the study and do not constitute a single scale. Labor efficiency/productivity, product quality and scrap rate find mention in other measures of manufacturing performance (Arthur, 1994; MacDuffie, 1995). MacDuffie (1995) controls for capital intensity and stage of manufacture in his measurements of labor productivity (number of hours/unit) and quality (number of defects typical to assembly, i.e., fit and finish, painting etc./unit) in the auto industry. Miller and Roth (1994) assess differences in manufacturing performance among different strategic firm types in terms of manufacturing lead time, changeover setup time, headcount, ratio of white to blue collar personnel, outgoing quality, number of grievances and % new products on-time, on a 1 - 7 scale. The items were selected from a list of 29 manufacturing indicators developed earlier (Roth and Miller, 1987). Perhaps of more significance is their report on the future areas of emphasis of international manufacturing industry. Labor management relationships, zero defects, manufacturing lead time reduction, use of CAD, new product and process innovations and SPC are identified as the salient areas of future manufacturing performance.

An examination of the manufacturing performance measurement literature reveals perceptible patterns of emphasis. Labor productivity, product quality, manufacturing cost and delivery reliability and lead time were ubiquitous in studies of manufacturing performance. Less common were mea

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were measures relating to product innovation, manufacturing cycle-time and organizational learning. Another issue is the choice between perceptual and objective measures. Most cross-sectional studies employ the perceptual approach. Concern has been expressed about the potential for respondent bias in single respondent studies. It is difficult to comment definitively on these issues. While multi-respondent studies are certainly more desirable, they entail substantially increased time, cost and complexity demands. Conventional financial and non-financial measures of manufacturing cost and product/process quality are easier to collect, interpret and benchmark than say, measures of tacit design or manufacturing knowledge in a firm.

2.5.2 *Manufacturing Flexibilities and Manufacturing Performance*

Although prior research has examined the impact of advanced manufacturing technology on manufacturing and firm performance (Voss, 1988; Gyan-Baffour, 1994; Ward et al., 1994), and the relationship between manufacturing flexibility and organizational performance (Swamidass and Newell, 1987; Gupta and Somers, 1996), few studies have dealt directly with the relationship between manufacturing flexibilities and manufacturing performance per se. Notable amongst those that did, are Kekre and Srinivasan's (1990) study of product line breadth and performance linkages, Sluti's (1992) investigation of flexibility and performance relationships, Suarez et al.'s (1996) examination of the effect of manufacturing flexibilities on manufacturing performance and MacDuffie et al.'s (1996)inquiry into the impact of product variety on manufacturing performance.

Kekre and Srinivasan (1990) found a small but significant positive relationship between product line breadth (one indicator of mix flexibil

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flexibility) and reductions in manufacturing costs. They also found that product variety does not impact inventory costs adversely. They attribute these results to the use of flexible manufacturing technology, parts standardization and lean process manufacturing strategies. Suarez et al. (1996) report similar findings of the lack of negative effects of mix or new product flexibilities on manufacturing costs or quality. High mix flexible plants were also found to have shorter design-to-manufacture cycle times. Sluti (1992) found some evidence of a positive relationship between product flexibility and delivery dependability, in his study of manufacturing plants in New Zealand. Consistent with previous research, MacDuffie et al. (1996) observed negligible negative effects of product complexity on labor productivity, in their study of automotive assembly plants around the world. In fact, option variability was associated with fewer hours per car, suggesting that some plants were on a "more flexible production frontier". Parts complexity, one of the more problematic effects of product variety, was however found to impact productivity adversely.

The paucity of studies on the manufacturing flexibility-manufacturing performance relationship may be due to several reasons. Most investigators have concentrated on the aggregate relationships between manufacturing performance and its antecedents, such as advanced manufacturing technology, and organizational strategies. The presence of mediating variables in the shape of various manufacturing flexibility capabilities has been largely ignored. Studies need to focus at a sufficiently strategic level to be able to conceptualize and incorporate such latent variables in the scope of research inquiry. Another explanation could lie in the intrinsically amorphous nature of the manufacturing flexibility construct, making measurement and analysis a

complex and difficult task. Additionally, flexibility is a concept which while prized by practitioners, is seldom clearly understood by managers (Lim, 1987). Even less understood are the interactions among different manufacturing flexibilities and how these impact operational and strategic goals. As a counterpoint to such arguments, it is recognized that manufacturing flexibility could be a key generator of firm specific competitive advantages. The key issue for companies is to identify the specific flexibilities they want, realize the implicit interactions and trade-offs involved, and determine the manner in which such flexibilities can be achieved.

2.6 A Summary of the Literature Review

The preceding review of prior research in the areas of manufacturing flexibility, its antecedents, and manufacturing performance introduced several issues.

First, literature has emphasized the complexity of the manufacturing flexibility concept and attendant implications for measurement. Table 2.3 of this research developed a taxonomy of manufacturing flexibilities, with tiered categories of operational, tactical and strategic flexibilities. Each level is subsumed by the next higher level. While literature addresses the multi-dimensionality of manufacturing flexibility in several studies, no rigorous empirical effort has been made to investigate the inter-relationships among different manufacturing flexibilities. One of the objectives of this research is to examine the nature and implications of such interactions among different manufacturing flexibilities.

Second, as observed by Gerwin (1993), operationalizing manufacturing flexibility remains the "single most important research objective" in flexibility research. The multiplicity of conceptual definitions has resulted in a proliferation of measures, representing different levels of flexibility aggregation. Despite this, very few scales have been developed with adequate statistical rigor. The problem of parts/process complexity differences across companies and industries contributes to measurement difficulties.

Third, literature offers a diversity of antecedents for manufacturing flexibility. Particular emphasis has been placed on the roles of technology and organizational structure. Advanced manufacturing technology has been the mainstay of manufacturing flexibility strategies. Such technology plans however, need facilitating organizational structures. In terms of manufacturing flexibility achievement, organic organization forms, incorporating employee empowerment and decentralized control features find favor over more mechanistic, centralized structures. The literature also indicated a recent interest in the role of sourcing in attaining manufacturing flexibility competencies. Studies had reported positive associations between buyer-supplier relationships different manufacturing flexibilities (Olhager, 1993; Suarez et al., 1996). However, such inquiries have typically been part of a larger research interest, and consequently deficient in their treatment of the sourcing-flexibility relationship.

This research focuses on the role of strategic sourcing as an antecedent of manufacturing flexibility. The role of advanced manufacturing technology is also examined in counterpoint - organizational factors were included in the technology construct, in view of their integral role in technology implementation.

Fourth, an examination of the sourcing literature provided insights on the potential effects of strategic sourcing on manufacturing flexi

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flexibilities. Strategic sourcing was characterized as the development and integration of sourcing strategies with the manufacturing and business goals of a firm.

Four principal dimensions of strategic sourcing emerged from the literature. A fundamental dimension of strategic sourcing is supply base optimization. Pruning the supply base to a single/dual sourcing policy for each part family/major assembly, enables mutual concentration of resources by both buyer and supplier. An attendant decision is the tiering of the supply base into first and lower level suppliers, with commensurate delegation of product and process development and second tier management responsibilities. Volume consolidation and parts bundling comprise other significant aspects of supply-base optimization. Buyer-supplier relationship practices was identified as another distinct dimension of strategic sourcing. The buyer-supplier relationship literature identifies interaction frequency and intensity, interdependence, asset commitment, information exchange, joint actions, supplier assistance, and trust development as significant determinants of relational health. Buyer-supplier relationship development forms an important element of strategic sourcing. Supplier capability auditing was discussed as the third dimension of strategic sourcing. Strategic sourcing goals require a supply-base with strong capabilities in priority area. Companies are increasingly relying on suppliers to achieve strategic customization, flexibility, product and process design capabilities. The fourth dimension of strategic sourcing was purchasing integration. The conceptual literature on strategic sourcing emphasizes the advantages to be gained from effective integration of purchasing activities with manufacturing and corporate strategies.

The sourcing literature does not offer a comprehensive conceptualization or treatment of strategic sourcing. The measurement literature is fragmented. Measures for the component dimensions are scattered over several research studies. Research does not provide a forum for a rigorous conceptualization, measurement or examination of the strategic sourcing construct. This research attempted to address this gap.

Fifth, the literature on advanced manufacturing technology was reviewed. The literature addressed advanced manufacturing technology as a multi-domain construct. This research develops advanced manufacturing technology as a composite of machine technology, infrastructural systems, design and engineering processes, and human resource management practices. The effective alignment of these 'hard' and 'soft' production elements generates manufacturing flexibilities in a firm. Since advanced manufacturing technology is conceived as a multi-domain construct, it requires measures for each of its component dimensions. The literature revealed several statistically validated scales of advanced manufacturing technology. While none measure the construct in the four constituent dimensions conceived in this study, enough individual item measures exist in the literature. This study adapts these to measure the dimensions of research interest in the advanced manufacturing technology construct.

Next, the literature on manufacturing performance was discussed in terms of content and operationalization. Work-floor performance areas such as scrap reduction, machine throughput time and inventory reduction find reflection in higher order performance parameters of manufacturing cost reduction performance, quality and manufacturing cycle time. These plant level performance indicators connect to customer driven accomplishment objectives such as responsiveness, perceived quality and delivery performance. It is important that the level of analysis of

manufacturing performance content be clarified prior to measurement, in order to avoid 'double counting'. For example, combining both scrap rate reduction and manufacturing cost reduction in the same performance measure would introduce common measure confounds in measurement. Among the more frequently used content measures were labor productivity, product quality, manufacturing cost and delivery performance. Less encountered were the performance areas of cycle time, new product/process innovation and organizational learning.

Several scales have been developed and validated in previous studies to measure manufacturing performance. The predominance of perceptual measures has created demands for multiple respondent, objective measure scales. However, the practical difficulties involved in such scale development make the task problematic. Reverse coded measures and competitor benchmarking questions (in addition to internal goal performance) provide a check of response accuracy.

Finally, the review examined the literature on the relationship between manufacturing flexibilities and manufacturing performance. Few studies addressed this relationship directly. The handful that did, reported positive or neutral relationships between mix flexibility and manufacturing cost reduction and quality. Plants with high mix flexibility were also found to have reduced new product introduction cycle times. However, parts complexity was found to impact productivity adversely. This research undertakes a detailed examination of the relationships between specific manufacturing flexibilities and individual areas of manufacturing performance.

The next chapter presents a conceptual framework of manufacturing flexibility and develops hypothesis for empirical testing.

CHAPTER 3

NOMOLOGICAL FRAMEWORK

This chapter develops a nomological framework for the study.. The literature review in the preceding chapter is used as a basis for developing the constructs in the framework. Relationships among the constructs derive from the research objectives of this study: investigate the impact of strategic sourcing on manufacturing flexibilities; investigate the inter-relationships among different manufacturing flexibilities; and investigate the impact of manufacturing flexibilities on manufacturing performance. Constructs are defined and hypotheses are developed for model testing.

3.1 Conceptual Framework

The conceptual framework used to guide data collection is shown in Figure 3.1 below.

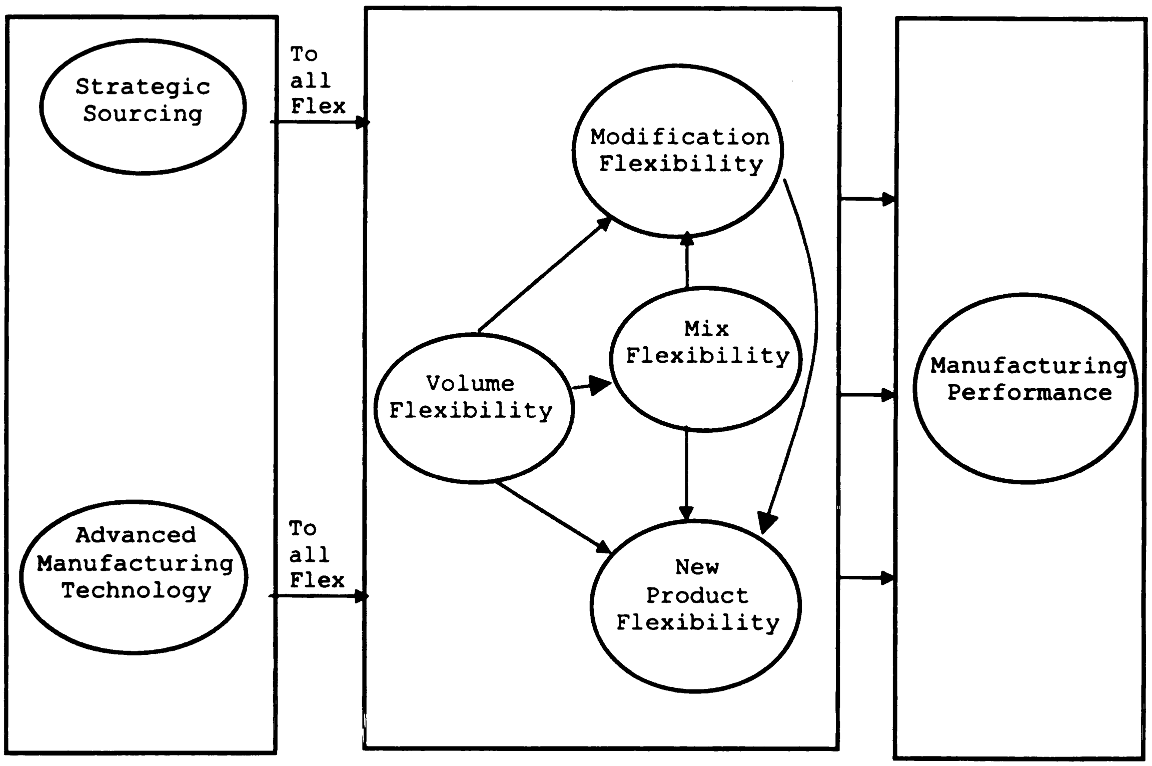

Figure 3.1
A CONCEPTUAL FRAMEWORK OF MANUFACTURING FLEXIBILITY

Strategic sourcing and advanced manufacturing technology are hypothesized to influence volume, mix, modification and new product flexibility capabilities. Volume flexibility is hypothesized to influence modification and new product flexibilities. Mix flexibility is hypothesized to influence modification flexibility and mew product flexibility. Mix, modification and volume flexibilities are hypothesized to influence new product flexibility. Finally, mix, modification, volume and new product flexibilities are hypothesized to impact manufacturing performance. The constructs in the framework are defined next.

Strategic Sourcing has been variously defined as the strategic evolution of sourcing priorities to proactively support and generate competitive advantages for the firm (Carter and Narasimhan, 1995; Watts et al., 1992); as the ultimate integration of sourcing strategies with firm strategies (Freeman and Cavinato, 1990; Reck and Long, 1988); as the deliberate reduction of vertical integration (Hill, 1994); as the conversion of fixed costs into variable costs (Welch and Nayak, 1992) and as the vertical integration of capabilities (Stukey and White, 1993).

In this research, strategic sourcing is defined as 'the extent to which purchasing engages in supply-base optimization, buyer-supplier relationship development, supplier capability auditing and purchasing integration strategies, to support strategic manufacturing objectives.' The construct dimensions are:

- Supply-base optimization: The rationalization of the supply-base, accompanied by parts bundling and volume consolidation practices.
- Buyer-supplier relationship development: The development of long-term relationships with the supply-base, employing trust building, asset commitment, information sharing, and supplier assistance practices.
- Supplier capability auditing: The assessment of supplier design capabilities and responsiveness performance in flexibility related issues.
- Purchasing integration: Purchasing participation in business strategy formulation and implementation.

Individual item measures were employed to assess each of these dimensions.

Advanced Manufacturing Technology has been defined in the literature, as the 'extent of use of advanced technological, methodological and structural concepts and methods' in a firm (Bessant, 1989; Bolk et.al, 1989). It is noted that organizational factors are recognized in this definition in view of their central role in technology implementation. Several measures exist in the literature for this construct, among which are the classical FMS classifications of Browne et al. (1984), the plant floor and modular machine layouts of Olhager (1993) and the NC/CNC machine population proportion of Gyan-Baffour (1994). The construct definitions provided by Tranfield et al. (1991) and Boyer et al. (1996) were of interest to this research because of their breadth of scope, transcending automated machine typology to enfold CAD/CAM, information technology, configurational processes, use of JIT/Kanban, and administrative processes in their description of an advanced manufacturing system. Similar definitions, involving cellular manufacturing, flexible process design, and JIT production processes have been proposed in related literature (McCutcheon, Raturi and Meredith, 1994; Dean and Snell, 1996).

Based on the literature, advanced manufacturing technology is defined as the 'use of advanced manufacturing, design, infrastructural, and human-resource management practices and systems in a plant, for achieving strategic manufacturing objectives'. The construct encompasses:

- The use of advanced manufacturing systems - CNC machines and flexible manufacturing systems
- The use of computer aided design, engineering and testing
- The use of infrastructural support systems - JIT manufacturing, automated material handling, kanban, minimal inventories, preventive

equipment maintenance, accelerated die changes and set-ups, parts bar coding, and EDI usage in manufacturing

- The use of innovative human resource management practices and structures in manufacturing - cross-functional teams, decentralized decision-making and worker multiple task training.

Manufacturing flexibility is treated as a multi-dimensional capability. This study concentrates on four facets of manufacturing flexibility - *mix flexibility, modification flexibility, volume flexibility and new product flexibility*. There are two reasons for doing so. First the main linkage between the buyer and the supplier occurs at the tactical (plant) level and the impact of strategic sourcing on manufacturing flexibility is most readily perceived at this level (Slack, 1990). Gerwin (1987) supports this view by proposing sourcing policies (in addition to manufacturing processes) as an alternative/additional source of plant wide flexibility. Second, the impact of advanced technology is manifested in tactical level flexibilities, albeit through operational level flexibilities. Measuring both operational and tactical flexibilities would be a redundant (and complex) exercise in relation to the conceptualized model. Mix, modification and volume flexibilities have been classified earlier as 'tactical' flexibilities occurring at the plant level. New product flexibility has been described as a 'strategic' flexibility - however, plant level management is generally expected to be aware of new product development. Other strategic flexibilities such as market flexibility which reflects the capability of the manufacturing system to drive market changes are more subjective and may require a corporate level perspective, not readily available to plant management.

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'realized' vs. 'potential' competence, since active operational relationships are proposed between manufacturing flexibilities and realized manufacturing performance.

Mix flexibility is defined as the ease with which the manufacturing system can switch between the manufacture of different products in a product mix.

Modification Flexibility is defined as the capability of the system to modify and manufacture existing products to meet customization demands. Modification flexibility is limited to minor design changes in similar product families.

Volume Flexibility is defined as the capability of the system to operate economically over a range of aggregate production volumes.

New Product Flexibility is defined as the capability of the plant to design, prototype and produce new products to meet stringent time and cost constraints.

Manufacturing Performance is defined as the extent to which the manufacturing system meets manufacturing goals. This construct is conceptualized at the manufacturing plant level, using the content dimensions of quality of conformance, manufacturing cycle time, new product introduction time reduction and manufacturing cost reduction performance. Delivery performance and responsiveness to customization requests are also included to reflect customer level manufacturing performance dimensions. While manufacturing may not have total responsibility for overall delivery performance or system responsiveness, it would be interesting to see if increased manufacturing flexibilities make a difference in these customer driven performance areas. These areas of manufacturing performance have been chosen for a variety of reasons. One reason is that lower 'shop-floor' level indicators such as scrap

reduction and set-up time/cost reduction are not readily accessible at the unit of analysis of this research, i.e. the purchasing manager. Another is that quality, cost, cycle-time, responsiveness and delivery performance have been identified as critical performance areas for world class manufacturers (Kim, 1994; Roth and Giffi, 1995). Additionally, a 'balanced scorecard' approach requires linking internal manufacturing processes to customer wants (Kaplan and Norton, 1992). Each performance dimension is measured and employed separately since different manufacturing flexibilities are anticipated to affect different areas of manufacturing performance.

3.2 Hypotheses Development

Positive relationships between product mix/volume flexibilities and supplier short lead times had been discovered by Olhager (1993). Rho, Hahm and Yu's (1994) study of 39 machinery and electronic firms in South Korea also revealed significant affinities between vendor relationships and manufacturing flexibility. However, the dynamics of these linkages remain indeterminate in the absence of specifics on the flexibility-sourcing relationship. Such cursory treatment of the sourcing-flexibility connection is also encountered in Suarez, Cusumano and Fine's (1996) 31 plant exploration of flexibility attributes and drivers in the international printed circuit board industry. Two principal comments can be made on this study. One, the authors by confining the sourcing-flexibility association to a single dimension (buyer-supplier relationship) potentially deprive the relationship of context, content and fullness. Second, the sparseness of the conceptualization is compounded by the inappropriateness and single-item nature of the operationalization of the buyer-supplier relationship ('% of assembly

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subcontracted'). While diluted by such design constraints, their findings provide preliminary support for the sourcing-flexibility bond (Das and Elango, 1995) and the contribution of suppliers to the attainment of mix. volume and new product flexibilities.

These research findings suggested a positive relationship between strategic sourcing and manufacturing flexibilities. Firms seeking mix and modification flexibilities will develop a supply base with quick response capabilities to product feature changes. The volume flexibility of a plant is enhanced when the supply base has the ability to respond to unanticipated volume and schedule corrections. Similarly, new product flexibility in a firm will be strengthened by sourcing of supplier capabilities in technology and process expertise.

The above discussions suggest the following hypothesis:

H1: *Strategic sourcing has a positive influence on mix flexibility*

H2: *Strategic sourcing has a positive influence on modification flexibility*

H3: *Strategic sourcing has a positive influence on volume flexibility*

H4: *Strategic sourcing has a positive influence on new product flexibility*

Manufacturing hardware and humanware investments targeted at reducing set-up times, facilitating work-flows and increasing capacity and product line variety will enhance the potential of the plant to maintain a broad product mix, add re-designed and new products and respond efficiently to volume and demand fluctuations.

Thus,

H5: *Advanced manufacturing technology has a positive influence on mix flexibility*

H6: *Advanced manufacturing technology has a positive influence on modification flexibility*

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H7: Advanced manufacturing technology has a positive influence on volume flexibility

H8: Advanced manufacturing technology has a positive influence on new product flexibilities

Literature offers several multiple level flexibility frameworks (Slack, 1987; Alvarez-Gill, 1994). None focus on the interplay among the different manufacturing flexibilities co-existing at the same level. Suarez et al. (1996) detected a positive correlation between mix flexibility and new product development flexibility. No relationship was found between mix flexibility and volume flexibility.

The production of a multiple range of products will create learning benefits in the organization, especially in terms of facilitating design and manufacturing changes.

Therefore,

H9: Mix flexibility has a positive influence on modification flexibility.

The capability of the manufacturing system to re-design and re-make existing products as well as manufacture a wide variety of products should foster organizational innovation and learning, in turn developing a culture which embraces new ideas and has the competence to turn these into new products.

Hence,

H10: Mix flexibility has a positive influence on new product flexibility;

H11: Modification flexibility has a positive influence on new product flexibility.

Minor design changes, if targeted towards market segmentation and market variety, may create unanticipated volume fluctuations for a firm, since the addition of each market segment contributes to demand

uncertainty. Managers, therefore, would prefer to acquire volume flexibility before embarking on modification strategies.

Thus,

H12: Volume flexibility has a positive influence on modification flexibility.

Introduction and commercial ramp-up of a new product may typically involve the prior addition of new facilities for design and capacity reasons. Capacity problems may arise if the new product does not cannibalize sales and when manufacturing segmentation targets distinct market segments for pre-existing and new manufactures. Suarez et al. (1996) argue for a negative relationship between product line variety and volume fluctuations on the grounds that a dip in sales in one product may be compensated by an increase in another and that individual product volume variations may not impact total volume significantly. Such 'portfolio balancing' strategies are more frequent in the realm of finance than manufacturing. In a manufacturing scenario, new products launches are conceived and evaluated using multiple factors, key among which is expected customer demand. New product markets may not be counter-cyclical to existing markets and may represent a significant portion of the total manufacturing volume. Also a plant with near equal individual product-line volumes (as implied by Suarez et al., 1996) would be an exception. Product mix scope and complexity are more likely to promote, not dampen volume fluctuations and thereby amplify the need for volume flexibility. Managers are expected to plan and design for volume flexibility as a precursor to targeting new product flexibility capabilities. By the same token, volume flexibility capabilities may also be required for broad product mix strategies which inherently increase market-segmentation and aggravate aggregate demand instability.

Therefore,

H13: Volume flexibility has a positive influence on new product flexibility;

H14: Volume flexibility has a positive influence on mix flexibility.

Literature has found significant relationships between flexibility and business performance (Swamidass and Newell, 1987; Gupta and Somers, 1996; Fawcett, Calantone and Smith, 1996). This research evaluates performance at the manufacturing level. There are three reasons for doing so. First, the inherent complexity of firm-level performance mitigates against prescriptive causal modeling. Second, the relationship between manufacturing flexibility and manufacturing performance may be more visible and easily interpretable than in the case of firm performance. Third, manufacturing performance should mediate the relationship between flexibility and organizational performance and hence afford a richer understanding of flexibility-performance relationship.

Whereas generic descriptions of flexibility gains are plentiful in the literature (Swamidass, 1988; Gyan-Baffour, 1994), not many studies have made explicit connections between different manufacturing flexibilities and manufacturing performance. This research attempts to fill this gap in the literature by relating the various flexibility types to the performance parameters of manufacturing cost reduction, quality improvement, manufacturing cycle time reduction, new product introduction time reduction , delivery performance and customization responsiveness. Each flexibility-performance relationship is discussed in turn.

Mix Flexibility And Manufacturing Performance:

Variety has double-edged connotations for performance. Variety can add to operational complexity in terms of increased part types, different part codes, production scheduling and control difficulties, and greater material sourcing and handling problems. Conversely, variety can contribute to organizational learning and worker multi-skilling, lend impetus to parts standardization and modularization, and enhance customization capabilities. Mix flexibility refers to the capability of the plant to be able to operate efficiently at a high level of variety. Mix flexibility ameliorates the ill-effects of variety while allowing the retention and growth of its positive aspects.

Previous research findings are inconclusive about the impact of product variety on manufacturing cost. Suarez et al. (1996) could not detect any positive relationship between mix flexibility and costs. Kekre and Srinivasan (1990) reported finding a marginal positive effect of product line breadth on manufacturing costs. However, MacDuffie (1996) found that parts complexity can detract from labor productivity and by implication, from manufacturing cost reduction performance.

Mix flexibility can reduce set-up costs, increase employee versatility, streamline supplies and material handling and increase productivity in a high variety manufacturing environment. Improvements in these operational aspects will cumulatively impact manufacturing cost reduction performance.

Skinner (1996), in recalling his classic discussion on tradeoffs, admits that 'advancing process and information technologies have changed the shape of trade-off curves and often allow much better performance on many of the traditional criteria such as cost and quality'. Categorical choices therefore do not necessarily have to be made between different

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performance goals such as quality or cost, in the new manufacturing paradigm. Empirical studies support these views. Considerations of focus may suggest an inverse relationship between mix flexibility and quality. However, as Skinner (1996) remarks, the notion of factory focus has expanded to include plants of 'considerable product mix complexity', using computer systems, process technologies and improved management techniques to better focus manufacturing policies around clearly defined manufacturing tasks. Suarez et al. (1996) observed the lack of adverse effects of mix flexibility on quality performance. Miller and Roth (1994) found that firms emphasizing a broad product line also emphasize quality conformance. With fewer set-ups, less frequent job interruptions, automated tool changes, increased worker versatility, and effective strategic sourcing employing a certified supply base, quality performance is anticipated to increase. Mix flexibility would also reduce the manufacturing processing waiting time through faster switchovers, thus reducing manufacturing cycle time.

The capability to manufacture a variety of products within a common manufacturing system is expected to improve organizational attitudes towards change. Mix flexibility may also help new product introduction time reduction to the extent that product innovation uses existing parts and processes. However, these relationships are indirect and derived. On the other hand, the ability to manufacture different products with little time penalty should have a direct repercussion on delivery performance. Customization capabilities may not be affected by mix flexibility. Mix flexibility endows a firm with the capability to produce a range of specific products. It does not, per se, promote the ability to customize offerings to suit individual customer requests.

The foregoing discussions lead to the following hypothesis:

H15: Mix flexibility has a positive influence on cost reduction performance

H16: Mix flexibility has a positive influence on quality improvements

H17: Mix flexibility has a positive influence on manufacturing cycle time reduction

H18: Mix flexibility has a positive influence on delivery performance

Modification Flexibility And Manufacturing Performance:

Connections can be drawn between modification flexibility and manufacturing costs. The ability to accommodate minor design changes without triggering repeated set-ups can account for substantial cost savings on the shopfloor. Possessing the capability to structure and manage a technologically adept, rapid response supply chain endows a plant with significant opportunities to effect minor design changes without excessive time or cost penalties. A manufacturer possessing a high degree of modification flexibility would be well positioned to differentiate and segment with more manufacturing economy.

Miller and Roth (1994) found that firms with 'innovator' characteristics, tend to emphasize new product introductions, manufacturing time reduction, and delivery speed and dependability. Such firms were also found to stress modification and new product flexibility. Organizations familiar with making incremental design changes can be expected to pioneer major changes in the course of time. Gains in manufacturing lead time and delivery performance could be obtained since repeated changeovers will not be necessitated by minor design changes. Gerwin (1987) argues that modification flexibility should be positively related to quality since it is easier to introduce quality improvements in a system which facilitates minor design changes. An opposite view

could argue that the capability to make post-design minor engineering changes easily at the manufacturing stage, may foster complacency in initial product design and actually retard the speed of quality improvement. On balance, though, the increasing trend towards concurrent engineering improves the design process naturally and encourages inculcation of quality considerations in the design stage. Finally, modification flexibility is expected to have a significant impact on a firms ability to respond effectively to customization demands.

These considerations suggest the following hypothesis.

H19: Modification flexibility has a positive influence on cost reduction performance

H20: Modification flexibility has a positive influence on quality improvement

H21: Modification flexibility has a positive influence on manufacturing cycle time reduction

H22: Modification flexibility has a positive influence on new product introduction time performance

H23: Modification flexibility has a positive influence on delivery performance.

H24: Modification flexibility has a positive influence on customization responsiveness performance

Volume Flexibility And Manufacturing Performance:

Marshak and Nelson(1962) define volume flexibility in terms of the gradient of the average cost curve. The minimum point of an average cost curve in a dedicated manufacturing setting may be lower than the minimum point of an average cost curve in a volume flexible environment. However, a flatter average cost curve provides more volume flexibility as the firm can depart from the optimal volume production point without incurring excessive cost penalties. The MES for a volume flexible system would be considerably lower than say, that of a low cost leader with dedicated

automation facilities in a high velocity volume change environment. Volume flexibility may then, as Schlie and Goldhar (1995) suggest, actually lower average cost of production in a volatile-demand market, effectively rendering traditional scale economies redundant.

Volume flexibility could influence quality adversely in that repeated adjustments to equipment speed and varying length runs may increase wear and tear and variance (Gerwin, 1987). In contrast, Miller and Roth (1994) report that firms with volume flexibilities also display superior quality performance. Certified suppliers may enable realization of volume flexibility capabilities without quality repercussions. Firms may also pay closer attention to quality when they anticipate quality problems.

Volume flexibility describes the capability to deal efficiently with swings in *aggregate* production volume. It is not expected to have a direct relationship with manufacturing cycle time, as such. It is also not expected to have a direct impact on new product introduction time reduction although the knowledge of a low MES of operations may encourage forays into small volume customization ventures. On the other hand, volume flexibility is expected to impact delivery performance directly and significantly. The ability to service sudden surges in demand is important to both delivery speed and reliability.

The preceding arguments lead to the following hypothesis:

H25: Volume flexibility has a positive influence on cost reduction performance.

H26: Volume flexibility has a positive influence on quality improvement.

H27: Volume flexibility has a positive influence on delivery performance.

H28: Volume flexibility has a positive influence on customization responsiveness.

New Product Flexibility and Manufacturing Performance:

New product flexibility has been defined in this study as the capacity to develop and manufacture new products within an acceptable cost and time frame. Ettlie and Penner-Hahn (1994) suggest that product flexibility reduces labor costs by increasing the number of new parts scheduled on the system. Suarez et al. (1996) found that new product flexibility has no adverse effects on manufacturing costs or quality. At the same time, Miller and Roth (1994) report that companies with new product flexibility capabilities identify manufacturing lead time reduction and new product introductions as competitive priorities. Sluti (1992) also detected a positive relationship between product flexibility and delivery dependability.

New product flexibility can be a function of both strategic sourcing and internal manufacturing competencies. Effectively implemented, new product flexibility could be expected to cut manufacturing cost, manufacturing cycle time and new product introduction time reduction , and enhance delivery performance. Additionally, customization responsiveness (major design changes) could be facilitated by new product flexibility capabilities. The relationship between new product flexibility and quality performance is not clear.

The above discussion suggest the following hypotheses:

H29: New Product flexibility has a positive influence on cost reduction performance

H30: New Product flexibility has a positive influence on manufacturing cycle time reduction.

H31: New Product flexibility has a positive influence on new product introduction time performance

H32: New Product flexibility has a positive influence on delivery performance.

H33: New Product flexibility has a positive influence on customization responsiveness performance.

This chapter presented a conceptual framework of manufacturing flexibility, and developed hypotheses relating the constructs of strategic sourcing, advanced manufacturing technology, manufacturing flexibilities and manufacturing performance. Construct definitions were developed for the individual constructs, based on the literature. Individual hypothesis were developed between the different dimensions of manufacturing flexibility and specific aspects of manufacturing performance. The next chapter describes the research design and sampling plan of the study.

CHAPTER 4

RESEARCH DESIGN

This chapter describes the research design of the study. It develops construct measures and scales for the constructs in the conceptual framework. Methods for scale refinement and validation are presented. Included in the chapter are a discussion of the key sampling issues of sample frame selection, sample size determination and data collection. The chapter concludes with a discussion of the data analysis methodology used in the research.

4.1 Measurement of Constructs

DeVellis (1991) provides a specific framework for scale development. Briefly, he recommends the following sequence of actions in building a scale:

1. Clarify and specify what is sought to be measured (construct definition),
2. Generate an item pool,
3. Choose the format of measurement
4. Have the initial item pool reviewed by experts,
5. Consider inclusion of validation items,
6. Administer items to a development sample,
7. Evaluate the items, and
8. Optimize scale length.

Scale development procedures in this research are patterned on the above guidelines.

4.1.1 *Scale Development*

Strategic Sourcing: Defined as 'the extent to which purchasing engages in supply-base optimization, buyer-supplier relationship development, supplier capability auditing and purchasing integration strategies, to support strategic manufacturing objectives.'

The sourcing literature has not yet developed a validated scale for strategic sourcing. However, studies have discussed and developed item measures to examine individual sourcing domains. The following studies have been consulted for developing measures for supply-base optimization - Handfield (1993 b); Monczka et al., (1993); Gadde and Hakansson, (1994); Robertson, (1995). Measures for buyer-supplier relationship practices were derived from the relationship and alliance literature - Landeros and Monczka, 1989; Heide and John, 1990; Ring and Van de Van, 1992, 1994; Kamath and Liker, 1994; Dyer, Cho and Wu, 1998 and others (see Table 2.6). Measures for supplier capability auditing are based in part on the supplier development and performance literature - Lascelles and Dale, 1990; Watts, Kim and Hahn, 1992; Monczka, Trent and Callahan, 1993; Watts and Hahn, 1993. Specific measures were also developed in this research for assessing supplier responsiveness and design capabilities, that seemed logically related to volume, mix, modification and new product flexibility objectives. Items for purchasing integration were grounded in the integration and strategic sourcing literature - Reck and Long, 1988; Freeman and Cavinato, 1990; Monczka and Trent, 1991; Gadde and Hakansson, 1994; Ellram and Carr, 1994; Robertson, 1995. The item pool thus generated for the four conceptualized dimensions of strategic sourcing is listed below:

Supply-base optimization

- *average number of suppliers per part*

- *is current number of suppliers high/low/right*

- *tiering of supply base into primary and secondary suppliers*

- *extent of volume consolidation*

- *extent of parts bundling*

Buyer-Supplier Relationship Development

- *nature of contractual relationship with supplier (short-term/long-term/partnership)*

- *trust building*

- *top management commitment to relationship*

- *joint problem-solving*

- *joint investments in specialized machinery/materials/assets*

- *financial assistance to supplier*

- *technological assistance to supplier*

- *quality training to supplier*

- *use of buyer-supplier similar mechanisms*

- *timely production information sharing with supplier*

- *timely production information sharing by supplier*

- *direct communication between production schedulers at buyer and supplier plants*

- *cost information sharing with supplier*

- *cost information sharing by supplier*

- *use of total cost concept*

- *use of formal supplier evaluation and feedback procedures*

- *granting supplier performance rewards and awards*

- *buyer concern for supplier earning a fair profit*

- *suppliers concern for buyer earning a fair profit*

Supplier Capability Auditing

- *quality performance*
- *cost performance*
- *ability for complex manufacturing*
- *ability to modify product to meet customer needs*
- *responsiveness to schedule delivery changes*
- *ability to accept late 'mix' changes in orders*
- *product modularization*
- *responsiveness to schedule volume changes*
- *assistance in buyer product/process design*
- *ability to design and supply new products*

Purchasing Integration

- *extent to which purchasing and manufacturing jointly establish goals*
- *purchasing regularly attends strategy meetings*
- *purchasing recommends and impacts changes in end products and inputs*
- *participates in cross-functional teams*
- *proportion of purchasing personnel who spend time in routine tasks (expediting, order generation)*
- *proportion of purchasing personnel who spend time in supplier development and certification*
- *proportion of purchasing personnel who spend time in market and price/cost analysis*
- *purchasing participation in product design*
- *purchasing participation in process design*
- *purchasing participation in developing sales bids*
- *purchasing is rewarded on strategic contributions (new products/technologies) to the company*

Advanced Manufacturing Technology: Defined as the 'use of human-resource, design, manufacturing, and infrastructural support practices and systems in a plant for achieving desired manufacturing capabilities'. Scale items for the advanced manufacturing technology construct integrate and develop on validated technology scales - Ward et al. 1994; Snell and Dean 1992; Dean, Yoon and Susman 1992; Boyer, Ward and Leong, 1996. The current scale includes organizational factors associated with the successful use of advanced manufacturing technology.

The item measures developed for this construct were:

<u>HRM practices</u>

The use of cross-trained employees

The use of teams in manufacturing

The use of decentralized decision-making in manufacturing

<u>Design practices</u>

The use of computer aided design

The use of computer aided engineering

The use of computer-aided testing

Modularization in design

<u>Manufacturing systems</u>

The use of flexible integrated manufacturing systems

The use of CNC technology

The use of computer aided manufacturing

The use of robotics

The use of cellular manufacturing and group technology

Infrastructural support systems

The use of automated material handling systems

The use of kanban/similar manufacturing practices

The use of in-plant electronic data interchange systems

The use of real-time process controls

The use of bar-coding

The use of set-up time reduction techniques

The use of preventive maintenance

JIT supplier deliveries

Manufacturing Flexibilities: Each flexibility was measured in terms of scope, response and cost. Item measures were based on pre-existing, validated literature (Gupta and Somers, 1992; Sethi and Sethi, 1990).

Mix Flexibility: Defined as the 'ease with which the manufacturing system can switch between the manufacture of different products within a product mix'. The item measures are described below:

The number of products in the product mix

The time required to change between different products in the product mix

The cost of changing between different products in the product mix

The extent of parts commonality in the product mix

Modification Flexibility: Defined as the 'capability to modify and manufacture existing products'.

The item measures are:

The time required to accommodate minor design changes

The cost required to accommodate minor design changes

The extent of new/extra parts required in making minor design changes

The extent of new/extra operations involved in making minor design changes

The complexity of new/extra operations involved in making minor design changes

Volume Flexibility: Defined as the 'capability to operate economically over a range of aggregate production volumes'. The following items are employed to measure this construct:

The range of aggregate production volume over which the firm can run profitably

The time required to increase production volume by 20%

The ease (machine/material availability, willingness to do overtime) of increasing the volume capacity of the system, when needed, without adding new equipment

The stability of unit manufacturing cost over a 20% fluctuation in production volume

New Product Flexibility: Defined as the 'capability to design, prototype and produce new products to meet stringent time and cost constraints'. Representative measures are:

The time required to introduce (design, prototyping, test and manufacture) new products

The cost involved in introducing new products (overtime, production interruptions, lost orders)

The number of new products introduced in a year

The number of new processes used in new products manufacture

The complexity of new processes used in new product design, prototyping and manufacture

Manufacturing Performance: Defined as 'the achievement of manufacturing goals in the areas of manufacturing cost reduction, quality improvement, production cycle time, product introduction time, delivery performance and customization responsiveness'. Performance measures have been adapted from the manufacturing performance literature (Roth and Miller, 1990;

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Dean and Snell, 1991; Miller and Roth, 1994). One major difference from conventional studies is the empirical treatment of manufacturing performance. Each dimension of manufacturing performance is measured in terms of internal goals, and competitor performance. The item measures for these performance areas were as follows:

The extent to which the company has been able to meet its cost reduction goals.

The extent to which the company has been able to meet its quality improvement goals

The extent to which the company has been able to meet its manufacturing cycle time reduction goals

The extent to which the company has been able to meet its product introduction time goals

The extent to which the company has been able to meet its delivery goals in terms of delivery speed and dependability

The extent to which the company has been able to meet its customization responsiveness goals

4.1.2 *Scale Validation*

Except for percentage metrics, all item measures were measured on a 1-5 'very low - very high' *Likert* scale. Although a larger response category (e.g. 1 - 7) affords more detail, the respondents may be not be in a position to make such refined judgments in a limited period of time. In terms of a trade-off between detail and aggregation, a 1-5 interval finds wide application in the manufacturing literature (Rho et al., 1994; Snell and Dean, 1992; Gupta and Somers, 1992). The *Likert* scale has been preferred over similar scales (semantic differential, visual analog) for several reasons. The first is the accepted use and established performance of *Likert* scales in manufacturing studies. Another reason for selecting a *Likert* scale was that the alternatives do not offer specific response categories. For example, the semantic differential scaling

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method describes a non-graded continuum, anchored by two extremes. The respondent's position on the continuum is open to mis-interpretation by both respondent and researcher, in the absence of interval points along the continuum, unlike the *Likert* scale. In contrast, literature provides abundant support for the assumption of numeric, equal intervals in a *Likert* scale, for purposes of multivariate data analysis (DeVellis, 1991; Nunnally, 1978 - pg. 17; Kerlinger, 1973).

Following the DeVellis (1991) guidelines, initial face validation for the item measures was achieved through discussions with practitioners and academics. Feedback was also obtained for other aspects such as instrument length, format and approximate completion time. A separate validation section was not added in view of instrument length considerations. However, reverse coding and distributed placement of item measures were used as a precautionary measure against undetected response bias.

A 'Q-sort' of the scales was undertaken through a blind administration of the item measures to a group of 3 academics and 3 practitioners. The subjects were requested to examine the item measures and relate these to their respective underlying constructs. Those items with a majority of incorrect linkages to underlying constructs, were subsequently dropped from the list of measures. Suggestions for re-wording item questions were also considered and implemented at this stage.

Final validation of the scales was undertaken by administrating the instrument to the study sample, and employing confirmatory factor analysis for evaluating reliability and validity.

4.2 Sampling Issues

4.2.1 *Sampling Frame*

The cross-functional nature of this study ideally required a multiple respondent sampling plan with participation from manufacturing and purchasing. However, cost and time considerations ruled out this approach and a single-respondent design was used. 'Halo' effects can adulterate data in single respondent research designs. However, the practical ease of obtaining single source observations makes them valuable in many research contexts. Despite the potential for bias, perceptual measures from single respondents remain the most commonly used data collection method in empirical research. Measures were pre-tested to reduce the possibility of 'halo' bias. The technical nature of the questions also limited the possibility of social desirability bias, an effect more commonly encountered in social studies research.

The unit of analysis was the purchasing manager or equivalent senior level sourcing executive at the plant or SBU level. Comparisons of initial interviews with purchasing and manufacturing managers did not reveal any consequential inconsistencies between their responses. The survey instrument was not considered overly technical and did not require detailed technical knowledge of manufacturing processes/equipment in the plant. It was also found that while manufacturing executives were generally aware of sourcing issues, senior purchasing management was relatively much more conversant with manufacturing demands and situations (reflecting perhaps, the internal 'customer-supplier' relationship between manufacturing and purchasing in some companies). As an additional measure to ensure the validity of the chosen unit of analysis, triangulation interviews with senior manufacturing and purchasing personnel were conducted in several site visits during item development, with consistent results. As a post-hoc test of inter-rater reliability, a random sub-sample of 20 responding firms was selected from the responses to obtain manufacturing's perspective on the manufacturing related items in the questionnaire. A sample of 25 manufacturing related items was selected at random from the questionnaire. A total of seven firms responded and telephonic interviews were conducted with the manufacturing managers of these firms, to obtain their responses to these 25 questions. Paired comparisons were made between the purchasing and manufacturing scores for these 25 items, for each of the 7 firms. The inter-rater reliability for each of the 7 firms was calculated (James, Demaree and Wolf, 1984). The average inter-rater reliability was 0.96, evidencing a high degree of agreement between purchasing and manufacturing perspectives on the relevant manufacturing related issues.

The sample frame was drawn from the manufacturing sector of the National Association of Purchasing Management member list on a cross-industry basis. The NAPM represents a total population of 37,199 purchasing professionals in the US (53% in manufacturing industries), of which more than 66% possess bachelors and more advanced degrees and have in excess of 9 years professional experience. The NAPM general member list was further screened to select only executive level purchasing professionals at the Purchasing Manager/Materials Manager/Purchasing Director/Vice-President level. High-ranking respondents tend to be more reliable sources of information than their subordinate ranks (Philips, 1981). The range of industries covered in the sample frame included high uncertainty business environments (computers, semi-conductors etc.) as well as more stable businesses such as industrial machinery and medical equipment. The relevant SIC codes were,

SIC 34 - Fabricated Metal Products, except Machinery and Transportation Equipment

SIC 35 - Industrial and Commercial Machinery and Computing Equipment

SIC 36 - Electronic and other Electrical Equipment and Components

SIC 37 - Transportation Machinery and Items

SIC 38 - Measuring, Analyzing and Controlling Instruments, Photographic, Medical and Optical Goods

These *SICs* cover the gamut of US manufacturing. Manufacturing industries excluded from the study were those from *SIC 20 -33* and *SIC 39* (Food, Tobacco, Textiles, Wood, Furniture, Paper, Printing, Chemicals, Oil refining, Rubber and Plastics, Leather, Stone/Clay/Glass products, Jewelry, Musical instruments, Toys, Pens, Advertising signs and other miscellaneous manufacturing industries).

4.2.2 *Sample Size*

Anticipating a minimum of three (final) measures per latent construct, a full structural equation analysis of the conceptual framework (Figure 3.1) required estimating a *minimum* of 58 parameters. A two-stage measurement and path model process required an anticipated maximum of 44 estimates for the largest model (CFA of Strategic Sourcing - Figure. 6.3). While some authors (Hair, Anderson, Tatham and Black, 1995) have stated 50 as the absolute minimum sample size for structural equation modeling, factors such as effect size, alpha levels and power levels influence sample size requirements. At any given alpha level, increased sample size will generate greater power. However, an overly large sample size (over 500 or so) magnifies small specification errors and may lead to model rejection (Kaplan, 1995). Conversely, an attenuated sample size may mask large specification errors and lead to model acceptance. Alternatively, the alpha level could be increased to achieve

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the power of the test. Calculation of an 'optimum' sample size is theoretically feasible, given preset alpha, power and effect size levels. The exploratory nature of this research rendered a-priori estimation of effect sizes difficult and ruled out the possibility of determining an optimum sample size. Anderson et al. (1995) suggest a minimum of five observations for each estimate, although a ratio of 10 observations per estimate is deemed desirable. Based on this recommendation, the targeted sample size for the 2 stage approach worked out to be 220 (44 estimates * 5 observations/estimate). Data analysis was conducted using two stage structural equation modeling.

4.2.3 *Data Collection*

Data collection was conducted in two phases. Phase 1 involved preliminary site visits, interviews and surveying of executive management in the sourcing and manufacturing areas across different industries.

Phase 2, following Dillman's (1978) guidelines, involved mailing the survey to senior level NAPM members selected at random from the NAPM member list. The mailing package consisted of a cover letter, the survey and a reply paid return envelope. Assuming a conservative 15-20% response rate, the mailing was addressed to around 1700 potential respondents. A reminder post card was mailed to all non-respondents after a week of mailing. Written follow-ups (with duplicate questionnaires) were mailed to all non-respondents approximately three weeks after the initial mailing.

4.3 Data Analysis Methodology

4.3.1 *Measure Refinement and Validation Procedures*:

Structural equation modeling was employed to analyze the data. It improves on other multivariate analysis techniques such as multiple regression, in several ways. First, SEM explicitly incorporates errors of measurement in its analysis. Another unique feature of SEM is its ability to evaluate models holistically, conducting formal tests of both global and individual parameter fit. Finally, SEM is the only technique which allows the simultaneous modeling and analysis of relationships between measured and latent variables, alongwith relationships among latent variables.

As with most multivariate analytical tools, SEM assumes normality, homoskedasticity and linearity. The data were analyzed initially for univariate and multivariate normality (Mardia's coefficient in EQS). Data analysis was undertaken using the two stage structural model approach with EQS. Evaluating the measurement and structural models individually reduces the probability of 'interpretational confounding' (Burt, 1971) and addresses possible identification problems.

Exploratory factor analysis was an option in developing the measurement models. However, literature has identified several inherent limitations of *exploratory factor analysis* (Ahire, Golhar and Waller, 1996). As Mulaik (1972) points out, exploratory factor analysis often falters when faced with interpretability issues. Lack of a-priori knowledge about construct covariation dynamics could mean that 'the interpretations given the factors may be nothing more than tautological transformations of the names of the original variables'. In contrast, confirmatory factor analysis embeds the underlying logic regarding the number of factors, the nature of their mutual relationships and the

magnitude of those relationships into factor constraints. Increasingly, research in the fields of marketing and organizational behavior has employed confirmatory factor analysis over exploratory factor analysis due to the conceptual strengths of the former approach (Venkatraman, 1989; Bollen, 1989). Following precedent (Anderson and Gerbing, 1982; Fornell and Larcker, 1981), the data were analyzed applying *confirmatory factor analysis* to build and verify the validity and reliability of the measurement models. Separate measurement models were developed and tested for the constructs of strategic sourcing, advanced manufacturing technology and manufacturing flexibility (multi-construct).

Convergent validity was evaluated from the standardized ($p < .05$) factor loadings for both exogenous and endogenous constructs, using a cut-off of 0.40 (Hair et al., 1995). However, marginal cases were acceptable if such items were considered central to the construct domain. Composite reliabilities (a) were evaluated using Cronbach's coefficient alpha. Nonetheless, coefficient alpha as an estimate of reliability is neither a necessary nor sufficient condition for unidimensionality (Anderson and Gerbing, 1982) Stringent discriminant validity tests are needed to confirm unidimensionality of the measurement model constructs.

Two methods were employed to assess the discriminant validity of the constructs. First, a pair-wise comparison of the latent factors in each of the two measurement models was undertaken to ascertain whether all inter-factors correlations were significantly different from 1, providing evidence of discriminant validity (Challagalla and Shervani, 1996). As a more rigorous test of discriminant validity (Fornell and Larcker, 1981), the average variance extracted for each construct was computed and verified to ensure that it is greater than the squared correlation between that construct and any other construct in the model.

Collectively, the various CFA evaluations served to establish confidence in the measurement models, enabling testing of the structural relationships in the model.

4.3.2 *Structural Model Evaluation Procedures*

The relationships between the latent constructs was evaluated using structural equation modeling. The conventional global test of model fit in covariance structure analysis evaluates the magnitude of the discrepancy between the sample and fitted covariance matrices and employs a χ^2 distributed 'T' statistic for this purpose. However, it has been generally recognized (Bentler and Bonnet, 1980; Bentler, 1990) that 'T' may not be distributed for small samples. Significant specification errors could be tolerated in small samples while trivial errors may cause model rejection in large samples. Specifically, the χ^2 fit statistic will almost always be significant in large samples (Hartwick and Barki, 1994). Additionally, a χ^2 test is essentially a statistical yes/no decision rule which cannot indicate the relative degree of fit between sample and model covariances. Therefore, other measures were employed to assess global model fit. The *Bentler and Bonnet Normed Fit Index* (NFI) has been found to underestimate its asymptotic value at small sample sizes (Hu and Bentler, 1995) and tends to overreject models even for moderate sample sizes. EQS also provides a type-2 incremental fit index in the form of the *Bentler-Bonnet Non Normed Fit Index* (NNFI) which has no substantial association with sample size (Marsh et al, 1988). Fit indices also include a comparative type-3 fit index (CFI) which is relatively unaffected by sample size (Bentler, 1990). Finally, the normed χ^2(χ^2 /d.f.) index can be applied to evaluate model parsimony (norm 2.00 - Hair et al., 1995). Of these indicators, Bentler (1992) recommends the use of the comparative fit index (CFI) as the index of choice. The CFI ranges from 0 to 1 and is derived from a comparison of a hypothesized model with an independent model. A CFI of 0.90 and above indicates an acceptable fit of the data to the model. All the above indicators of fit were employed in the analysis of the data.

The standardized coefficients of the paths among latent variables indicate individual parameter estimates and were evaluated for statistical significance (t-tests).

This chapter presented the research design of the dissertation. Item measures for individual constructs were developed and listed, and the methods used for scale validation described. Sample frame and sample size selection rationale were explained. The chapter concluded with details of the data collection process and the data analysis methodology. The next chapter presents the development of measurement and path models from the data.

CHAPTER 5

DATA ANALYSIS

This chapter begins with a brief introduction to structural equation modeling and shows the conceptual framework in full SEM format (Figure 5.1). Considerations of sample size are explained to justify the choice of the 2 stage approach to the analysis of data. The chapter presents a profile of the respondents, before proceeding with a description of the measurement and path models. First and second order confirmatory analysis (CFA) models were developed and tested for the constructs in the study. The CFAs were validated by using stacked SEMs, grouping the data into first wave and second wave respondents. Non-response bias was also investigated in the process. Path model analyses were used to examine the hypothesized relationships among the latent variables.

5.1 Structural Equation Modeling

Structural equation modeling (SEM) was employed to analyze the data, using the EQS software program. It improves on other multivariate analysis techniques such as multiple regression, in several ways. First, SEM explicitly incorporates errors of measurement in its analysis. A second unique feature of SEM is its ability to evaluate models holistically, conducting formal tests of both global and individual parameter fit. Finally, SEM is the only technique which allows the modeling and analysis of relationships between latent variables.

SEM is a comprehensive statistical approach to examining hypotheses about relationships among observed and latent variables. A full structural equation model can be stated as follows:

$$\eta = B\eta + \Gamma\xi + \zeta \qquad (1)$$

$$y = \Lambda^{y}\eta + \varepsilon \qquad (2)$$

$$x = \Lambda^{x}\xi + \delta \qquad (3)$$

Equation (1) represents the structural model and expresses the hypothesized relationships among the model's latent constructs. The m x 1 vector η includes the latent endogenous constructs, while the n x 1 vector ξ contains the latent exogenous constructs. The coefficient matrix **B** describes the inter-relationships among the endogenous constructs. The coefficient matrix Γ indicates the effects of exogenous on endogenous constructs. The vector ζ represents the error terms in equations. Equations (2) and (3) are factor-analytic measurement models which link the latent constructs to observable indicators. The p x 1 vector 'y' specifies the measures of the endogenous constructs, and the q x 1 vector 'x' consists of the measures of the exogenous constructs. The coefficient matrices Λ^{y} and Λ^{x} indicate how 'y' relates to η and 'x' relates to ξ, respectively. The vectors ε and δ represent measurement errors.

SEM begins with the specification of relationship parameters to be estimated. Fixed parameters are set at zero. Free parameters are estimated from the data. SEM has two components. The measurement component prescribes and estimates the psychometric properties of the latent constructs in a model. The structural component prescribes and estimates relationships among the latent variables identified and validated in the measurement component. A basic consideration when building a SEM is the issue of identification, the restriction being that that for any model to be estimated, it must be either just identified or overidentified. Model fit is estimated iteratively, through a series of comparisons between the observed covariance matrix and the implied covariance matrix, the objective being to minimize the resultant residual matrix. Several tests of global fit have been developed in the literature. SEM also offers individual parameter estimates with significance indicators.

Figure 5.1 shows the hypothesized conceptual model in EQS notation. It is a path model of latent variable relationships (F to F) with nested measurement models (F to V) of strategic sourcing, advanced manufacturing technology, different manufacturing flexibilities and different dimensions of manufacturing performance.

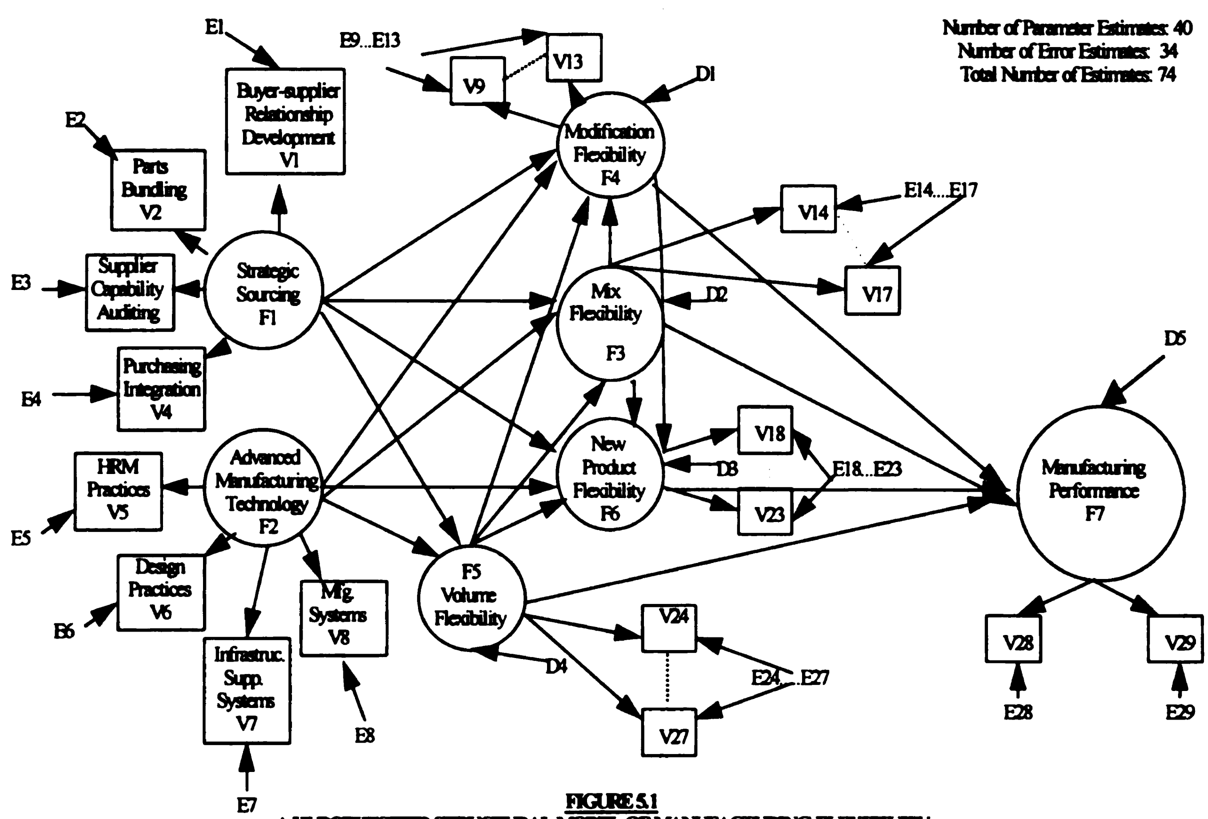

FIGURE 5.1
A HYPOTHESIZED STRUCTURAL MODEL OF MANUFACTURING FLEXIBILITY

Data analysis was undertaken using the two stage structural model approach with EQS. The most widely used fitting function for SEM (Bollen, 1989), the maximum likelihood (ML) method, was employed for parameter estimation. Evaluating the measurement and structural models individually reduces the probability of 'interpretational confounding' (Burt, 1971) and addresses possible identification problems. Also, the sample size (n=322) constrained the evaluation of a full SEM, due to power considerations. Based on the number of item measures indicated by factor analysis, there were 74 estimates required to be made, if a full SEM was to be employed (Figure 5.1 above). The resulting sample-parameter ratio of 4.35:1 was much lower than the 10:1 sample-estimate ratio prescribed in the SEM literature (Bagozzi and Yi, 1988). Accordingly, a full SEM was not tested and a two stage approach was adopted for the data analysis. Separate measurement models were constructed and evaluated for each latent construct in the model. The relationships among the latent constructs were subsequently examined through path model analyses.

5.2 Respondent Profile

200 responses were received in response to the first mailing of the questionnaire. Another 122 responses were received after the follow-up letter was sent, making a grand total of 322 responses. This figure does not include returns, refusals and unusable responses. The response rate was 19%, which compares well with past studies on manufacturing flexibility (Gupta and Somers, 1996). However, as explained earlier, the number of responses was still not adequate to engage in full structural equation modeling of the conceptual model. A profile of the respondents is presented below:

Number of valid responses: *322*

Respondent Titles:	*VP's/Director Purchasing/Materials*	*50*
	Purchasing/Commodity/Materials Managers	*179*
	Senior Buyers/Buyers	*7*
	Other Titles(Operations Mgr, Purchasing Engg.)	*6*
	No Response	*80*

Company Sales($ mil)	*<1*	*>1-10*	*>10-50*	*>50-100*	*>100-500*	*>500*
# of respondents	*2*	*31*	*72*	*41*	*74*	*94*

No Response: 8

Plant Sales($ mil)	*<1*	*>1-10*	*>10-50*	*>50-100*	*>100-500*	*>500*
# of respondents	*2*	*32*	*108*	*66*	*72*	*38*

No Response: 4

Number of Employees in Plant	*≤100*	*>100-200*	*>200-500*	*>500-1000*	*>1000*
# of respondents	*59*	*80*	*81*	*43*	*55*

No Response: 4

Product Type	*Made-to-stock*	*Engg-to-order(to)*	*Make-T-O*	*Assy-T-O*
# of respondents	*76*	*53*	*130*	*62*

No Response: 1

Process Characteristics	*Job Shop*	*Batch*	*Repetitive*	*Continuous*
# of respondents	*109*	*71*	*117*	*24*

No Response: 1

Product Life Cycle	*Growth*	*Maturity*	*Decline*
# of respondents	*148*	*160*	*13*

No Response: 1

The data were examined for non-response bias using multi-group stacked measurement models (see next section). An ANOVA test failed to reveal any statistically significant differences among the category means for company sales, plant sales, number of employees, product type, process characteristics or product life cycle, across the different SIC groups.

5.3 Evaluation of Measurement Models

Evaluation of the measurement models was conducted as follows:

a) The data were examined for univariate and multivariate normality, using EQS output. Cases with missing values are automatically deleted from analysis by EQS.

b) Multi-factor CFAs were developed with appropriate item measures.

c) Initial runs were conducted and the LM test output consulted for post-specifying model parameters, wherever justified.

d) Model iterations were continued until satisfactory global fit indications were obtained, with substantive parameter associations. Multiple indicators of global fit were used(Bollen and Long, 1993; Tanaka, 1993).

e) Convergent validity was evaluated from the standardized factor loadings for the constructs. Reliabilities (α) were estimated using coefficient alpha. Two methods were employed to assess the discriminant validity of the constructs. First, a pair-wise comparison of the latent factors in each of the two measurement models was undertaken to confirm whether all inter-factors correlations were significantly different from 1.00 (Singh and Rhoads, 1991; Challagalla and Shervani, 1996). Second, the average variance extracted for each construct was compared to ensure that it was greater than the squared correlation between that construct and any other construct in the model (Fornell and Larcker, 1981; Dillon and Goldstein, 1984).

f) The CFA's were examined for common methods bias employing the error covariance (theta-delta) matrix and LM test results.

g) Multi-group analyses were conducted on the CFAs' in order to support model validity and demonstrate the absence of non-response bias. A

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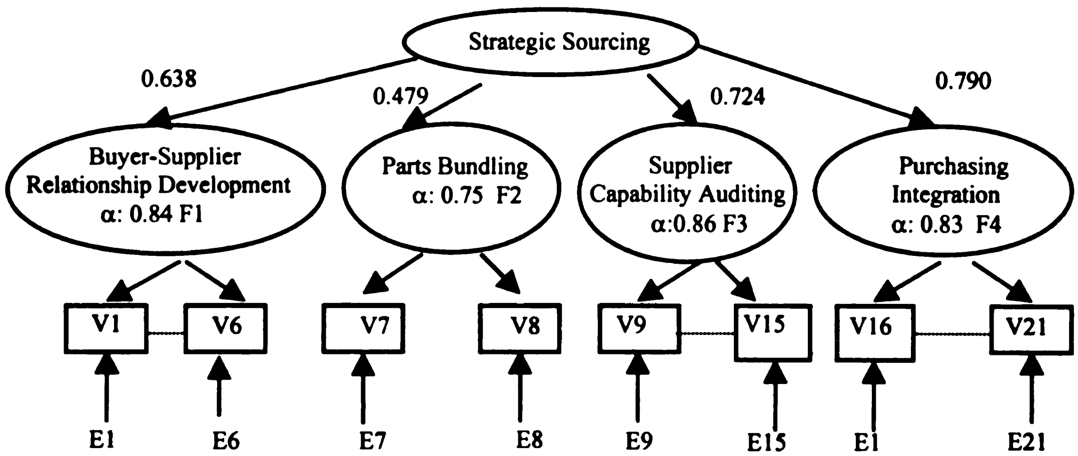
description of the individual CFA's follows.

5.3.1 CFA for Strategic Sourcing (SS)

The SS construct was conceptualized as a second order factor model (Figure 5.2), with four first-order dimensions.



V1: Contractual r'ship with supplier (0.570 - loading)

V2: Degree of mutual trust (0.639)

V3: Top mgt. commitment to r'ship (0.763)

V4: Joint problem solving (0.810)

V5: Production info. sharing with supplier (0.626)

V6: Production info. sharing by supplier (0.582)

V13: Supplier responsiveness to volume changes (0.536)

V7: Extent of volume consolidation (0.865)

V8: Extent of parts bundling (0.703)

V9: Supplier ability to modify product (0.523)

V10: Supplier responsiveness to delivery changes (0.510)

V11: Supplier ability to accept late 'mix' changes in orders (0.416)

V12: Modularization of supplier products (0.507)

V14: Supplier assistance in product design (0.859)

V15: Supplier ability in new product design (0.826)

V16: Purchasing regularly attends corporate strategy meetings (0.613)

V17: Purchasing impacts changes in end products (0.740)

V18: Purchasing primarily spends time on market and price/cost analysis (0.543)

V19: Purchasing participates in NPD (0.695)

V20: Purchasing participates in process design (0.733)

V21: Purchasing is measured on strategic metrics (new products/technology) (0.595)

CFI: 0.981
BBNNFI:0.976
BBNFI: 0.924
X2: 215.14, 166 d.f, p <.006

FIGURE 5.2
A CONFIRMATORY FACTOR MEASUREMENT MODEL OF STRATEGIC SOURCING

A first order CFA with four factors was developed and validated initially, followed by a second order CFA. Only two item measures relating to volume consolidation and parts bundling loaded on the first-order 'supply-base optimization' factor. Considering the limited domain of these item measures, it was deemed appropriate to re-name the 'supply-base optimization' factor as 'parts bundling'.

There were a total of 44 estimates required to be made in the SS measurement model, with 21 measured observed variables. Therefore, there were 231 (21(21+1)/2) pieces of information in the sample covariance matrix for estimation purposes and the model was identified with 187 (231 - 44) degrees of freedom.

Normality

No evidence of noticeable departures from normality of the data existed. Table 5.1 presents the univariate skewness and kurtosis statistics, all of which were under 2.0 and 7.0, respectively (Chou and Bentler, 1995). Outlier elimination enhanced the multivariate normality of the data, as indicated by the relatively small normalized Mardia's estimate of 18.51 (Mardia, 1970; Byrne, 1994).

First-Order CFA

Table 5.2 provides the fit indices for the initially hypothesized CFA model. Post-hoc model fitting was undertaken by identifying mis-specified parameters in the model (Bollen 1989; Byrne, 1994) with selective implementation of the LM test results. Significant associations indicated by the LM test, were accommodated only within the same sub-scale. Items with weak loadings (<0.40) or with significant cross-loadings on multiple factors were dropped from the analysis at this stage.

Table 5.3 presents the results of the final first order CFA for the SS construct. The strong global fit measures obtained in the final model (CFI:0.982; NNFI: 0.977 and NFI: 0.926) support the decision to stop model iteration at this point. Further modifications as indicated by the LM test output in the final model (Table 5.4), did not make substantive sense and would invite criticisms of model 'overfit'.

Further, no negative error variances were found, indicative of good model fit (Bagozzi and Yi, 1988).

Convergent validity was indicated by the strong and significant ($p<0.5$) item loadings. All loadings (with the exception of one item - 0.41) were at 0.494 or above. Reliabilities for the factors ranged between 0.751 to 0.863 (coefficient alpha). All inter-factor correlations were found significantly different from 1.00, indicating the discriminant validity of the model. The average variance extracted for each factor was found greater than the squared correlation between that factor and any other factor in the CFA model, providing a more rigorous confirmation of the presence of discriminant validity (Table 5.5). Nomological validity was indicated by the existence of significant and positive inter-factor correlations. Common method bias was examined by allowing errors to covary and screening the covariance matrix of error terms Θ_δ for significant covariances. Only two significant cross-loading error covariances were found in a total of 19 error covariances. The remaining 17 error covariances were sub-scale items, pertaining to the same factor. It is not surprising that some same-scale items may display covariance in their error terms (Byrne, 1988). The significant multivariate error covariances indicated by the LM test (see Table 5.4) offer relatively small χ^2 values to an already well-fitting model. From a substantive perspective, these cross-factor error covariances represented idiosyncrasies in the data, that should be ignored to avoid model 'overfit'. Collectively, the relatively small number of cross-factor error covariances taken together with the presence of an already well fitting model, demonstrated the absence of any significant systemic common method bias.

Second-Order CFA

Table 5.6 presents the results of the second order CFA of SS, which positions SS as the latent construct reflected in the 4 first order factors. The model was identified with 166 degrees of freedom. Model fit was similar to the first order model and the loadings of the first order factors on the SS construct were positive (0.479 - 0.790) and significant. The first order factors were consequently aggregated into the higher order SS latent construct, for measurement purposes.

Multi-Group Analysis

A multi-group analysis of the second order CFA model of SS was conducted to validate the model as also undertake a simultaneous test for non-response bias. The objective was to test for measurement invariance across the first (n = 200) and second (n = 122) wave of respondents. Invariance at the path model level will exist, if invariance can be established at the measurement model level. Accordingly, the factor loadings and factor covariances were constrained equal between the two groups of respondents. Error terms were not constrained, since the equivalency of error variances and covariances is usually the least important hypothesis to test in cross-group validation (Bentler, 1992; Byrne, 1988). Fixed parameters in the CFA cannot be constrained equal across groups. Table 5.7 presents the results of the stacked model. The global indices represent an excellent fit (CFI: 0.969; NNFI: 0.963; NFI: 0.867). The LM test did not indicate any significant multivariate parameters. Based on these results, the path model was run with aggregated data across the two response waves.

The results also served as a stringent test of the absence of non-response bias. A wave represents a response generated by a stimulus, in this case, a survey followed by a reminder with a duplicate questionnaire (Armstrong and Overton, 1977). Respondents to the follow-up letter were assumed to be equivalent to non-respondents, since a post-survey stimuli was required to elicit their response (Pace, 1939).

5.3.2 CFA for Advanced Manufacturing Technology(AMT)

The AMT latent construct was conceptualized as a second order model (Figure 5.3). A first order CFA was developed and validated, with the 4 conceptualized factors: HRM practices, design practices, infrastructural support systems and manufacturing systems. The first-order model was followed by a second order CFA.

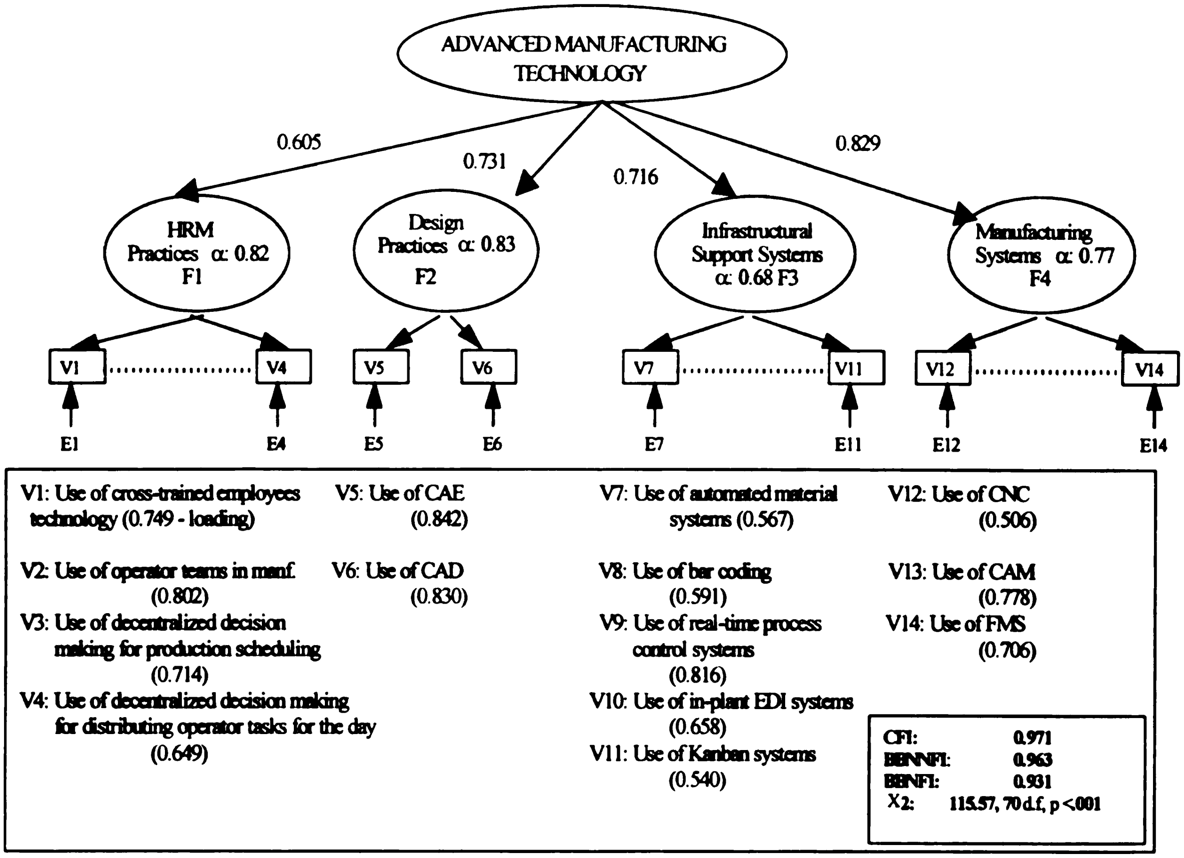


FIGURE 5.3
A CONFIRMATORY FACTOR MEASUREMENT MODEL OF ADVANCED MANUFACTURING TECHNOLOGY

There were a total of 30 estimates required to be made in the AMT measurement model, with 14 measured observed variables. Therefore, there were 105 (14(14+1)/2) pieces of information in the sample covariance matrix for estimation purposes and the model was identified with 75 (105 - 30) degrees of freedom.

Normality

All univariate skewness and kurtosis statistics were under 2.0 and 7.0, respectively (Chou and Bentler, 1995), indicating univariate normality of the data (Table 5.8). Multivariate normality was indicated by the relatively small normalized Mardia's estimate of 9.34, after performing outlier elimination (Mardia, 1970; Byrne, 1994).

First-Order CFA

Table 5.9 provides the fit indices for the initially hypothesized CFA model. Post-hoc model fitting was undertaken to identify mis-specified parameters in the model (Bollen, 1989; Byrne, 1994). Significant cross loadings, observed from the LM test, were accommodated only within the same sub-scale. Other cross-loading items were dropped from the analysis, as were items with weak loadings (<0.50) (see Table 5.21).

Table 5.10 presents the results of the final first order CFA for the AMT construct. The global fit measures obtained in the final model (CFI: 0.987; NNFI: 0.982 and NFI: 0.947) evidenced strong data convergence. Further modification was indicated by the LM test on the final model (Table 5.11) - however, substantive considerations ruled out the implementation of these modifications. The absence of negative error variances indicated good model fit (Bagozzi and Yi, 1988).

Convergent validity was indicated by the strong and significant ($p<0.5$) item loadings. All loadings were at 0.50 or above. Factor reliabilities ranged between 0.673 to 0.828 (coefficient alpha). Discriminant validity was confirmed by verifying that all inter-factor correlations were significantly different from 1.00. Further, the average variance extracted for each factor was found greater than the squared correlation between that factor and any other factor in the CFA model, providing a more rigorous confirmation of the presence of discriminant validity (Table 5.12). Nomological validity was indicated by the existence of significant and positive inter-factor correlations. Common method bias was evaluated by releasing and examining the covariance matrix of error terms Θ_δ for significant covarying errors.

Only three significant error covariances were found, all within individual sub-scales. From a substantive perspective, these cross-factor error covariances represent idiosyncrasies in the data, that should be ignored to avoid model 'overfit'. The significant multivariate error covariances indicated by the LM test offered relatively small χ^2 values to an already well-fitting model (see Table 5.11). Collectively, the small number of cross-factor error covariances taken together with the evidence of an existing excellent model fit, evidenced the absence of systemic common method bias.

Second-Order CFA

Table 5.13 presents the results of the second order CFA of AMT, in support of the multi-dimensionality of the AMT construct. The model was identified with 70 degrees of freedom. Model fit paralleled the first order model and the loadings of the first order factors on the SS construct were positive and significant. The first order factors were consequently aggregated into the higher order AMT latent construct, for measurement purposes.

Multi-Group Analysis

Similar to the SS CFA, a multi-group analysis of the second order CFA model of AMT was conducted to validate the model and test for non-response bias. The test for measurement invariance was conducted across the first (n = 200) and second (n = 122) wave of respondents. Table 5.14 presents the results of the stacked model. Both model validity and non-response bias were confirmed by the excellent global fit indices (CFI: 0.986; NNFI: 0.983; NFI: 0.901). The LM test failed to indicate any significant multivariate parameters.

5.3.3 CFA for Manufacturing Flexibilities

Four dimensions of manufacturing flexibility were conceptualized in the flexibility CFA: volume flexibility, mix flexibility, modification flexibility and new product flexibility. Subsequent screening of items and repeated iterations with various substantive combinations of item measures failed to validate a four factor model. Specifically, the item measures for volume flexibility failed to load coherently on any single factor. Faced with this situation, two options were available: a) specify volume flexibility by making an essentially arbitrary choice of any one item measure or b) drop the volume flexibility factor and proceed with a CFA (and path analysis) with the remaining three dimensions of manufacturing flexibility. Single item indicator constructs are undesirable, because they fail to account for measurement unreliability. As Bentler and Chou (1987) caution, even two indicator models may require factor covariances for identification purposes. On the other hand, volume flexibility is an important concept in the manufacturing literature and has been explicitly measured in the past. While proper care had been taken to select items from established scales (Gupta and Somers, 1992; Sethi and Sethi, 1990), the current data failed to replicate past measurement scales of volume flexibility. Separate industry-wise analysis (job shop or batch / repetitive or manufacturing) did not result in improved loadings for the volume flexibility factor. Upon consideration, the volume flexibility construct was dropped from further analysis. The most important concern was to maintain rigor in the methodological analysis. Also, exclusion of the volume flexibility factor would preclude potential interpretational confounding at the path model level. As a post-hoc measure, it may be feasible to re-visit a random selection of respondent firms and test a larger selection of volume flexibility measures for constructing a valid scale for the construct. However, such actions lie beyond the immediate scope of the dissertation.

The manufacturing flexibility CFA was thus developed for a 3 factor first order model, comprising of mix flexibility, modification flexibility and new product flexibility (Figure 5.4).

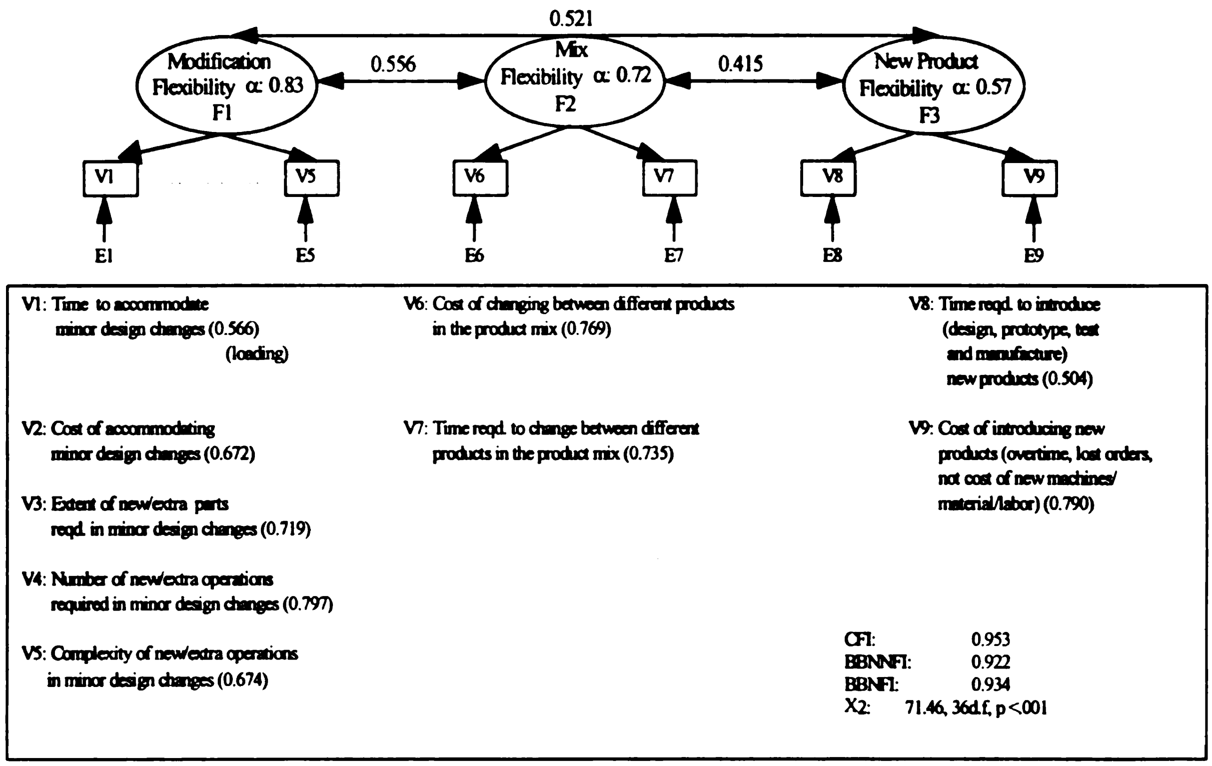


FIGURE 5.4
A CONFIRMATORY FACTOR MEASUREMENT MODEL OF MANUFACTURING FLEXIBILITY

There were a total of 18 estimates required to be made in the manufacturing flexibility measurement model, with 9 measured observed variables. Therefore, there were 45 (9(9+1)/2) pieces of information in the sample covariance matrix for estimation purposes, and the model was identified with 27 (45 - 18) degrees of freedom.

Normality

Univariate normality of the data were attested by the low univariate skewness and kurtosis statistics (under 2.0 and 7.0, respectively - Table 5.15). Multivariate normality was indicated by the small normalized Mardia's estimate of 7.97, achieved after eliminating major outliers.

First-Order CFA

Table 5.16 provides the fit indices for the initially hypothesized CFA model. The relatively low fit indices (CFI: 0.834, NNFI: 0.750, NFI: 0.817) led to post-hoc model fitting, using two sub-scale error covariances from the LM test output. Items with weak loadings (<0.50) or with significant cross-loadings on multiple factors were dropped from the analysis at this stage (see Table 5.21).

Table 5.17 presents the final results of the CFA for the flexibility constructs. The revised model displayed a much improved fit (CFI: 0.953, NNFI: 0.922, NFI: 0.934). The global fit measures obtained in the final model evidence strong data convergence. Further modification was indicated by the LM test (Table 5.18) - however, substantive considerations ruled out the implementation of these modifications. Further modifications were not pursued to avoid model 'overfit'. The absence of negative error variances indicated good model fit (Bagozzi and Yi, 1988). Convergent validity was indicated by the strong and significant ($p<0.5$) item loadings. All loadings were above 0.50. Factor reliabilities were between 0.564 to 0.830 (coefficient alpha). All inter-factor correlations were found significantly different from 1.00, demonstrating the discriminant validity of the CFA. As a more stringent confirmation of discriminant validity, the average variance extracted for each factor was computed and found greater than the squared correlation between that factor and any other

factor in the CFA model (Table 5.19). Nomological validity was indicated by the existence of significant and positive inter-factor correlations. Common method bias was evaluated by examining the released covariance matrix of error terms Θ_δ for significant covarying errors. Only two significant error covariances were found, both instances involving sub-scales. From a substantive perspective, these cross-factor error covariances represent idiosyncrasies in the data, that should be ignored to avoid model 'overfit'. The significant multivariate error covariances indicated by the LM test offered relatively small χ^2 values to an already well-fitting model. The small number of multivariate cross-factor error covariances identified in the LM test and the small implied improvement in model fit, confirmed the absence of systemic common method bias.

Multi-Group Analysis

A multi-group analysis of the CFA model was conducted for model validation and non-response bias evaluation. The test for measurement invariance was conducted across the first (n = 200) and second (n = 122) wave of respondents. Table 5.20 presents the results of the stacked model. Both model validation and non-response bias were confirmed by the strong global fit indices (CFI: 0.944; NNFI: 0.923; NFI: 0.900). The LM test failed to indicate any significant multivariate parameters.

5.3.4 Measurement of Manufacturing Performance

This research treats manufacturing performance as a collection of separate constructs, each relating to a individual area of performance (cost reduction, manufacturing cycle time reduction etc.). The item measures for individual manufacturing performance construct were essentially single indicators, albeit benchmarked against internal and external (competitor) goals. A CFA would have been a redundant exercise in these circumstances and was not considered necessary. Each manufacturing performance construct was measured by summating the scores on the internal and external item measures. The reliabilities (Cronbach's alpha) of these summed constructs are indicated below:

Manufacturing Cost Reduction Performance	*- a: 0.783*
Quality Performance	*- a: 0.826*
Manufacturing Cycle Time Reduction Performance	*- a: 0.812*
New product introduction time reduction Performance	*- a: 0.791*
Delivery Performance	*- a: 0.896*
Customization Responsiveness Performance	*- a: 0.822*

The construct reliabilities well exceeded the minimum limit (0.60) suggested for new scales (Nunnally, 1978).

5.3.5 Measurement Issues

Table 5.21 presents a comprehensive list of a-priori item measures, vis-à-vis the item measures finalized in the CFA's. While some attrition was expected (and experienced), the measurement analysis could not provide complete scales for two constructs - supply-base optimization and volume flexibility. Only two of 5 item measures relating to supply-base optimization loaded on a common factor. Both these measures pertained to parts bundling and volume consolidation, an aspect of supply-base optimization. The other dimensions of supply-base optimization sought to be measured, were supply-base reduction and supply-base tiering. The remaining three measures did not load well on any specific factor. It was decided to refrain from constructing independent, additional 'supply-base reduction' or 'supply-base tiering' factors with single item measures, considering the cautions issued in the methodology literature (Bentler and Chao, 1987). In consideration of the truncated measurement results, 'supply-base optimization' was more appropriately re-named as 'parts bundling'. The supply-base optimization dimension of the strategic sourcing construct was thus measured in a partial manner. The deviations from the theorized measurement model were not totally surprising, considering the exploratory nature of the strategic sourcing scale. No other published sourcing study has validated a strategic sourcing measure of similar complexity and scope and items for each of the four first-order factors of strategic sourcing had been developed with care, pre-tested, and based on available literature. In retrospect, it appears reasonable to expect volume consolidation/parts bundling to load separately from supply-base reduction or re-structuring. However, the failure of the supply-base reduction and supply-base tiering items to load coherently was a surprise. Apparently, firms may be adopting a piece-meal approach to supply-base optimization, with supplier reduction not being concomitant with supplier tiering or volume consolidation/parts bundling. Whether such an approach diminishes the impact of strategic sourcing initiatives remains to be investigated, though intuition suggest so. This measurement analysis suggests that future scales for supplier optimization may obtain better results by using multiple measures for each of its three constituent domains.

The inadequacy of the item measures for volume flexibility was more surprising, considering that a majority of these had been adopted

from an established and empirically validated scale (Gupta and Somers, 1992). These items were also screened through a Q-test and pre-tested in academia and industry. For reasons explained earlier (see section *5.3.3)*, volume flexibility was eliminated from further analysis and a measurement model was developed and validated, using the remaining constructs of mix, modification and new product flexibility. A closer look at the item measures for volume flexibility suggest possible reasons for the failure of the measurement model. Volume flexibility was assessed through a combination of time, range, and cost stability item measures. A number of potential incompatibilities became apparent on post-mortem - for example, the 'time needed to increase production volume by 20%' may not load on the same factor as the item 'the range of aggregate production volume over which the firm can run profitably'. Similarly, the 'ease of increasing volume capacity' may be related to non-cost and time issues, such as worker willingness to perform overtime, material availability etc. Two lessons can be drawn from this failure. One, established scales may not find replication in different environments, and thus should be supplemented with additional measures based on logic and discussion. Two, alternative measures of volume flexibility are required to be developed - plant slack may represent one such item.

Overall, the a-priori measures loaded in reasonable magnitude and strength to enable the development and validation of CFAs for the constructs under study. Future research may consider it worthwhile to improve on these scales, using the insights provided by this study

5.4 Evaluation of Path Models

The multi-group analysis for the preceding CFAs confirmed the equivalence of the first and second wave of responses. Consequently, all further analysis was undertaken on a single group basis.

Figure 5.5 shows the conceptual flexibility framework for the path model analyses (without the volume flexibility construct).

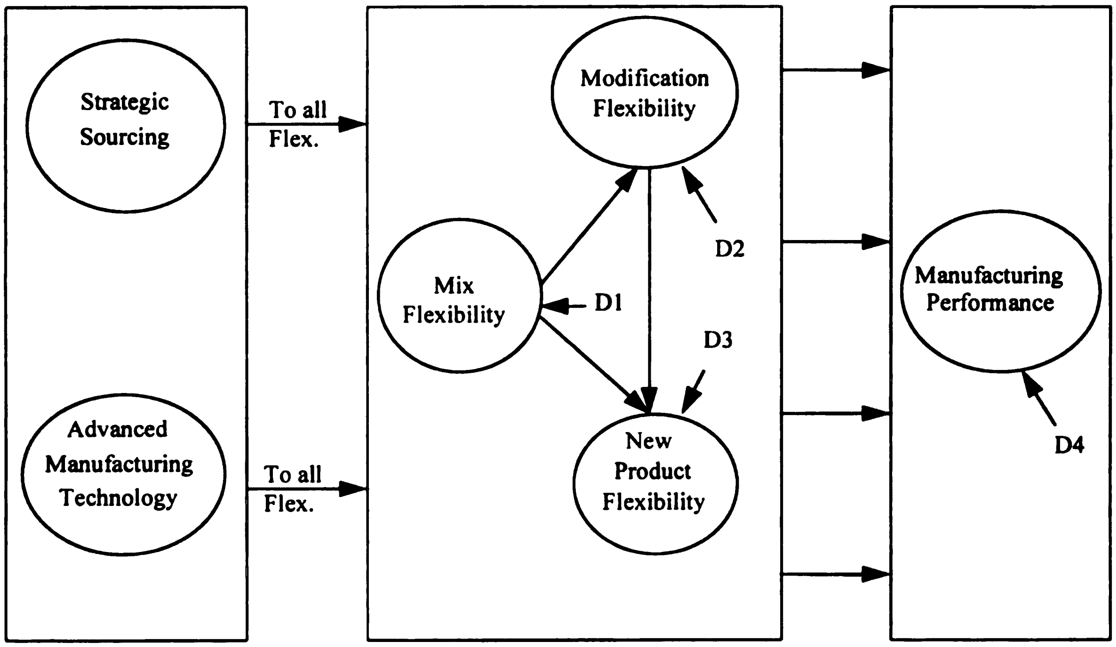


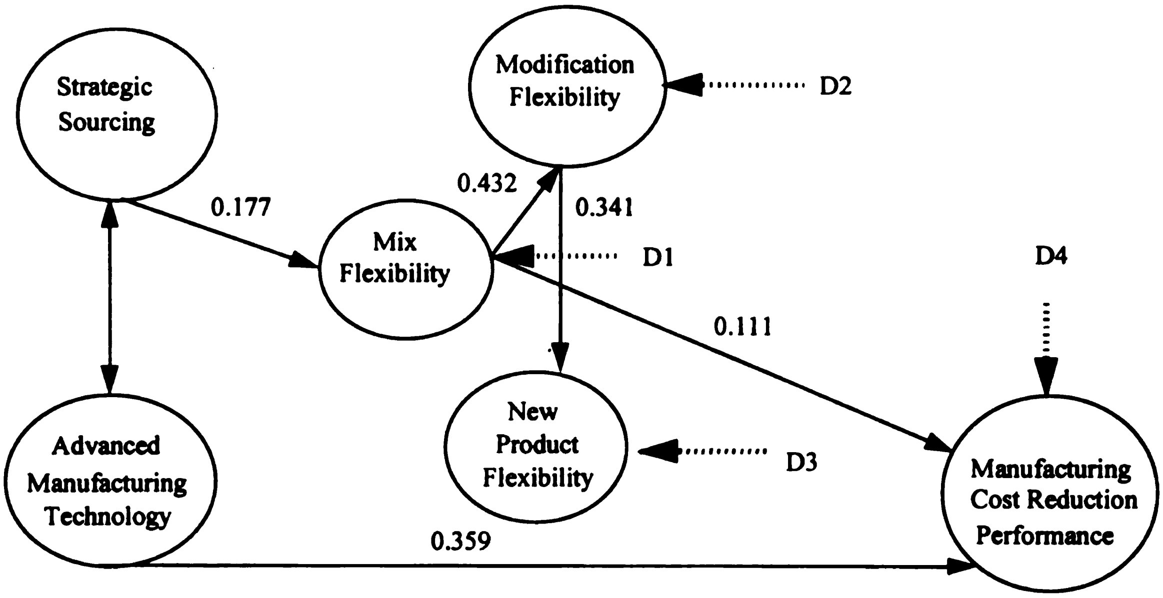
FIGURE 5.5
A CONCEPTUAL FRAMEWORK OF
MANUFACTURING FLEXIBILITY FOR PATH MODEL ANALYSIS

The research hypotheses (see section 3.1.2) required that manufacturing flexibilities be related to individual dimensions of manufacturing performance. Thus, separate path model analysis were developed and evaluated for each dimension of manufacturing performance. The poor fit indices of the initial path model analysis prompted consecutive runs with sequential implementation of Wald and LM test results. The Wald test signifies paths that can be dropped without affecting model fit adversely.

Six path models were finalized, each relating to a specific dimension of manufacturing performance. It is noted that the most significant post-fitting in all the hypothesized path models occurred through a direct path from advanced manufacturing technology to manufacturing performance. Although LM tests indicated the potential of a direct path from SS to manufacturing performance, this path was not accommodated in any of the models. While SS may have direct effects on various dimensions of manufacturing performance, that is not the hypothesis of interest here. The research focus of this dissertation is on the impact of SS on flexibility capabilities and related indirect effects on manufacturing performance. The already excellent overall fit of the final path models also discouraged the addition of data-driven paths for fit indices inflation purposes. The next section describes the results of the individual path analysis.

5.4.1 Path Model Analysis with Manufacturing Cost Reduction Performance

Figure 5.6 shows a post-fitted path model with manufacturing cost performance as the performance variable. Manufacturing cost reduction performance was assessed through respondent perceptions, relative to internal goals and relative to competition (α = 0.783).



CFI: 0.978
BBNNFI: 0.946
BBNFI: 0.956
C2: 11.09, 6 d.f, p <.09

FIGURE 5.6
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH MANUFACTURING COST REDUCTION PERFORMANCE

The global fit indices evidenced excellent model fit (CFI: 0.978; NNFI: 0.946; NFI: 0.856; χ^2: 11.09, 6 d.f, p<.09). All path coefficients were significant. Significant paths were found between strategic sourcing and mix flexibility, between mix flexibility and modification flexibility, between modification flexibility and new product flexibility, and between mix flexibility and manufacturing cost reduction performance. A significant post-fitted path was observed between advanced manufacturing technology and manufacturing cost reduction performance.

5.4.2 Path Model Analysis with Manufacturing Quality Performance

Figure 5.7 shows a path model employing quality performance as the performance variable. Quality performance was measured in terms of product defect reduction performance, relative to internal and competitor goals (α = 0.826).

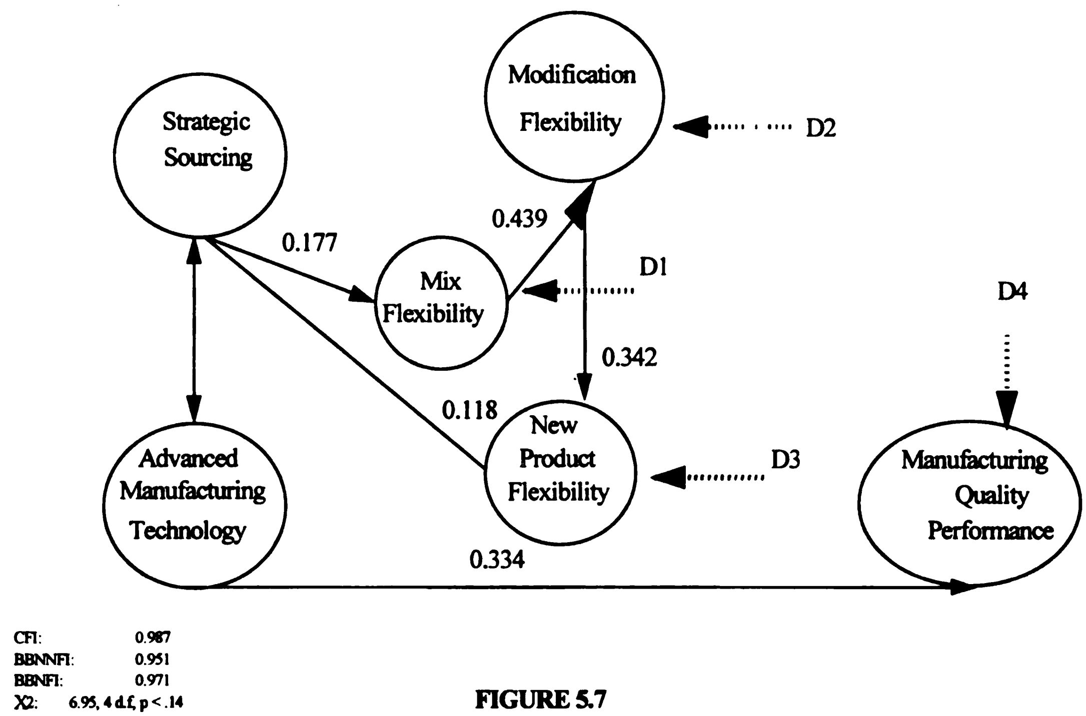


FIGURE 5.7
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH MANUFACTURING QUALITY PERFORMANCE

The fit indices indicate strong model fit (CFI: 0.987; NNFI: 0.951; NFI: 0.971; χ^2 = 6.95, 4 d.f., p<0.14). Significant paths were found between strategic sourcing and mix flexibility, between mix flexibility and modification flexibility, and between modification flexibility and new product flexibility. A post-fitted significant path was found between advanced manufacturing technology and manufacturing quality performance.

5.4.3 Path Model Analysis with Manufacturing Cycle Time Reduction Performance

Figure 5.8 shows a path model, using cycle time reduction as the manufacturing variable. Manufacturing cycle time reduction performance was measured by respondent perceptions of their performance in this area, relative to internal and competitor goals (α = 0.812).

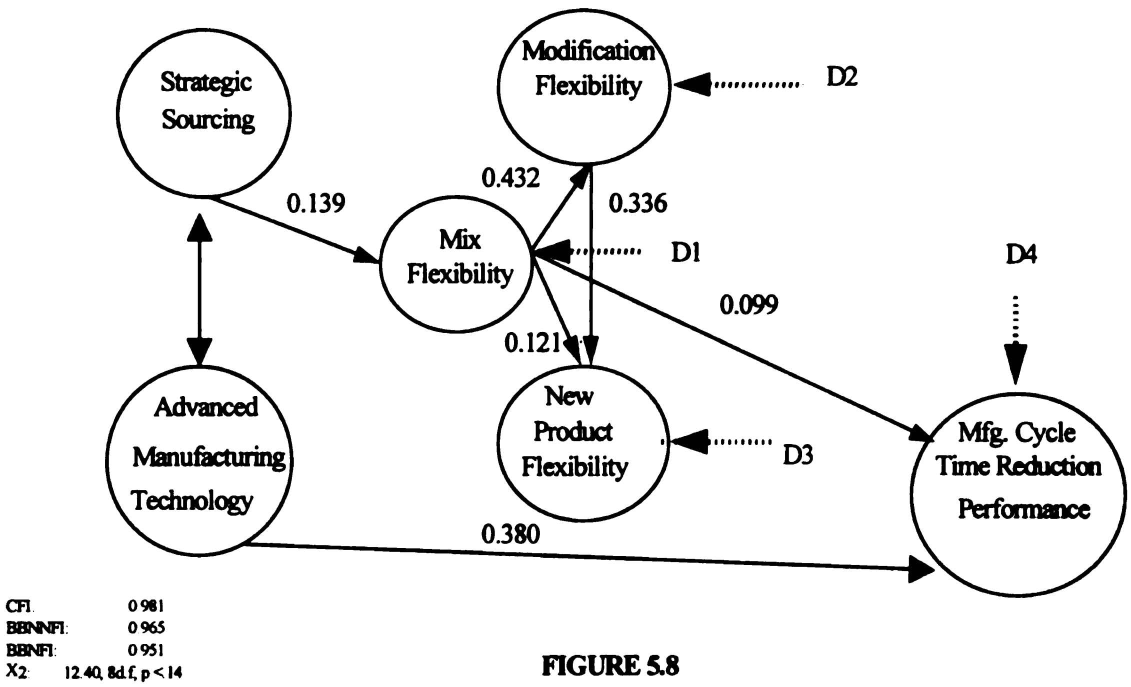
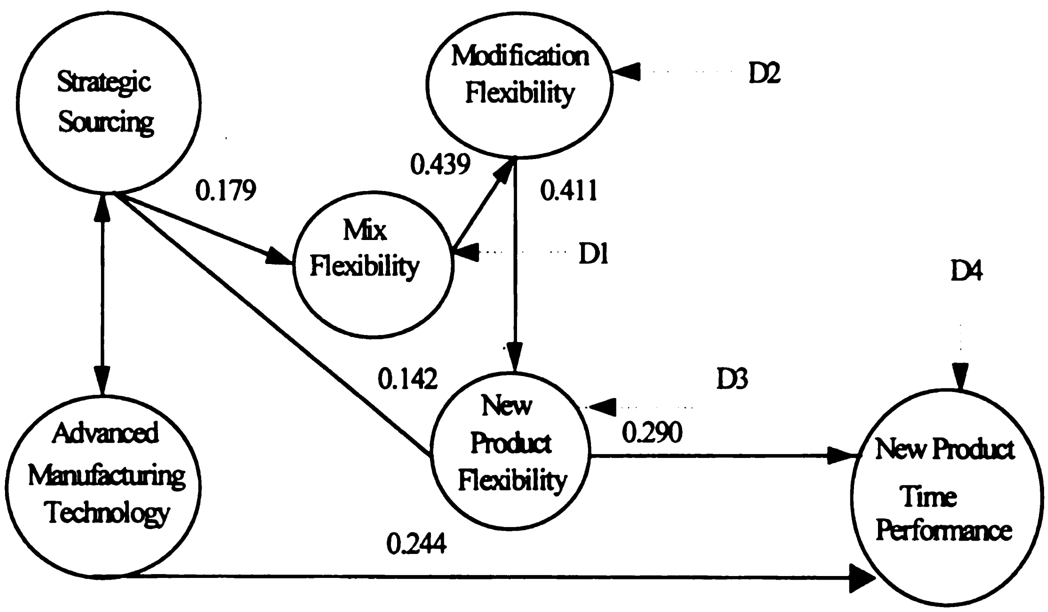


FIGURE 5.8
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH MANUFACTURING CYCLE TIME REDUCTION PERFORMANCE

The overall fit indices confirmed a good fit of the data to the model (CFI: 0.981; NNFI: 0.965; NFI: 0.951; χ^2 = 12.40, 8 d.f., p<0.14). Significant paths emerged between strategic sourcing and mix flexibility, between mix flexibility and modification/new product flexibility, between modification flexibility and new product flexibility, and between mix flexibility and manufacturing cycle time reduction performance. A significant (post-hoc) relationship was also found between advanced manufacturing technology and manufacturing cycle time reduction performance.

5.4.4 Path Model Analysis With New Product Introduction Time Reduction Performance

Figure 5.9 shows a path model with new product introduction time reduction performance, as the performance variable. This performance construct was measured through perceptions of new product introduction time reduction performance, relative to internal and competitor goals (α = 0.791).



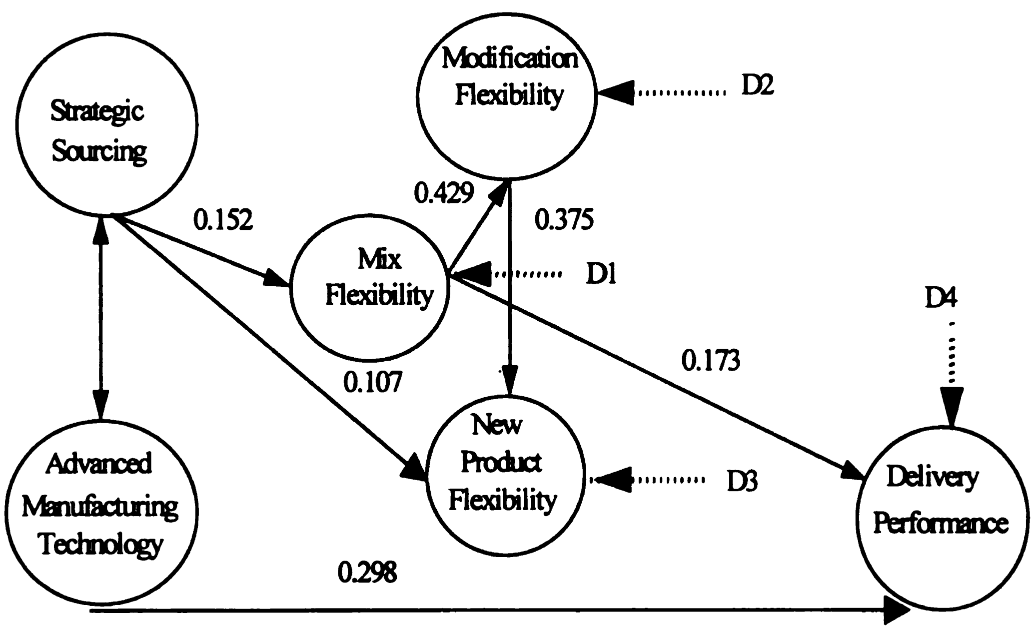
CFI: 0.947
BBNNFI: 0.900
BBNFI: 0.919
X2: 21.44, 8 d.f. p<.01

FIGURE 5.9
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH NEW PRODUCT INTRODUCTION TIME PERFORMANCE

The fit indices indicate good model fit (CFI: 0.947; NNFI: 0.900; NFI: 0.919; χ^2 = 21.44, 8 d.f., p<0.01). The analysis showed significant paths between strategic sourcing and mix/new product flexibility, between mix flexibility and modification flexibility, between modification flexibility and new product flexibility, and between new product flexibility and new product introduction time reduction performance. A post-fitted significant path was introduced between advanced manufacturing technology.

5.4.5 Path Model Analysis with Delivery Performance

Figure 5.10 shows a path model with delivery performance as the performance variable. Delivery performance was measured through perceptions of delivery speed and delivery dependability performance, relative to internal and competitor goals (α = 0.896).



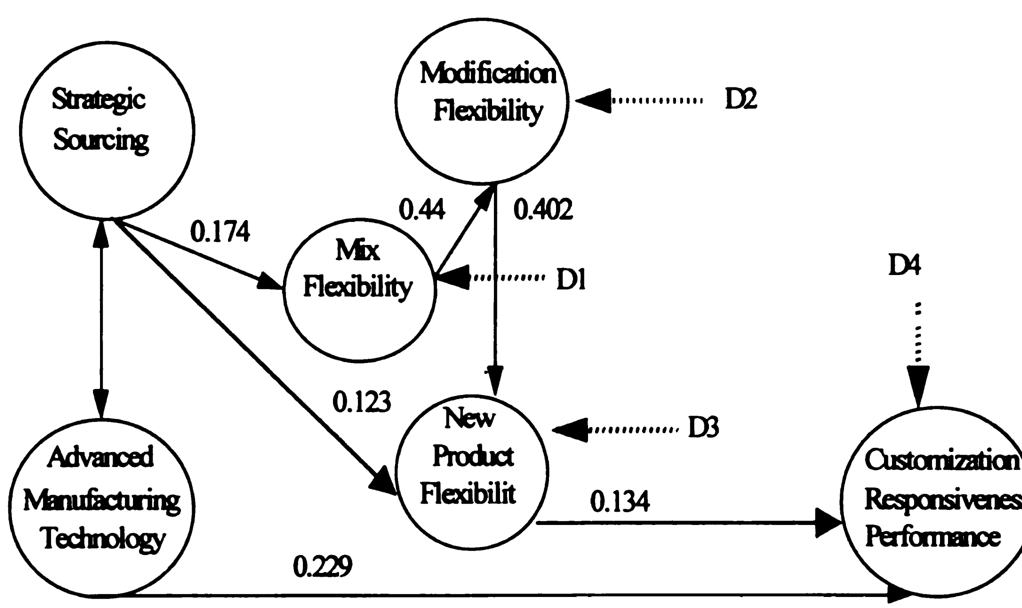
CFI: 0.964
BBNNFI: 0.922
BBNFI: 0.938
X2: 15.57, 7 d.f, p<.03

FIGURE 5.10
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH DELIVERY PERFORMANCE

The fit indices indicate strong model fit (CFI: 0.964; NNFI: 0.922; NFI: 0.938; χ^2 = 15.57; 7 d.f., p<0.03). The analysis indicated significant paths between strategic sourcing and mix/new product flexibility, between mix flexibility and modification flexibility, between modification flexibility and new product flexibility, and between mix flexibility and delivery performance. A significant path was fitted post-hoc, between advanced manufacturing technology and delivery performance.

5.4.6 Path Model Analysis with Customization Responsiveness Performance

Figure 5.11 shows a path model, with customization responsiveness performance as the performance variable. Customization responsiveness was assessed by respondent perceptions of responsiveness to customization requests, relative to internal and competitor goals (α = 0.822).



CFI: 0.948
BBNNFI: 0.902
BBNFI: 0.916
X2: 19.36, 8 d.f., p<.02

FIGURE 5.11
A POST-FITTED PATH MODEL OF MANUFACTURING FLEXIBILITY WITH CUSTOMIZATION RESPONSIVENESS PERFORMANCE

The fit indices indicate strong model fit (CFI: 0.948; NNFI: 0.902; NFI: 0.916; $c^2 = 19.36$, 8 d.f., $p<0.02$). Significant paths were found between strategic sourcing and mix/new product flexibility, between mix flexibility and modification flexibility, between modification flexibility and new product flexibility, and between new product flexibility and customization responsiveness performance. A significant path was incorporated between advanced manufacturing technology and customization responsiveness performance, based on the LM test results. Table 5.22 presents the summary results of the path model analyses.

5.5 Industry Effects

ANOVA was employed to identify the presence of industry effects on the major constructs of the model. Individual SIC-wise path model analyses were not developed due to the constraint of inadequate group sample-size. Table 5.23 presents the results of the ANOVA, performed on the mean scores for advanced manufacturing technology, strategic sourcing, mix flexibility, modification flexibility and new product flexibility, for the five different SIC groups in the data. Significant differences ($p<.01$) were observed for only two of the 25 means involved in the analysis. Specifically, the means for mix flexibility were found to be significantly different for SIC groups 35 and 36. However, the magnitude of this difference was not very large ($\mu SIC35=3.18$ vs. $\mu SIC36=3.69$). In the second case, the means for new product flexibility were found to be significantly different between SIC's 34 and 35. In this instance too, the absolute difference was not large ($\mu SIC34=2.85$ vs. $\mu SIC35=2.29$). In sum, the ANOVA analysis reported negligible industry effects on the main constructs of the path models.

This chapter presented a respondent profile and tested for industry effects on the respondent profiles and model constructs. Structural equation modeling was employed to develop and test first and second-order confirmatory measurement models of the primary constructs. The measurement models were examined for construct, discriminant and nomological validity. Multi-group analysis was employed to demonstrate the external validity of the measurement models, and test for non-response bias. Path models were developed for examining the relationships among the latent constructs. Individual path models were developed and tested for individual dimensions of manufacturing performance. The next chapter discusses the results of the path analysis relative to the hypotheses, and explores relevant implications for theory and practice.

CHAPTER 6

DISCUSSION OF RESULTS

This chapter comprises a discussion of the results of the data analysis and the implications thereof. The results of the path analysis are presented and discussed first, in the following order: flexibility antecedents, flexibility synergies, and flexibility influences on manufacturing performance. Next, the broader implications of the results of the path analyses are considered from different strategic perspectives. The chapter concludes with a discussion of the theoretical and managerial implications of the study.

6.1 Path Model Analysis Results - Relationships and Implications

6.1.1 Strategic Sourcing and Manufacturing Flexibilities

The path model analysis provided selective confirmations of the hypothesized relationships between strategic sourcing and manufacturing flexibilities. The following hypotheses were validated:

H1: Strategic sourcing has a positive influence on mix flexibility

The relationship was found significant for all the path models. The path coefficients between strategic sourcing and mix flexibility ranged between 0.139 - 0.179, across the various models with different manufacturing performance dimensions.

H4: Strategic sourcing has a positive influence on new product flexibility

This relationship was found significant for the path models with quality, new product introduction time reduction performance, delivery and customization responsiveness performance. The path coefficients between strategic sourcing and new product flexibility ranged between 0.107 - 0.142.

The results failed to confirm the following hypothesis:

H2: Strategic sourcing has a positive influence on modification flexibility

The following hypothesis could not be tested, due to the elimination of volume flexibility from the data analysis.

H3: Strategic sourcing has a positive influence on volume flexibility

The results vindicate academic and practitioner opinions of the growing importance of strategic sourcing in a firm's strategic manufacturing agenda. In particular, the impact of strategic sourcing on mix and new product flexibility - both acknowledged sources of competitive advantage in current business environments - was of interest. The results affirmed and extended previous research on sourcing-flexibility relationships. The findings support Olhager's (1993) positive association between supplier delivery speed and mix flexibility. Suarez et al. (1996) noted significant positive relationships between buyer-supplier relationships and mix and new product flexibilities. Such findings have been of limited value due to their uni-dimensional conceptualization of the sourcing construct. The findings from this research advances our understanding of the sourcing-flexibility relationship by employing a richer, multi-dimensional definition of strategic sourcing.

The positive influence of strategic sourcing on mix and new product flexibilities suggests, by implication, that parts bundling, buyer-supplier relationship development, supplier capability auditing, and purchasing integration are important strategies for achieving mix flexibility objectives. Volume leverage has been traditionally perceived as an important gain from parts bundling and volume consolidation policies. Parts consolidation offers suppliers opportunities for a deeper understanding of component fit and design suitability issues. It also stimulates the production learning curve at the suppliers facilities and enables suppliers to improve mix manufacturing capabilities. Familiarity with a broader range of parts and sub-systems enhances supplier capabilities for both product design innovation and variety manufacturing (Monczka et al, 1993).

Such supply-base generated advantages do not appear as a matter of course. Relationships have to be developed between buyers and critical suppliers in order to initiate, maintain and improve supplier capabilities and contributions. Based on the CFA item loadings (Figure 5.2), the development of long-term contracts, exchanges of production information, trust-building, obtaining top management commitment, and joint-problem solving appear to be critical to a successful buyer-supplier relationship development strategy.

Reliance on supplier capabilities in design or process, demands systematic supplier capability auditing in key performance areas. The CFA item loadings (Figure 5.2) indicate that supplier responsiveness, design, and manufacturing versatility are critical strengths for flexibility-oriented purchasers. Supplier contributions to mix or new product flexibilities would be strongly dependent on their capabilities in these areas. Purchasing should focus on supplier performance in these areas for flexibility gains.

The findings also indicate that mix or new product flexibilities can be attained when supplier capabilities and sourcing strategies are aligned with manufacturing and business priorities. Purchasing integration constitutes a critical aspect of strategic sourcing. The CFA (Figure 5.2) loadings show that regular purchasing participation in business strategy formulation and product and process design activities, and a purchasing emphasis on strategic market analysis, are essential elements of a purchasing integration strategy. In such strategies, purchasing measurement and reward systems should be based on strategic metrics, such as contributions to new product development and new technology acquisition.

The positive impact of strategic sourcing on mix and new product flexibilities therefore, develops from a synergistic combination of sourcing strategies, and is not constrained to any one sourcing practice or policy. In contrast to past research, this study therefore, presents the sourcing-flexibility relationship in a richer and more interpretable form, providing new insights and understandings of relationships.

The analysis revealed a significant, albeit weak (0.09 approximately) indirect relationship between strategic sourcing and modification flexibility. The relationship was mediated by mix flexibility, which was in turn, directly influenced by strategic sourcing. The failure to find any significant direct effects between strategic sourcing and modification flexibility could be due to several reasons. It is possible that minor design/feature changes might not require the active involvement of the supply-base. Such incremental changes could be process, not product based. Minor product design modifications could be handled by the buyer's design and engineering departments independently, without placing significant new re-design demands for externally sourced parts and systems. Supplier modification capabilities (a significant item measure of strategic sourcing), were apparently being utilized primarily for new product development purposes in the sampled firms.

The magnitude of the path coefficients (0.107 - 0.179) between strategic sourcing, and mix and new product flexibilities raise some questions. What other significant antecedents could exist for these flexibilities? This study had posited volume flexibility as one such antecedent. However, this construct could not used due to measurement problems. Advanced manufacturing technologies (AMT) was hypothesized as another influence factor. However, the results did not support these hypotheses. It is possible the hypothesized effects could not be detected because of the elimination of volume flexibility from the data analysis. The relationship between AMT and volume flexibility, and the implications of dropping volume flexibility from the analysis are discussed in section *6.1.2*, below. Another potential source of plant level flexibilities is labor flexibility, which has not been explicitly measured and employed in this research. Although the AMT measures included employee multi-skilling, labor flexibility encompasses additional factors that were not measured in this study, such as overtime capability and willingness, and appropriate measurement and reward systems. Theoretically, a certain amount of mix and new product flexibility at the overall SBU/company level could also be provided by slack capacity. Automakers have been known to use surplus facilities to introduce new models and expand product mix. Both GM and Ford have turned some of their idle/underutilized passenger car plants into fast-selling truck manufacturing facilities. In such cases, the technology may consist of long-capitalized dedicated transfer lines (not AMT) that provide the excess manufacturing capacity to produce different/new products, and thus enhance mix and new product flexibilities at the SBU/company level.

Considering the multiplicity of influences on manufacturing flexibilites, the observed path coefficients between strategic sourcing, and mix and new product flexibility cannot be viewed as trivial.

In summary, the results of the data analysis provided partial support for the hypothesized relationships between strategic sourcing and the different manufacturing flexibilities. The findings confirmed the viability of strategic sourcing as a strategic route for the attainment of mix and new product manufacturing flexibilities. The findings also indicated specific sourcing strategies and practices appropriate for a supply-chain based flexibility strategy.

6.1.2 Advanced Manufacturing Technology(AMT)and Manufacturing Flexibilities

None of the hypothesized relationships between advanced manufacturing technology and the different manufacturing flexibilities (see below) were supported by the results of the data analysis.

H5: Advanced manufacturing technology has a positive influence on mix flexibility

H6: Advanced manufacturing technology has a positive influence on modification flexibility

H7: Advanced manufacturing technology has a positive influence on volume flexibility

H8: Advanced manufacturing technology has a positive influence on new product flexibilities

At first glance, the results seemed surprising. The failure to find a significant relationship between AMT and manufacturing flexibilities contradicted much of the past research on manufacturing flexibility (Meredith, 1988; Lei and Goldhar, 1990; Parthasarthy and Sethi 1992). On reflection, this could be attributed to three reasons - unsuccessful implementation of AMT, alternative AMT utilization goals, or a specific conceptual/measurement deficiency in this research. The finding of significant post-hoc relationships between AMT, and manufacturing performance areas such as cost reduction and quality improvement, suggests the latter two causes.

There is some evidence in the advanced technology and manufacturing literature to explain the lack of impact of advanced manufacturing technology on manufacturing flexibilities. Flexibility may not be among the avowed or obtained goals of advanced manufacturing technology. Dean (1987) found that cost reduction is frequently the dominant reason for implementing such systems. In another study, Dean and Snell (1996) failed to find a statistically significant relationship between advanced manufacturing technology and flexibility strategy performance, lending support to claims about the alternative utilization of such systems. Ettlie (1988) found positive effects of robotics performance in the areas of costs, productivity and payback. These reports suggest that advanced manufacturing technology is perceived as a collection of labor saving mass production techniques employed primarily for cost-cutting, not flexibility generating purposes (Zuboff, 1988; Susman and Dean, 1989). Firms also overorder and then under-utilize new technologies, indicating a lack of strategic clarity (Adler, 1988). In other situations, advanced manufacturing technology such as FMS may have been pushed into an organization in order to serve as a test case or for government/customer satisfaction reasons (Nobel, 1984; Groth, 1993). There may be another explanation for the dearth of significant findings for the AMT-flexibility relationship. The strategic driver behind AMT investments has conventionally been volume flexibility, i.e., the ability to produce in varying batch sizes without excessive cost or time penalties. An exemplar is GM's massive manufacturing technology investments of the 1980's. As the conceptual model in this research depicts (Figure 3.1), volume flexibility underlies and facilitates the other flexibilities. Mix flexibility is assisted, when the plant already has the capability to make rapid batch size changes. Similarly, both modification and new product flexibilities can be enabled more easily, when manufacturing can produce different products in varying batch sizes, without excessive cost or time handicaps. Hence, volume flexibility may be considered the natural goal of many AMT systems. These conjectures are supported by the significant (post-hoc) direct influence of AMT on customization, manufacturing cycle time, delivery and new product introduction time reduction performance performances, in the path models. Theoretically, part of each of these AMT-performance relationships could be mediated by volume flexibility. Batch size variation ability should have a positive impact on all these manufacturing performance areas. Volume flexibility could not be included in the path models for lack of adequate measurement. However, a regression was run between AMT and a possible indicator of volume flexibility ('ease of increasing volume capacity without adding new equipment'). The regression indicated a significant and positive relationship ($p<.03$; beta: 0.126, R^2 :0.01) between the two variables. The relatively low R^2 could be ascribed to the single item representation of volume flexibility. Quite possibly, stronger results may have been forthcoming, if the scale for volume flexibility used in this study could have been validated and deployed. A valid, improved scale for volume flexibility is required to be developed to verify such conjectures.

At the very least therefore, there is reason to speculate that AMT could impact important manufacturing flexibility areas, in a flexibility-based strategy. Of course, companies may be employing their advanced technology capabilities for other goals, too. Additional research is required to explore these possibilities more fully.

6.1.3 Inter-relationships among Mix, Modification and New Product Flexibilities

The path analysis results generally supported the hypothesized relationships among mix, modification and new product flexibilities. Specifically, the following hypothesis were supported:

H9: Mix flexibility has a positive influence on modification flexibility

The path coefficients ranged from 0.429 to 0.440 and were significant for all the path models.

H11: Modification flexibility has a positive influence on new product flexibility

The path coefficients ranged between 0.336 to 0.441 and were significant for all the path models.

The following hypothesis was supported only for the case using manufacturing cycle time reduction as the manufacturing performance variable:

H10: Mix flexibility has a positive influence on new product flexibility

The path coefficient was significant and positive (0.121).

The following hypotheses could not be examined due to the exclusion of volume flexibility from the scope of the data analysis:

H12: Volume flexibility has a positive influence on modification flexibility

H13: Volume flexibility has a positive influence on new product flexibility

H14: Volume flexibility has a positive influence on mix flexibility.

The flexibility literature is deficit in studies of flexibility inter-relationships. The findings of this study present new knowledge on the nature of flexibility synergies and associated implications. The capability of the manufacturing system to easily alternate between production of different items in its product mix (mix flexibility) was hypothesized to influence the capacity to make minor product design changes for customization purposes. The findings showed that mix flexibility has a positive and significant effect ($p<.05$) on modification flexibility. The path coefficients were substantial and ranged from 0.429 - 0.440. These findings are new to the flexibility literature and have significant implications. Customization based business strategies appear best pursued using two flexibility capabilities - modification flexibility and mix flexibility. Firms challenged by customization demands would benefit from developing modification flexibility capabilities. Such capabilities can be facilitated when a firm already possesses mix flexibility capabilities. The ability to make minor design changes would encourage an increase in offered product features/options. In order to actually do so, the plant would require to obtain rapid-change manufacturing abilities to meet customer delivery expectations for their custom orders. The capacity to effect minor changes in product features is not of much use, if manufacturing lacks the ability to switch quickly and economically switch between production runs of customized products. Companies who do the former, without possessing the latter capability, may not able to sustain a competitive customization strategy for long. Honda won its 'motorcycle war' with Yamaha in the 1980's, based on its design innovation ability. However, a large part of their success could be ascribed to their manufacturing ability to develop and sustain an expanding product mix, while meeting profitability and time objectives. Mix flexibility can help foster organizational familiarity with the process of change. Companies can exploit this familiarity to develop and deploy modification flexibilities for competitive advantage. Mix flexibility was also found to impact new product flexibility, in the case of firms with manufacturing cycle time reduction goals. This relationship was significant, but not as strong as that between mix and modification flexibilities (0.121 vs. 0.440). The relationship seemed logical, since new product introduction and manufacture should be facilitated when a plant has the manufacturing ability to cope with the product manufacturing changes inherent in expanded product lines. Since this relationship was not observed in the other path models, it is too early to speculate on the generalizability of the finding. Previous research observed a significant correlation between mix flexibility and new product flexibility (Suarez et al., 1996). It can therefore be stated that mix flexibility is not likely to have an adverse effect on new product flexibility. More definitive conclusions require additional research.

The research findings indicated that modification flexibility had a substantial and significant influence ($p<.05$) on new product flexibility. The path coefficients between modification flexibility and new product flexibility ranged between 0.336 - 0.411. Comparisons with past research could not be made because previous studies have not examined this relationship. New product introduction has enterprise wide ramifications in terms of design challenges, engineering difficulties, production dislocations, sourcing decisions and marketing strategy changes. It can be reasoned that a plant accustomed to making small design modifications in its products, would find it easier to transition to the more radical forms of change generally encountered in new product introduction. Such plants with superior modification capabilities would have internalized the change process to a degree, and consequently be more inclined to initiate or adapt to more extreme product/process based changes. Sourcing, design, engineering, manufacturing, finance, marketing and logistics, would be more receptive to altered states of operations. New product flexibility is a strategic competence for companies competing in short product life-cycle environments. The findings of this study suggest that such firms would be well advised to develop incremental design change capabilities, prior to placing radical new product demands on their manufacturing system. Evidence provided by studies of the differences in the new product development approaches of Japanese and American firms support this argument (Dertouzos, Lester and Solow, 1989; Gomory, 1989; Womack, Jones and Roos, 1990). Even in companies such as 3M and Rubbermaid, with explicit new product development targets (25% of sales should come from new products), incremental innovations far outnumber the truly revolutionary changes. The Booz, Allen and Hamilton survey of 1982, revealed that only about 10% of all new products are "new to the world" products. Similar results were reported in a Fortune study of new product introductions from 1989 to 1993 (Martin, 1995).

Figure 6.1 shows the synergistic relationship between mix, modification and new product flexibilities.

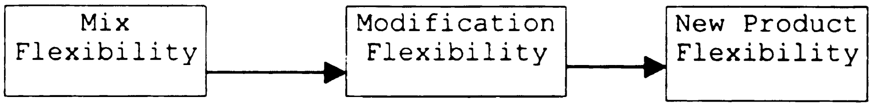


Figure 6.1

Inter-Relationships among Mix, Modification and New Product Flexibilities

These inter-relationships suggest a strategic sequence in the attainment of manufacturing flexibilities. A company interested in developing modification flexibilities would seem to benefit from prior attention to mix flexibility capabilities. Strong mix and modification flexibility capabilities would appear to support the development of new product flexibility. In other words, the capability to maintain and rapidly alternate product manufacture in a large product mix, should be developed in advance of implementing a modification or new product oriented manufacturing strategies. Organizations that experience change as a routine phenomenon develop innovation and learning faculties in their systems, and are less likely to be intimidated by new challenges. Such organizations may possess latent capabilities in product modification and new product design, which could be identified and activated for competitive objectives. Managers could be made cognizant of such opportunities.

An argument could be made for a reverse sequence in the attainment of these flexibilities. That is, a company could initially develop new product flexibility, and then progress to modification and mix flexibility acquisition. However, this sequence is not as conceptually appealing as the one discussed earlier. As mentioned earlier, previous research suggests that radical change is facilitated by the prior presence of incremental change, and not the other way around. Also, a plant must have the manufacturing capability to incorporate new or modified products into its existing product mix, while meeting delivery and throughput demands for all its products. Creating new or re-designed products without ensuring adequate mix flexibility capabilities, might lead to scheduling and delivery problems at the manufacturing stage.

6.1.4 Mix Flexibility and Manufacturing Performance

The hypothesized relationships between mix flexibility and different dimensions of manufacturing performance were confirmed to the following extent :

H15: Mix flexibility has a positive influence on cost reduction performance

H17: Mix flexibility has a positive influence on manufacturing cycle time reduction.

H18: Mix flexibility has a positive influence on delivery performance

The following hypothesis was not supported:

H16: Mix flexibility has a positive influence on quality improvements

The analysis showed a positive and significant (0.111, $p<.05$) influence of mix flexibility on manufacturing cost reduction performance. In contrast, past research offers largely indeterminate conclusions in its examinations of the relationship between mix flexibility and manufacturing cost. Kekre and Srinivasan (1990) found that product line breadth has a positive, albeit marginal influence on manufacturing costs. Suarez et al. (1996) investigation of this relationship could not detect any positive effects of mix flexibility on cost reduction. Yet conceptually, plants with the ability to change between manufacture of different products with low transition penalties, should be able to experience cost gains from this capability. Mix flexibility derives from reduced set-up costs, increased employee versatility and a responsive supply-base. Such factors should increase productivity in a high variety manufacturing environment and impact cumulative manufacturing costs. The results indicate that reduced time and cost to change indeed reduce total manufacturing costs. Three factors may account for the relatively low effect size. One, mix flexibility will have maximum impact when the product demands for the products in the product mix are negatively correlated. Positively correlated demands may result in a situation where total demand exceeds plant capacity. The plant could then utilize its full capacity in satisfying just one or a few products from within the product mix, and not exploit its mix flexibility capabilities. Second, mix flexibility would provide maximum benefit in a dynamic market environment. Extended stability in demand or manufacturing patterns could again lead to the neglect of this capability in a plant's manufacturing strategy. Finally, manufacturing cost reduction performance is a function of multiple influences. External factors such as commodity input price increases, and increases in logistics/utility rates will affect manufacturing costs. Internal factors such as the overhead accounting system differences, plant age, worker turnover, and measurement and reward systems would also effect manufacturing costs. Mix flexibility is one among many influences on manufacturing cost. As the results indicate, it has a tangible impact on manufacturing cost - an impact that is likely to increase in high velocity market conditions.

The results also indicate a significant and positive (0.099; $p<.05$) relationship between mix flexibility and manufacturing cycle time reduction performance. The findings are consistent with previous research

(Das and Nagendra, 1993; Suarez et al., 1996). Mix flexibility should reduce processing waiting times through faster switchovers, thus reducing manufacturing cycle time. Ready availability of inputs from a supply-base responsive to order-mix changes, would reduce change times between manufacture of items in the product mix. The relatively modest effect size could be attributed to the broad nature of the performance measure. Mix flexibility contributes to cycle time reduction by diminishing change-over time between the manufacture of different products in the product mix. A variety of other influences, such as advanced manufacturing technology (faster throughput), and measurement and reward systems (piece rated vs. time rated pay) can affect manufacturing cycle time. A strong relationship between mix flexibility and manufacturing cycle time is also predicated on the frequency of product changeovers - plants with mix flexibility capabilities may not fully utilize it in their manufacturing strategy.

The positive and significant (0.173, $p<.05$) relationship between mix flexibility and delivery performance was also consistent with past research (Sluti, 1992). The capability to reduce inter-product changeover times would be expected to impact delivery performance positively. The failure to find a significant relationship between mix flexibility and quality performance merits more discussion. While 'factory focus' proponents would probably argue for a negative relationship between variety (increased operational complexity) and quality, modern technology and supply chain management systems have expanded the notion of 'focus', considerably (Skinner, 1996). Recent research reports that mix flexibility may not have any adverse effect on product quality and could even promote quality of conformance (Suarez et al., 1996; Miller and Roth, 1994). Variation can be managed effectively through worker familiarity with change and learning processes. The results of this study suggest that quality (defect reduction) performance remains unaffected by mix flexibility. Interpreted in this fashion, the findings provide reassurance to concerns of increased quality variations accompanying increased product changeovers. The findings indicate that product uniformity to quality specifications could remain unaffected by product mix related changeovers.

From an overall perspective, the multiple linkages between mix flexibility and different aspects of manufacturing performance, serve to underscore the importance of this flexibility in an agility-based manufacturing strategy. The results suggest that mix flexibility could have a direct and positive impact on important manufacturing goals in the areas of cost reduction, manufacturing cycle time reduction and delivery performance. At the same time, rapid manufacturing switches within a product mix do not seem to affect product conformance quality adversely. Plants with goals in these manufacturing performance areas could benefit by developing and deploying mix flexibility capabilities. The results also substantiate the conceptual positioning of mix flexibility as a fundamental requirement for facilitating modification and new product flexibilities.

6.1.5 Modification Flexibility and Manufacturing Performance

None of the hypothesis relating modification flexibility to manufacturing performance was supported by the results of the data analysis.

H19: Modification flexibility has a positive influence on cost reduction performance.

H20: Modification flexibility has a positive influence on quality improvement.

H21: Modification flexibility has a positive influence on manufacturing cycle time reduction.

H22: Modification flexibility has a positive influence on new product introduction time reduction

H23: Modification flexibility has a positive influence on delivery performance.

H24: Modification flexibility has a positive influence on customization responsiveness.

The question then arises - how does modification flexibility benefit a plant? The results indicate that modification flexibility impacts new product flexibility. Modification flexibility's effect on manufacturing performance thus appears to be mediated by new product flexibility. The advantage of being able to make minor design changes in the product-mix without severe transition penalties, is reflected in an increased ability to rapidly introduce new products, ultimately enhancing customization and new product introduction time reduction performance.

Miller and Roth (1994) found that firms emphasizing new product introductions, also emphasized modification and new product flexibility. The absence of an adverse relationship between modification flexibility and quality performance again demonstrates the uniformity of performance that plants can obtain using manufacturing flexibilities in a dynamic manufacturing environment (Upton, 1994). The classic manufacturing trade-offs between design variety, and quality/cost/delivery seem to be mitigated by the development of appropriate manufacturing flexibility capabilities. While the absence of unfavorable effects was noted, the hypothesized positive effects of modification flexibility on cost reduction and cycle-time reduction were not supported by the data. As discussed earlier, manufacturing costs are subject to multiple influences, some of which may interact with modification flexibility to impact cost reduction performance. As such, the main effects of modification flexibility may be subsumed in such interaction effects. For example, a production-volume based evaluation system may discourage workers from implementing design changes that could interrupt production flow. In contrast, workers evaluated with customization based criteria, would find it advantageous to adapt to changes in product/process design. The failure to find significant relationships between modification flexibility, and customization responsiveness and delivery performance was puzzling. The ability to accommodate customer preferences in product (minor) design features was expected to improve customization performance. Increased modification flexibility however, may be a necessary, but insufficient condition for enhanced customization performance. While manufacturing may possess the capability to effect minor product design changes at reasonable time and cost, associated business processes involving marketing, accounting and logistics should be aligned to exploit these modification flexibility skills. An unresponsive order taking system will negate the positive effects of any design and delivery advantages in manufacturing. Similarly, an distributional and logistical process inefficiencies may effect both customization responsiveness and delivery performance adversely, despite manufacturing's promptness in responding to customization requests from customers. These speculations require additional research and more specific measures. A possible modification flexibility related customization performance measure for future research could be the ratio: 'customization requests received by manufacturing / the number of such requests denied because of lack of quick, economical design change capabilities.' However, information at this level of manufacturing detail would be difficult to obtain without direct access to manufacturing executives and plant records.

6.1.6 New Product Flexibility and Manufacturing Performance

The research results supported the following hypothesized relationships between new product flexibility and manufacturing performance:

H31: New Product flexibility has a positive influence on new product introduction time performance.

H33: New Product flexibility has a positive influence on customization responsiveness performance.

The following hypothesis were not supported by the results of data analysis:

H29: New Product flexibility has a positive influence on cost reduction performance.

H30: New Product flexibility has a positive influence on manufacturing cycle time reduction.

H32: New Product flexibility has a positive influence on delivery performance.

New product flexibility had a positive and significant impact on new product introduction time reduction performance (0.290, $p<.05$), and on customization responsiveness performance (0.134, $p<.05$). Both influence relationships point to the importance of developing this flexibility capability in dynamic markets. These results are consistent with previous research that had found positive associations between new product flexibility and new product introductions (Miller and Roth, 1994). New product flexibility requires the ability to design, prototype and manufacture new products, within stringent cost and time constraints.

Plants that develop this flexibility capability could gain significant customization and new product based differentiation advantages. Companies such as Intel and Motorola have long thrived on such competitive strategies.

While new product flexibility could be expected to have a direct influence on new product introduction reduction time and customization performance, its effects on cycle-time, manufacturing costs and delivery may be more indirect. From one perspective, the absence of adverse effects between new product flexibility, and cycle-time, delivery and cost reduction performance provides another refutation of the 'trade-offs' paradigm in the production literature. Suarez et al. (1996) noted a similar lack of adverse effects of new product flexibility on manufacturing cost and quality. These results suggest that plants that can develop new product flexibility without necessarily experiencing adverse repercussions in other manufacturing performance areas. As the findings indicate, this could a benefit of strategic sourcing. Active involvement of the supply base and purchasing in new product development work could help avoid major disruptions in current in-house production.

The results of this research suggest that new product flexibility could be an important influence on the achievement of new product introduction time and customization performance objectives. The implications for manufacturing cost reduction, delivery and manufacturing cycle-time performance are less clear. The absence of any adverse relationships indicates that the pursuit of new product flexibility need not compromise the attainment of these manufacturing goals.

In summary, the results of the path model analyses provided selective affirmations of the following relationships: strategic sourcing and specific manufacturing flexibilities; mix modification new product flexibilities; and specific flexibilities and dimensions of manufacturing performance. The results failed to support the hypothesized relationships between AMT and manufacturing flexibilities.

6.2 Path Model Analysis Results - Strategic Implications

6.2.1 A Supply Chain Perspective

Figure 6.2 presents the results of the path analysis in aggregate form. The path coefficient ranges (across different manufacturing performance dimensions) for significant relationships are indicated.

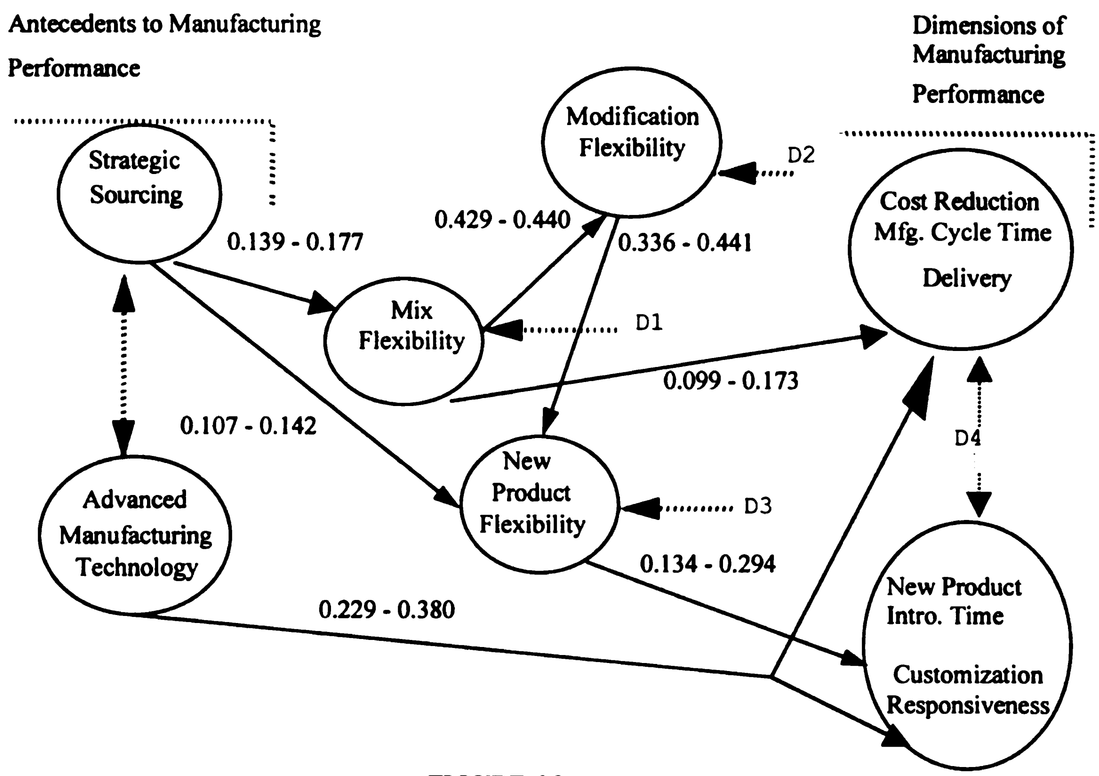


FIGURE 6.2
AN AGGREGATE PATH MODEL OF MANUFACTURING FLEXIBILITY

Figure 6.2 above shows a sharp difference in the relative effects of mix and new product flexibilities on manufacturing performance. Mix flexibility is found to impact cost reduction, cycle time and delivery performance. New product flexibility is found to impact new product introduction time and customization responsiveness performance. From a supply chain management perspective, companies competing on delivery and cost should focus on developing mix flexibility as a manufacturing capability. In contrast, companies competing on innovation and customization should emphasize the acquisition of new product flexibilities. The results of the study suggest that strategic sourcing could be a viable means for the development of these flexibilities. The results also suggest that the a-priori development of mix and modification flexibilities, could facilitate companies in their pursuit of new product flexibility.

From a strategic perspective, companies for whom agility is a competitive priority would focus on developing high levels of manufacturing flexibilities. Consider the case where customer and competitive pressures create high velocity business environments demanding superior agility performance (Greis and Kasarda, 1997). One way to fulfill such performance demands is through the development and deployment of manufacturing flexibilities (Chung and Chen, 1990; Upton, 1995; Goldhar and Lei, 1995). This study suggests that such manufacturing flexibilities, in turn, could be targeted through strategic sourcing capabilities centered on purchasing integration, volume consolidation, supplier relationship development, and the employment of specific supplier capabilities. It is the ability of the supply-base to respond to demands made by changes in the buyer's plant that contributes to the effectiveness with which the buyer's plant makes these changes. The research results support the basic premise of the study: careful selection, development and integration of suppliers with appropriate capabilities will contribute to manufacturing's ability to make product-mix changes and introduce new products. Supply-base strategies would focus on the selection, development and certification of suppliers with the requisite responsiveness and technological capabilities to fulfill specific manufacturing flexibility targets.

Viewed in this light, the results serve to vindicate an important link between strategic sourcing and manufacturing flexibilities in a supply-chain based strategy to meet the demands of dynamic markets.

At an operational level, the results of the confirmatory factor analysis for strategic sourcing (Figure 5.2) highlight the specific sourcing practices that can be adopted to obtain a responsive and involved supply-base. To this end, buyers may have to develop and administer customized supplier assessment and supplier selection tools, with a different focus from traditional cost, quality or delivery centered evaluation systems. For example, in designing a suitable supplier assessment system, buyers should place appropriate weights for supplier responsiveness and design capabilities. Similarly, supplier audit procedures and data collection systems should be re-directed to evaluate and monitor supply-base responsiveness and design strengths as critical supplier attributes. Supply-base re-organization could also be an important factor in this process. There is evidence in the literature of substantial technological and design benefits obtained through innovative supply-base rationalization and tiering (McMillan, 1990; Nishiguchi, 1994). Research shows that first tier, 'partner suppliers' have deep inputs into their customer's design and quality processes (Kamath and Liker, 1994; Wood, Kaufman and Merenda, 1996) and are providers of options and solutions to their customers. Studies have also suggested that buyers may need to develop long-term relationships with key suppliers in order to derive integration benefits (Ellram, 1991). In

order to do so, purchasing and manufacturing would require to invest in behavioral and economic factors such as trust, satisfaction, commitment, information exchange, asset specificity and joint problem solving with the supply base (Morgan and Hunt, 1994; Nishiguchi, 1994; Gulati, 1995). These relationship development activities are likely to require personnel training, re-orientations in performance measurement and reward systems, and synergistic information technology investments in buyer and supplier organizations.

A flexibility-based strategic sourcing policy has company wide implications. The development of a responsive, integrated supply base could push changes in production, engineering and marketing strategies. To illustrate, early supplier involvement in design can contribute to easy design change capabilities, encouraging engineering and manufacturing to pursue new product development and increase product-line variety. Marketing could then exploit these internal competencies to build new product and customization based differentiation strategies for competitive advantage. Manufacturers can thus create and support corporate competitive order-winning competencies by targeting specific manufacturing flexibilities with suitable supply base strategies. Clearly, for cost and quality focused firms, flexibility adds another strategic option in their competitive arsenal - quality improvements, lay-offs and cost reduction strategies have plateaued or offer decreasing competitive returns (Kim, 1994).

Flexibility 'order winners' may change rapidly in a dynamic competitive environment and may need to be constantly updated for each market and customer segment. In such conditions, managers should consider the implications of inter-relationships among different types of manufacturing flexibilities. Consider two plants manufacturing similar products: plant A has superior modification flexibility and plant B has a traditional rigid high volume-low variety manufacturing system. New market pressures may force a firm to compete on new product introduction performance. Others things being equal, plant A would be a natural choice for implementing the new competitive strategy. The strong modification flexibility capability of plant A would have engendered a culture of acceptance of change in the plant organization. Workers in plant A would be relatively more familiar and comfortable with new product introductions due to their prior experience with the incremental product/process design changes inherent in a high modification flexibility manufacturing environment. Thus advance consideration of potential synergies among operational flexibilities may facilitate the development of specific manufacturing flexibility goals in an enterprise.

6.2.2 Inter-relationships among Strategic Sourcing Practices

Table 6.1 presents the correlations among the individual item measures of the four factors of the strategic sourcing construct. Most of the strategic sourcing practices are significantly ($p<.05$; $p<.01$) correlated to one another. Focusing on medium and strong effects among these correlations (>0.30) revealed some interesting patterns and possibilities. Volume consolidation and parts bundling, were significantly correlated with most of the other sourcing practices. However, these correlations were not very strong (0.09-0.29), suggesting that, to start with, these two practices may be conducted somewhat independent of the others. Volume leveraging for cost goals may not always evolve into the higher levels of strategic sourcing envisaged in the strategic sourcing frameworks in the literature(Reck and Long, 1988; Freeman and Cavinato, 1990). Contractual relationships with key suppliers correlated strongly (0.33-0.49) with trust development, top management commitment, joint problem solving and information exchanges between the buyer and the supplier. These effects confirm the role of relationship building practices in developing sustainable buyer-supplier relationships. The correlations (0.41-0.64) between top management commitment and the extent of joint production information sharing and problem solving, underscore the importance of senior management support in a relational development program (Gulati and Nohria, 1992; Ellram and Edis, 1996). Production schedule information sharing by the supplier also correlated strongly (0.31-0.36) with supplier assistance in product design, purchasing participation in business strategy formulation, and purchasing's impact on changes in end products. Similar, albeit weaker correlations (0.24-0.26) were found between production schedule information sharing by buyers and the latter three practices. These findings suggest that preliminary actions such as production scheduling synchronization of key inputs across buyer-supplier units, could develop and encourage deeper forms of supplier involvement. Additionally, the correlations between information sharing and purchasing influence on final product changes and strategy development, suggest that a coherent supply chain strategy may underlie such buyer-supplier information exchnages. Further insights are offered by the presence of strong multi-collinearity among different supplier capabilities. Supplier ability in product design correlated strongly (0.75) with supplier assistance in new product design. Suppliers proficient in product design appeared to have concomitant capabilities (0.37-0.0.45) in product modification, product modularization, and responsiveness to delivery, order-mix and order volume changes. Interestingly, the pattern of correlations among supplier capabilities is similar to the pattern of inter-flexibility relationships found in the buyer plants. Supplier new product development abilities seem to be fostered by supplier capabilities in modification, mix and volume responsiveness. Supplier assistance in product design also correlated strongly (0.31-0.41) with purchasing participation in product and process design, as well as with purchasing's impact on final product changes. Active purchasing involvement with manufacturing goals appears to enable supplier involvement in product design. There were strong correlations (0.35-0.53) between purchasing measurement and rewards on strategic metrics, and purchasing participation in corporate strategy meetings, purchasing's impact on end-product decisions, purchasing participation in new product/process development and purchasing focus on market and price analysis. These effects are indicative of the potential impact of measurement systems on functional direction and performance. Purchasing departments evaluated and rewarded on contributions to strategic business goals of technology and new product design may engage more intensely in new product development and other non-traditional activities. They also could be evolving from routine activities such as order generation and expediting, to more sophisticated responsibilities in market analysis and monitoring for business. Such escalated roles appear to stimulate purchasing's 'say' in terms of end product development and product line changes.

The results of the correlation analysis suggest that managers should bundle sets of related strategic sourcing practices for maximum impact on flexibility performance. The correlations suggest that buyers acquire and develop supplier capabilities in strategic sets, rather than on an ad-hoc, piece-meal basis, for effective performance. Further, the alignment of purchasing goals with business goals appeared to be strongly associated with several other key strategic sourcing practices.

This chapter discussed the results of the data analysis. The findings generally supported the hypothesized influence relationships between strategic sourcing and manufacturing flexibilities. The failure to find a significant relationship between AMT and the manufacturing flexibilities was noted and discussed. The findings of significant inter-relationships among the manufacturing flexibilities provided the first empirical evidence of such linkages in the flexibility literature. The chapter ends with a discussion of the managerial and theoretical implications of the study. The next chapter highlights the contributions of the study, and concludes the dissertation with a discussion of study limitations and future research possibilities.

CHAPTER 7

CONCLUSION

This chapter concludes the dissertation. The contributions of the research to the flexibility and sourcing literature and practice are discussed and presented. Research limitations are noted and future research avenues identified.

7.1 Contributions

This research can be positioned under the general rubric of supply-chain based competitive strategies, and more specifically, as an investigation of the influence of strategic sourcing on manufacturing flexibilities. This study makes several contributions to theory development in the sourcing and flexibility literature. A conceptual framework of manufacturing flexibility, its dimensionality, measurement, antecedents and outcomes, is proposed and tested. The exploration of manufacturing flexibility interactions addresses another gap in the flexibility literature. Finally, very few studies have specifically looked at relationships between manufacturing flexibilities and individual dimensions of manufacturing performance. This research does so, and thereby contributes to the manufacturing strategy literature. The choice of structural equation modeling for data analysis enhances the rigor and validity of the analysis.

The study addresses a gap in the sourcing and flexibility literature by explicating the role of an unexplored antecedent, i.e., strategic sourcing, in the development of manufacturing flexibility capabilities in a plant. In particular, the distinct patterns (Figure 6.2) in the relationships between mix and new product flexibilities and different dimensions of manufacturing performance suggest separate strategic routes to specific competitive performance priorities. The linkages between strategic sourcing, and mix and new product flexibilities position sourcing in the (new) role of an enabler of supply chain based strategies to attain competitive 'change capabilities' in a plant.

Hines (1996) called for a "definition and measurement of strategic sourcing", as an important step towards developing a 'grand' theory of sourcing. This research conceptualizes, dimensionalizes and measures the construct of strategic sourcing. While earlier studies have assessed sourcing through unidimensional, single/limited indicators, this research visualizes strategic sourcing as a synergistic combination of sourcing strategies in key areas - parts bundling, buyer-supplier relationship development, supplier capability auditing, and purchasing integration. Table 6.2 presents the correlation matrix among these constituents of strategic sourcing. The following statements are based on these correlation patterns:

- Strategic sourcing represents the integrated implementation of a few, minimum, fundamental sourcing strategies, in alignment with the competitive priorities of a firm.
- Purchasing integration enables the alignment of sourcing strategies with business strategy, by associating the purchasing function with the corporate strategy formulation process.
- The strong correlations among the strategic sourcing factors encourages conjectures of a sequential relationship among the sourcing strategies. This is further elaborated later in this chapter.

Further research is required to examine these speculations.

In summary, this study contributes to the sourcing literature in

several ways. It develops and tests a conceptual framework relating strategic sourcing to manufacturing flexibilities; develops, measures and validates a definition of strategic sourcing; and develops empirically based insights on the fundamental dimensions of the strategic sourcing construct. Each of these contributions advances the body of knowledge in the sourcing discipline.

This study addresses several important theoretical gaps and gray areas in the manufacturing flexibility literature. It conducts the first rigorous empirical investigation of the antecedent role of strategic sourcing in manufacturing flexibilities. In doing so, it adds to our theoretical understanding of the manufacturing flexibility construct and its drivers. This investigation also examines the relationship between advanced manufacturing technology and manufacturing flexibilities - a gray area in the flexibility literature. Previous empirical research on the contributions of advanced technology to manufacturing flexibilities, reports inconclusive findings (Jaikumar, 1986; Pagell and Handfield, 1998). The results of this research suggest that advanced manufacturing technology may not be a viable direct route to mix or new product flexibilities. Another unique contribution of this research emerges from its examination of the inter-relationships among manufacturing flexibilities. Previous studies have been confined to conceptual discussions or simple correlational analysis of a few flexibility dimensions (Gupta and Goyal, 1992; Suarez, 1996). This study hypothesizes and confirms a sequential relationship among mix, modification and new product flexibilities. This research also explores the relationship between manufacturing flexibilities and manufacturing performance - an under-researched area in the flexibility literature. The differential influence of mix and new product flexibilities on the manufacturing competitive priorities of cost, time, delivery and customization, affirms the existence of distinct strategic linkages between manufacturing flexibilities and competitive performance goals.

The findings of this study have positive implications for purchasing and manufacturing executive decision makers. For the practitioner, the research results offer a deeper understanding of the complex issues faced in achieving manufacturing flexibility. The findings provide direction on targeting specific manufacturing flexibilities with suitable supply base strategies. Each flexibility can have different drivers and understanding the relevant relationships is critical to successful implementation of manufacturing flexibility programs. Managers can be made aware of the complementarities among flexibilities and factor these into their action plans. Finally, by examining definite relationships between manufacturing flexibilities and manufacturing performance(s), this research provides managers with valuable insights on leveraging supply chain strategies for gains in targeted performance areas.

This research provides prescriptory insights for companies interested in pursuing a flexibility-based competitive strategy. For such firms, a possible course of action would be to:

- determine the specific nature of the manufacturing flexibilities required to fulfil competitive goals
- assess the gaps between desired and current levels of such manufacturing flexibilities
- consider the flexibility synergies and identify the desired pre-requisite flexibilities
- identify and implement the strategic sourcing practices that can develop and enhance these a-priori flexibilities
- identify and implement the specific strategic sourcing activities that lead to the desired manufacturing flexibility.

The findings of this research: link specific manufacturing flexibilities with the achievement of specific areas of manufacturing performance; provide measurement scales to evaluate flexibility levels in a plant; and suggest supply-chain based strategies for achieving desired manufacturing flexibilities.

Sourcing and manufacturing managers could also take a more proactive approach:

- ➢ assess existing supply-base capabilities in responsiveness and design
- ➢ identify manufacturing flexibilities that could be potentially obtained from such supply-base capabilities
- ➢ create executive awareness of such opportunities and determine competitive performance goals
- ➢ develop manufacturing flexibilities with assistance from the supply-base (and other resources)to target performance objectives
- ➢ deploy manufacturing flexibilities for competitive advantage

While not examined explicitly in this study, it could be useful to speculate about the sequential relationship among the four explicated dimensions of strategic sourcing. The correlation analysis in Table 6.2 provides the relevant information. It can be observed that 'Parts Bundling' is relatively less related to the other dimensions, and could be an isolated practice in some firms. The other dimensions displayed significant multi-collinearity. Based on these collinearities and a study of the sourcing literature, a possible deployment sequence of sourcing strategies in a strategic sourcing program is outlined below:

- Purchasing participates in business strategy formulation, influences the determination of strategic goals, and develops compatible functional-level plan objectives
- Purchasing measurement and reward systems are re-oriented to emphasize strategic metrics (technology, design, market analysis etc.)

- Purchasing focuses initially on parts bundling and volume consolidation, with associated supply-base rationalization - there is evidence in the literature to support the preliminary use of these practices in most sourcing strategies (Monczka and Trent, 1991; Robertson, 1995).

- Purchasing develops long-term relationships with key suppliers, by investing in trust-generating practices, such as joint problem solving and information sharing.

- Purchasing audits and obtains the benefits of supplier capabilities in non-traditional areas such as design and response time. Cost and quality gains would have been attained earlier through volume leveraging.

- Purchasing reviews and revises its strategic priorities and measurement systems to ensure continued compatibility with manufacturing and business goals

The initial cost/quality gains from supply-base rationalization and volume leveraging could prepare the grounds for a positive interface with executive management. Cost reduction and quality improvement are common performance objectives for most firms. Consistent presentation of positive, real results to management in these competitive performance areas, should facilitate purchasings' entry into the business strategy formulation process.

In conclusion, this research contributes to theory development in manufacturing flexibility by proposing and testing a conceptual framework of manufacturing flexibility, and its antecedents and performance outcomes. The study identifies specific linkages between individual manufacturing flexibilities and specific manufacturing performance dimensions. It suggests supply chain based strategies to utilize the relationships found in the conceptual framework for competitive advantage. It contributes to theory development in sourcing by developing a definition and scale for strategic sourcing and investigating the role of sourcing in developing manufacturing flexibility capabilities in an enterprise. This study contributes to the manufacturing and purchasing profession by identifying and discussing the use of specific sourcing practices that could facilitate the development of manufacturing flexibilities in a firm.

7.2 Limitations of the Research

Certain limitations apply to this research. A reason for concern in the data analysis is the possibility of 'omitted variable' bias. This can affect data analysis results and interpretation, (Boulding and Staelin, 1995). Tests with the theta-delta matrix of SEMs have been used to identify such effects. However, these provide more definitive confirmation of common method bias in measures than an indication of an absence of omitted variable bias. It is desirable to be able to refute the hypothesis that "omitted" variable effects bias relationships between the exogenous and endogenous constructs. This study employs theoretical logic and extant literature to substantiate the hypothesized impact of exogenous variables on dependent variable in the conceptual framework (Figure 3.1). The task becomes more complex when relationships involve endogenous variables such as manufacturing performance, that are potentially subject to multiple influence factors. Since only one observation was collected per plant in the sample, a definitive confirmation of the absence of omitted variable bias cannot be furnished. However, the mere presence of omitted variable effect need not necessarily bias study results. Omitted variable effects lead to omitted variable bias, only when the omitted variable is not correlated significantly with measured exogenous variables. An examination of such correlations however, requires explicit identification and estimation of omitted variables, a task beyond the purview of this study.

Another limitation of the study derives from the post-hoc adjustments to the initial path models. Although such modifications were made with due care and logic, it is desirable to cross-validate these models on another sample.

The single respondent based data collection methodology constitutes another research limitation. A dyadic study involving manufacturing and purchasing would have been preferable. A triad approach to data collection, involving key suppliers, purchasing and manufacturing would be ideal. Resource and time constraints precluded the implementation of such enhanced data collection designs.

7.3 Future Research Directions

An examination of the sequential relationship among the four conceptualized dimensions of strategic sourcing could provide interesting and useful information for sourcing theory and practice. The correlational patterns among the component item measures of these four dimensions of strategic sourcing also invite sequence and causality explorations. In the measurement area, future research could concentrate on refining the strategic sourcing and manufacturing flexibility scales developed in this study. In particular, the development of a valid, multiple item scale for volume flexibility remains an important, unresolved issue.

From a strategic perspective, it would be interesting to examine the impact of firm strategy on the sourcing-flexibility-performance relationship structure. The strategic frameworks developed by Porter (1980) or Miles and Snow (1978) could be adopted for this purpose. The relationship of product life cycle to manufacturing flexibility and its antecedents offers another opportunity for further research. It would also be interesting to examine the role of technological complexity on the constructs and relationships of the conceptual framework tested in this research. Finally, the scope of the conceptual framework could be extended to include firm performance.

APPENDIX A

APPENDIX A - TABLES

Table 2.1
A Classification of Key Manufacturing Flexibility Literature

Category	Study	Key Conclusions
Contextual	Swamidass and Newell, 1987	Environmental uncertainty influences flexibility. Flexibility's role in strategy formulation affects performance.
	Slack, 1988	Strategy determines choice of flexibility.
	Suarez, Cusumano and Fine, 1991	Market uncertainty and firm strategy determine type and amount of needed flexibility.
	Gerwin, 1993	Environmental uncertainty influences manufacturing strategy. Manufacturing strategy determines required manufacturing flexibility.
Typology	Mandelbaum, 1978	Distinguishes between action flexibility and state flexibility.
	Hutchinson and Holland, 1982; Warnecke and Vettin, 1982; Steinhilper, 1985	Define flexibility in two aspects - short-term and long-term.
	Swamidass, 1988	Flexibility type is determined by position of firm on the volume-variety continuum.
	Upton, 1994	Distinguishes between operational, tactical and strategic flexibility. Adds dimensions of time, uniformity and mobility.

Table 2.1 (contd.)

Micro-Taxonomies	Browne et al., 1984; Lim, 1986; Yilmaz and Davis, 1987.	Define manufacturing flexibility into eight distinct types
	Gerwin, 1987	Defines 7 types of manufacturing flexibilities
	Swamidass, 1987(a)	Lists 20 different nomenclatures of manufacturing flexibility types in the literature
	Adler, 1988	Distinguishes between product (mix, modification) and process (routing, volume, expansion) flexibility
	Taymaz, 1989	Classifies flexibility into component, operational and system levels
	Sethi and Sethi, 1990	Identify 11 different types of manufacturing flexibilities
	Gerwin, 1993	Classify manufacturing flexibility into mix, changeover, modification, volume, rerouting, material and responsiveness flexibilities
	Suarez et al., 1996	Distinguish between lower-order (routing etc) and higher-order (mix etc) flexibilities

Table 2.2

Manufacturing Flexibility Terminology

	Machine	**Process**	**Product**	**Routing**	**Volume**	**Expansion**	**Process Sequence**	**Production**
Mandelbaum 1978		Action						State
Buzacott 1982	Machine	Job						
Zelenovic 1982		Adaptation						Application
Gerwin 1982		Design	Parts	Routing	Volume			Mix
Slack 1983		Quality	New Product		Volume			Product mix
Carter 1986	Machine	Mix	Mix change	Routing		Expansion		Production
Frazelle 1986		Design	Parts	Routing	Volume			Mix
Son and Park 1987	Process		Equip		Demand			Product
Barad and Sipper 1988	Machine set-up	Process		Routing	Volume		Operations	
Taymaz 1989		Design	Parts	Routing	Volume			Mix *
Sethi and Sethi 1990	Machine	Process	Product	Routing	Volume	Expansion	Operation	Production
Suarez et al 1996			Mix		Volume			Mix

Table adapted from Gupta and Goyal, 1989.
*(Production flexibility defined as overall system flexibility)

Table 2.3

A Taxonomy of Manufacturing Flexibilities

Level	Mfg. Flexibility Dimensions	Description*	Supporting Literature
Operational Flexibilities (Machine/shop level)	Equipment Flexibility	The ability of a machine to switch among different types of operations without prohibitive effort	Browne et al., 1984; Carter, 1986
	Material Flexibility	The ability of equipment to handle variations in key dimensional input properties	Gerwin, 1987, 1993;
	Routing Flexibility	The ability to vary machine visitation sequences for processing a part	Browne et al., 1984; Gerwin 1987, 1993
	Material Handling Flexibility	The ability of the material handling system to move material effectively through the plant	Sethi and Sethi, 1990; Gupta and Somers, 1992
	Program Flexibility	The ability of equipment to run unattended for long periods of time	Sethi and Sethi, 1990; Gupta and Somers, 1992
Tactical Flexibilities (Plant level)	Mix Flexibility	The ability of a manufacturing system to switch between different products in the product mix	Browne, et al., 1984; Gerwin, 1993; Gupta and Somers, 1996
	Volume Flexibility	The ability of the manufacturing system to vary aggregate production volume economically	Slack, 1983; Browne et al., 1984; Sethi and Sethi, 1990
	Expansion Flexibility	The ability to expand capacity without prohibitive effort	Browne et al., 1984; Gupta and Somers, 1992
	Modification Flexibility	The ability of the manufacturing process to customize products through minor design modifications	Gerwin, 1983, 1993

Table 2.3 (contd.)

Strategic Flexibilities (Firm Level)	New Product Flexibility	The ability of the manufacturing system to introduce and manufacture new parts and products	Browne, et al., 1984; Gerwin, 1987, 1993; Taymaz, 1989; Gupta and Somers, 1996
	Market Flexibility	The ability of the manufacturing system to adapt to or influence market changes	Sethi and Sethi, 1990; Gerwin, 1993

*Each flexibility incorporates the dimensions of range, time and cost in its definition. Flexibilities can be potential or realized.

Table 2.4

A Taxonomy of Key Flexibility Measurement Literature

	Qualitative	**Quantitative**
Economic Consequences		Buzacott 1982 Son & Park, 1987
Performance Criteria	Zelenovic 1982 Gerwin 1982, 1985, 1989 Frazelle 1986 Carter 1986 Azzone and Bertele 1987 Barad and Sipper 1988	Chatterjee et al. 1984 Gustavsson 1984 Falkner 1986 Primrose and Leonard 1986 Taymaz, 1989
Multi-Dimensional Approach	Slack 1983 Gupta and Buzacott 1987 Yilmaz and Davis, 1987 Dixon, 1992 Gupta and Somers, 1992, 1996 Suarez et al. 1996	
Petri-Nets		Barad and Sipper 1988 Venkatesh and Mohammad, 1993
Information Theory		Kumar 1987 Yao 1986 Gupta et al. 1989
Decision Theory	Mandelbaum and Buzacott 1986	Hutchinson and Yao 1989 Mandelbaum and Brill 1989

Adapted from Gupta and Goyal, 1989.

Table 2.5
Selected Flexibility Measures

Flexibility Dimension	**Author(s)/Citations**	**Measure(s)**
Operational Flexibilities		
Equipment Flexibility The ability of a machine to switch among different types of operations without prohibitive effort	Buzacott, 1982	Ratio of expected production rate with disturbances to the expected production rate without disturbances
	Carter, 1986	Range of tasks, changeover cost and time for individual machines.
	Falkner, 1986	Ratio of set-up time to processing time
	Son and Park, 1987	Ratio of output to idle cost of equipment
	Sethi and Sethi, 1990	Investment's residual value for a new model / original investment in the machine
	Gupta and Somers 1996	# of different operations a typical machine can perform without prohibitive changeover costs or times
Routing Flexibility The ability to vary machine visitation sequences for processing a part	Browne et al., 1984, Gupta and Somers, 1992	% decline in throughput because of machine breakdowns
	Carter, 1986	Ratio of existing # to possible # of links between machines in the given system
	Son and Park, 1987	Ratio of output to waiting cost of parts processed
	Chung & Chen, 1989	Average # of possible ways part can be processed in the given system
	Gupta and Goyal, 1989	Ratio of expected production to production of fully operating system
	Gupta and Somers, 1992	Cost of production lost as a result of expediting a pre-emptive order
Material Flexibility The ability of equipment to handle variations in key dimensional and metallurgical properties of inputs	Gerwin, 1987; Gupta and Somers, 1992	The extent of variations in key dimensional and metallurgical properties that a typical machine can handle

Table 2.5 (contd.)

Flexibility Dimension	**Author(s)/Citations**	**Measure(s)**
Material Handling Flexibility The ability of the material handling system to move material effectively through the plant	Stecke and Browne, 1985	Ranking of material handling systems in order of flexibility and their use
	Chatterjee, 1987; Gupta and Somers, 1992	Ratio of # of material handling paths supported to the maximum # of possible paths in the system
	Gupta and Somers, 1992	The ability of material-handling systems to move different parts for proper positioning and processing throughout the manufacturing facility The ability of the material handling system to link every machine to every other machine
Program Flexibility The ability of equipment to run unattended for long periods of time	Sethi and Sethi, 1990	Expected percentage uptime during the 2nd and 3rd shifts
	Gupta and Somers, 1992	The ability of the manufacturing system to run unattended during the 2nd and 3rd shifts
Tactical Flexibilities		
Mix Flexibility The ability of a manufacturing system to switch between different products in a product mix	Jaikumar, 1986	# of part types produced in FMS
	Son and Park, 1987	Ratio of output to set-up cost
	Gupta and Somers, 1992	Changeover cost
	Dixon, 1992	Average # of different product characteristics made simultaneously, made monthly, monthly average cost of changeovers between different product characteristics and average changeover time between characteristics
	Ettlie and Hahn, 1994	Number of parts, Number of part families and average changeover time
	Suarez et al., 1996	Use principal component analysis to combine physical (size & number), technological (product density) and market (number of final application product categories) factors

Table 2.5 (contd.)

Flexibility Dimension	**Author(s)/Citations**	**Measure(s)**
Volume Flexibility The ability of the manufacturing system to vary aggregate production volume economically	Browne et al., 1984	Minimum aggregate production volume at which plant runs profitably
	Falkner, 1986	Stability of manufacturing costs over widely varying volumes
	Ancelin, 1986 (cited Sethi and Sethi, 1990)	Total available time less (required time + maintenance time) / required time
	Gerwin, 1987	Ratio of average volume fluctuations to production capacity limit
	Fiegenbaum and Karnani, 1991	Standard deviation of unit sales
	Gupta and Somers, 1992	Range of volumes over which firm can run profitably
	Suarez et al., 1996	Log (Production volume fluctuation / cost/unit * fraction of defectives) Volume fluctuation = ratio of highest monthly production to lowest monthly production in each year for given period
Expansion Flexibility The ability to expand capacity without prohibitive effort	Browne et al., 1984	The maximum potential for expansion of a system, easily and modularly
	Gupta and Somers, 1996	Time and cost for doubling the output of the system Ease of expanding capacity and capability of the system when needed Time required to add a unit of capacity

Table 2.5 (contd.)

Flexibility Dimension	**Author(s)/Citations**	**Measure(s)**
Modification Flexibility The ability of the manufacturing process to customize products through minor design modifications	Dixon, 1992	Variety of modified products made Diff. in modified product characteristics (diff. in weight, raw material, colors) # of modified products with new processing Cost of intro.a modified product to full produc. # of modification prototype/samples reqd. Time required to make and ship modified product
	Gerwin, 1993	The variety of minor design changes the manufacturing system is capable of making in a product. Time required to make such modifications
Strategic Flexibilities		
New Product Flexibility The ability of the manufacturing system to introduce and manufacture new parts and products	Browne et al., 1984; Gupta and Somers, 1996	The universe of parts types the system can produce without adding major capital equipment
	Jaikumar, 1986; Dixon, 1992; Gupta and Somers,1992	Number of new parts introduced per year
	Dixon, 1992	Breakdown of new products in terms of differences in colors, material used How many new products used mainly entirely new parts How many new products used mainly new processes Cost of introducing a new product to full production # of new product prototypes/samples required % of plant management and machine time devoted to making samples Time required to make and ship new product
	Suarez et al., 1996	New product concept design, development and manufacture cycle (total) time
	Gupta and Somers, 1996	Time required to introduce new products

Table 2.5 (contd.)

Flexibility Dimension	**Author(s)/Citations**	**Measure(s)**
Market Flexibility The ability of the manufacturing system to adapt or influence market changes	Sethi and Sethi, 1990	Cost of delay in meeting customer orders Weighted measure of new product, volume and expansion flexibilities

Table 2.6

Key Operating Characteristics of Collaborative Buyer-Supplier Relationships

Authors	Operating Characteristic
Dwyer, Schurr and Oh, 1987 Heide and John, 1988 Hallen, Johnson and Seyed-Mohamed, 1991 Metcalf, Frear and Krishnan, 1992 Mohr and Spekman, 1994 Heide, 1994 Stuart and McCutcheon, 1995 Mayer, Davis and Schoorman, 1995 Ellram and Edis, 1996 Lusch and Brown, 1996	Co-dependence
Heide and John, 1990 Stuart, 1993 Heide and Miner, 1992 Gulati, 1995 Ellram and Edis, 1996	Long-term perspective
Dwyer, Schurr and Oh, 1987 Smitka, 1991 Sako 1992 Ring and Van de Van, 1992, 1994 Kamath and Liker, 1994 Nishiguchi, 1994 Morgan and Hunt, 1994 Zaheer and Venkatraman, 1995 Gulati, 1995 Aulakh, Kotabe and Sahay, 1996	Trust
Landeros and Monczka, 1990 Gulati and Nohria, 1992 Dyer, 1994 Nishiguchi, 1994 Gentry and Vellenga, 1996 Ellram and Edis, 1996	Asset-specific Commitments Top Management Commitment
Ford, 1983 Stuart, 1993 Mohr and Spekman, 1994 Macbeth, 1994 Stuart and McCutheon, 1995 Gentry and Vellenga, 1996 Celly and Frazier, 1996 Mohr, Fischer and Nevin, 1996	Coordination, Communication & Information Sharing
Dwyer, Schurr and Oh, 1987 Mohr and Spekman, 1994 Kamath and Liker, 1994 Stuart and McCutcheon, 1995	Joint Problem Solving

Table 2.7

The Evolution of Advanced Manufacturing Technology

Time Period	Manufacturing Technology
1940's	Non-numerically controlled machines, e.g. lathes, grinders, milling machines etc.
1950 & 60's	Numerically controlled machine tools
1970's	Development of CNC machines
1980's - 90's	Computer integrated manufacturing systems
Mid-90's	Development of integrated supply chain CAD/CAE/CAM/CAT systems

Adapted from Das and Khumawala, 1989.

Table 5.1
Univariate and Multivariate Normality Statistics for the Final 1st Order Strategic Sourcing CFA

Variable	Skewness	Kurtosis
V1	-0.7288	-0.4349
V2	-0.6608	0.8508
V3	-0.7037	0.1932
V4	-0.5589	0.1733
V5	-0.5890	-0.3571
V6	-0.1884	-0.6379
V7	-0.3561	-0.8320
V8	0.2006	-1.0020
V9	-0.4473	-0.4161
V10	-0.7553	0.0527
V11	-0.4342	-0.4403
V12	-0.0826	-0.5857
V13	-0.6048	-0.0352
V14	-0.4193	-0.6454
V15	-0.1835	-0.7717
V16	-0.1516	-1.0855
V17	0.1314	-0.7891
V18	0.0559	-0.7891
V19	0.1701	-0.9656
V20	0.1509	-0.7182
V21	0.6223	-0.4730

Mardia's Coefficient:	67.68
Normalized Estimate:	18.51

Table 5.2
Goodness-of-Fit Indices for the Initial 1st Order Strategic Sourcing CFA

n	289
χ^2	245
Degrees of Freedom	185
p-Value	0.002
CFI	0.977
NNFI	0.971
NFI	0.914

Table 5.3
Fit Indices for the Final 1st Order Strategic Sourcing CFA

n	289
χ^2	210.44
Degrees of Freedom	163
p-Value	0.007
χ^2 / d.f.	1.29
CFI	0.982
NNFI	0.977
NFI	0.926

Standardized Equations	Standard Errors	t-Values
Buyer-Supplier Relationship Development (F1) (α: 0.836)		
V1= 0.566*F1 + 0.824 e1	0.111	7.916
V2= 0.636 F1 + 0.772 e2	(Path fixed at 1.00 for latent factor scale determination)	
V3= 0.762*F1 + 0.647 e3	0.131	11.321
V4= 0.812*F1 + 0.583 e4	0.142	10.023
V5= 0.627*F1 + 0.779 e5	0.165	8.547
V6= 0.580*F1 + 0.815 e6	0.161	8.034
Parts Bundling (F2) (α: 0.751)		
V7= 0.885 F2 + 0.465 e7		
V8= 0.687*F2 + 0.727 e8	0.793	5.928
Supplier Capability Auditing (F3) (α: 0.863)		
V9= 0.514 F2 + 0.858 e9		
V10= 0.496*F2 + 0.868 e10	0.123	7.911
V11= 0.405*F2 + 0.914 e11	0.116	6.642
V12= 0.494*F2 + 0.869 e12	0.128	7.072
V13= 0.523*F2 + 0.852 e13	0.130	7.545
V14= 0.878*F2 + 0.478 e14	0.271	6.693
V15= 0.841*F2 + 0.540 e15	0.261	6.614

Table 5.3 (Contd.)

Purchasing Integration (F4)
(α: 0.829)

V16=	0.607 F4 + 0.795 e16		
V17=	0.742*F4 + 0.670 e17	0.096	11.093
V18=	0.546*F4 + 0.838 e18	0.100	6.928
V19=	0.696*F4 + 0.718 e19	0.130	8.248
V20=	0.730*F3 + 0.683 e20	0.120	8.522
V21=	0.595*F3 + 0.804 e21	0.111	7.510

Table 5.4
LM Test Results for the Final 1st Order Strategic Sourcing CFA

Cumulative Multivariate Statistics

Step	Parameter	Chi-Square	D.F.	Probability
1	e20,e4	9.115	1	0.003
2	e11,e5	17.009 2	2	0.000
3	v6,F4	23.739 3	3	0.000
4	v9,F4	30.010 4	4	0.000
5	v16,F1	35.785 5	5	0.000
6	v16,F3	42.659 6	6	0.000
7	e12,e8	48.280 7	7	0.000
8	e18,e11	53.720 8	8	0.000
9	v2,F2	58.521 9	9	0.000

Table 5.5
Discriminant Validity Results for the Final 1st Order Strategic Sourcing CFA

Factor	Avg.Variance Extracted	Sqd. Correlations of Factor with other Factors
Buyer-Supplier Relationship Development (F1)	0.449 (>)	F1---F2: 0.130 (S.E.: 0.044)
		F1---F3: 0.221 (S.E.: 0.029)
		F1---F4: 0.217 (S.E.: 0.037)
Parts Bundling (F2)	0.628 (>)	F2---F1: 0.130
		F2---F3: 0.072 (S.E.: 0.048)
		F2---F4: 0.157 (S.E.: 0.071)
Supplier Capability (F3) Auditing	0.380 (>)	F3---F1: 0.221
		F3---F2: 0.072
		F3---F4: 0.340 (S.E.: 0.053)
Purchasing Integration (F4)	0.432 (>)	F4---F1: 0.217
		F4---F2: 0.157
		F4---F3: 0.340

All inter-factor correlations were significant ($p<.05$), positive and significantly different from 1.00

Table 5.6
Goodness-of-Fit Indices for the 2nd Order Strategic Sourcing CFA

n	289
χ^2	215.14
Degrees of Freedom	166
p-Value	0.006
CFI	0.981
NNFI	0.976
NFI	0.924

		Standardized Equations	Standard Errors	t-Values
Buyer-Supplier Relationship Development (F1)				
	V1=	0.570*F1 + 0.821 e1	0.105	8.398
	V2=	0.639 F1 + 0.769 e2	(Path fixed at 1.00 for latent factor scale determination)	
	V3=	0.763*F1 + 0.646 e3	0.122	12.140
	V4=	0.810*F1 + 0.587 e4	0.129	10.952
	V5=	0.626*F1 + 0.780 e5	0.154	9.083
	V6=	0.582*F1 + 0.813 e6	0.152	8.506
Parts Bundling (F2)				
	V7=	0.865 F2 + 0.504 e7		
	V8=	0.703*F2 + 0.711 e8	0.142	5.834
Supplier Capability Auditing (F3)				
	V9=	0.523 F2 + 0.852 e9		
	V10=	0.510*F2 + 0.860 e10	0.116	8.453
	V11=	0.416*F2 + 0.909 e11	0.113	6.924
	V12=	0.507*F2 + 0.862 e12	0.119	7.682
	V13=	0.536*F2 + 0.844 e13	0.119	8.229
	V14=	0.859*F2 + 0.512 e14	0.232	7.519
	V15=	0.826*F2 + 0.564 e15	0.225	7.403

Table 5.6 (contd.)

	Standardized Equations	Standard Errors	t-Values
Purchasing Integration (F4)			
	V16= 0.613 F4 + 0.790 e16		
	V17= 0.740*F4 + 0.673 e17	0.094	11.164
	V18= 0.543*F4 + 0.840 e18	0.098	6.947
	V19= 0.695*F4 + 0.719 e19	0.128	8.288
	V20= 0.733*F3 + 0.680 e20	0.118	8.595
	V21= 0.595*F3 + 0.804 e21	0.109	7.562
First Order Factor Loadings on SS Construct (F5)			
	F1= 0.638*F5 + 0.770 D1	0.131	4.885
	F2= 0.479 F5 + 0.878 D2		
	F3= 0.724*F5 + 0.690 D3	0.181	4.502
	F4= 0.790*F5 + 0.614 D4	0.249	4.976

Table 5.7
Goodness-of-Fit Indices for Multi-Group Stacked Strategic Sourcing CFA Model

n	200 (first wave); 122 (second wave)
χ^2	441.82
Degrees of Freedom	352
p-Value	0.001
CFI	0.969
NNFI	0.963
NFI	0.867
No significant LM test result	

Table 5.8
Univariate and Multivariate Normality Statistics for the Final 1st Order AMT CFA

Univariate Statistics

Variable	V7	V12	V13	V14	V5
Skewness	1.1017	0.1557	-0.0683	0.4326	-0.7868
Kurtosis	-0.2511	-1.6193	-1.5297	-1.4748	-0.7193

Variable	V6	V8	V9	V10	V11
Skewness	-0.9937	0.5442	0.5178	0.6644	0.1000
Kurtosis	-0.1027	-1.2090	-1.3137	-1.1512	-1.4581

Variable	V1	V2	V3	V4
Skewness	-0.3620	0.1390	0.5843	0.5493
Kurtosis	-0.8503	-1.4581	-1.0359	-1.1100

Multivariate Kurtosis

Mardia's Coefficient (G2,P) = 22.4239
Normalized Estimate = 9.3416

Table 5.9
Goodness-of-Fit Indices for the Initial 1st Order AMT CFA

n	311
χ^2	159.11
Degrees of Freedom	96
p-Value	0.001
CFI	0.965
NNFI	0.956
NFI	0.917

Table 5.10
Fit Indices for the Final 1st Order AMT CFA

n	311
χ^2	89.15
Degrees of Freedom	68
p-Value	0.043
χ^2 / d.f.	1.31
CFI	0.987
NNFI	0.982
NFI	0.987

	Standardized Equations	Standard Errors	t-Values
HRM Practices (F1) (α: 0.821)			
	V1= 0.666 F1 + .746 E1	(Path fixed at 1.00)	
	V2= 0.825*F1 + .565 E2	0.141	10.631
	V3= 0.674*F1 + .738 E3	0.117	9.640
	V4= 0.642*F1 + .766 E4	0.116	9.249
Design Practices (F2) (α: 0.828)			
	V15= 0.882 F2 + .471 E16		
	V6= 0.821*F2 + .570 E6	0.075	11.265
Infrastructural Support Systems (F3) (α: 0.673)			
	V7= 0.568 F3 + .823 E7		
	V8= 0.596*F3 + .803 E8	0.145	8.016
	V9= 0.804*F3 + .595 E9	0.173	9.054
	V10= 0.636*F3 + .772 E10	0.162	7.780
	V11= 0.558*F3 + .830 E11	0.143	7.659
Manufacturing Systems (F4) (α: 0.767)			
	V12= 0.513 F4 + .859 E12		
	V13= 0.762*F4 + .647 E13	0.202	7.102
	V14= 0.721*F4 + .693 E14	0.148	9.339

Table 5.11
LM Test Results for the Final 1st Order AMT CFA

Cumulative Multivariate Statistics

Step	Parameter	Chi-Square	D.F.	Probability
1	v11,F1	11.062 1	1	0.001
2	v1,F2	20.972 2	2	0.000
3	e4,e6	29.064 3	3	0.000
4	e9,e12	34.417 4	4	0.000
5	v13,F1	39.903 5	5	0.000
6	v16,F3	42.659 6	6	0.000
7	v11,F4	44.286 7	7	0.000
8	e2,e10	48.816 8	8	0.000
9	v2,F2	58.521 9	9	0.000

Table 5.12
Discriminant Validity Results for the Final 1st Order AMT CFA

Factor	Avg. Variance Extracted	Sqd. Corr. of Factor with other Factors	
HRM Practices(F1)			
	0.498 (>)	F1---F2: 0.179	(Std. Error: 0.085)
		F1---F3: 0.385	(Std. Error: 0.069)
		F1---F4: 0.208	(Std. Error: 0.070)
Design Practices(F2)			
	0.726(>)	F2---F1: 0.179	
		F2---F3: 0.163	(Std. Error: 0.081)
		F2---F4: 0.372	(Std. Error: 0.114)
Infrastructural Support Systems(F3)			
	0.430 (>)	F3---F1: 0.385	
		F3---F2: 0.163	
		F3---F4: 0.382	(Std. Error: 0.079)
Purchasing Integration (F4)			
	0.432 (>)	F4---F1: 0.208	
		F4---F2: 0.372	
		F4---F3: 0.382	

All inter-factor correlations were significant, positive, and significantly different from 1.00

Table 5.13
Goodness-of-Fit Indices for the 2nd Order AMT CFA

n	311
χ^2	115.57
Degrees of Freedom	70
p-Value	0.001
CFI	0.971
NNFI	0.963
NFI	0.931

	Standardized Equations	Standard Errors	t-Values
HRM Practices (F1)			
	V1= 0.749 F1 + .663 E1 (Path fixed at 1.00)		
	V2= 0.802*F1 + .598 E2	0.141	10.631
	V3= 0.714*F1 + .700 E3	0.117	9.640
	V4= 0.649*F1 + .761 E4	0.116	9.249
Design Practices (F2)			
	V15= 0.842 F2 + .539 E16		
	V6= 0.830*F2 + .557 E6	0.075	11.265
Infrastructural Support Systems (F3)			
	V7= 0.567 F3 + .824 E7		
	V8= 0.591*F3 + .807 E8	0.145	8.016
	V9= 0.816*F3 + .578 E9	0.173	9.054
	V10= 0.658*F3 + .753 E10	0.162	7.780
	V11= 0.540*F3 + .841 E11	0.143	7.659
Manufacturing Systems (F4)			
	V12= 0.506 F4 + .863 E12		
	V13= 0.778*F4 + .628 E13	0.202	7.102
	V14= 0.706*F4 + .708 E14	0.148	9.339
First Order Factor Loadings on AMT Construct			
	F1= 0.605*F5 + .796 D1	0.075	8.076
	F2= 0.731*F5 + .683 D2	0.084	10.086
	F3= 0.716*F5 + .698 D3	0.073	7.666
	F4= 0.829*F5 + .559 D4	0.098	7.038

Table 5.14
Goodness-of-Fit Indices for Multi-Group Stacked AMT CFA Model

n	200 (first wave); 122 (second wave)
χ^2	174.82
Degrees of Freedom	152
p-Value	0.099
CFI	0.986
NNFI	0.983
NFI	0.901
No significant LM test result	

Table 5.15
Univariate and Multivariate Normality Statistics for the Final Manufacturing Flexibility CFA

Univariate Statistics

Variable	V6	V7	V1	V2	V8
Skewness	-0.255	-0.240	-0.357	-0.227	0.463
Kurtosis	-0.478	-0.392	-0.510	-0.499	0.549

Variable	V9	V3	V4	V5
Skewness	0.229	-0.280	-0.363	-0.261
Kurtosis	-0.597	-0.469	-0.066	-0.404

Multivariate Kurtosis

Mardia's Coefficient (G2,P) = 11.7879
Normalized Estimate = 7.4341

Table 5.16
Goodness-of-Fit Indices for the Initial Manufacturing Flexibility CFA

n	317
χ^2	194.34
Degrees of Freedom	24
p-Value	0.001
CFI	0.834
NNFI	0.750
NFI	0.817

Table 5.17
Fit Indices for the Final Manufacturing Flexibility CFA

n	315
χ^2	71.46
Degrees of Freedom	36
p-Value	0.001
χ^2 / d.f.	1.98
CFI	0.953
NNFI	0.922
NFI	0.934

	Standardized Equations			Standard Errors	t-Values
Modification Flexibility (F1)					
(α: 0.830)					
	V1=	0.556 F1	+ .831 E1	(Path fixed at 1.00)	
	V2=	0.672*F1	+ .740 E2	0.094	12.085
	V3=	0.719*F1	+ .695 E3	0.145	8.489
	V4=	0.797*F1	+ .604 E4	0.142	8.657
	V5=	0.674*F1	+ .739 E5	0.139	7.863
Mix Flexibility (F2)					
(α: 0.715)					
	V6 =	0.769 F2	+ .640 E6		
	V7 =	0.735*F2	+ .678 E7	0.124	7.446
New Product Flexibility (F3)					
(α: 0.564)					
	V8 =	0.504 F3	+ .864 E8		
	V9 =	0.790*F3	+ .613 E9	0.336	4.663

Table 5.18
LM Test Results for the Final Manufacturing Flexibility CFA

Cumulative Multivariate Statistics

Step	Parameter	Chi-Square	D.F.	Probability
1	e4,e2	19.157 1	1	0.000
2	e4,e8	32.012 2	2	0.000
3	e4,e3	37.436 3	3	0.000

Table 5.19
Discriminant Validity Results for the Final Manufacturing Flexibility CFA

Factor	Avg. Variance Extracted	Sqd. Corr. of Factor with other Factors	
Modification Flexibility (F1)			
	0.473 (>)	F1---F2: 0.309	(Std. Error: 0.045)
		F1---F3: 0.271	(Std. Error: 0.040)
Mix Flexibility (F2)			
	0.565 (>)	F2---F1: 0.309	
		F2---F3: 0.172	(Std. Error: 0.046)
New Product Flexibility (F3)			
	0.380 (>)	F3---F1: 0.271	
		F3---F2: 0.172	

All inter-factor correlations were significant, positive, and significantly different from 1.00

Table 5.20
Goodness-of-Fit Indices for Multi-Group Stacked Manufacturing Flexibility CFA Model

n	200 (first wave); 122 (second wave)
χ^2	108.51
Degrees of Freedom	52
p-Value	0.001
CFI	0.944
NNFI	0.923
NFI	0.900

No significant LM test results

Table 5.21
Measures Dropped vis-à-vis Measures Retained

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Strategic Sourcing				
	Parts Bundling (supply-base optimization)	*Average number of suppliers per part*		X
		Is number of suppliers appropriate/low/high		X
		Tiering of supply base into primary and secondary suppliers		X
		Extent of volume consolidation	X	
		Extent of parts bundling	X	
	Buyer-Supplier Relationship Development	*Nature of contractual relationship with supplier short-term/long-term/ partnership)*	X	
		Trust building	X	
		Top management commitment to relationship	X	
		Joint problem-solving	X	
		Joint investments in specialized machinery/materials /assets		X
		Financial assistance to supplier		X
		Technological assistance to Supplier		X
		Quality training to supplier		X
		Use of buyer-supplier councils similar mechanisms		X

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Strategic Sourcing (contd.)	Buyer-Supplier Relationship Development	*Timely production information sharing with supplier*	X	
		Timely production information sharing by supplier	X	
		Direct communication between production schedulers at buyer and supplier plants		X
		Cost information sharing with supplier		X
		Cost information sharing by supplier		X
		Use of total cost concept		X
		Use of formal supplier evaluation and feedback procedures		X
		Granting supplier performance rewards and awards		X
		Buyer concern for supplier earning a fair profit		X
		Suppliers concern for buyer earning a fair profit		X

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Strategic Sourcing (contd.)	Supplier Capability Auditing	*Quality performance*		X
		Cost performance		X
		Ability for complex manufacturing		X
		Ability to modify product to meet customer needs	X	
		Responsiveness to schedule delivery changes	X	
		Ability to accept late 'mix' changes in orders	X	
		Product modularization	X	
		Responsiveness to schedule volume changes	X	
		Assistance in buyer product/process design	X	
		Ability to design and supply new products	X	
	Purchasing Integration	*Extent to which purchasing and manufacturing jointly establish goals*		X
		Purchasing regularly attends strategy meetings	X	
		Purchasing recommends and impacts changes in end products and inputs	X	
		Participates in cross-functional teams		X

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
	Purchasing Integration	*Proportion of purchasing personnel who spend time in routine tasks (expediting, order generation) (reverse coded - rc)*		X
		Proportion of purchasing personnel who spend time in supplier development and certification		X
		Proportion of purchasing personnel who spend time in market and price/cost analysis	X	
		Purchasing participation in product design	X	
		Purchasing participation in process design	X	
		Purchasing participation in developing sales bids		X
		Purchasing is rewarded on strategic contributions (new products/technologies) to the company	X	

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Advanced Mfg. Tech.				
	HRM Practices	*The use of cross-trained employees*	X	
		The use of operator teams in manufacturing	X	
		The use of decentralized decision-making for production scheduling	X	
		The use of decentralized decision-making for operator task distribution	X	
	Design Practices	*The use of computer aided design*	X	
		The use of computer aided engineering	X	
		The use of computer-aided testing		X
		Modularization in design		X
	Infrastruct. Support Systems	*The use of automated material handling systems*	X	
		The use of kanban/similar manufacturing practices	X	
		The use of in-plant electronic data interchange systems	X	
		The use of real-time process controls	X	

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
	Infrastruct. Support Systems	*The use of bar-coding*	X	
		The use of set-up time reduction techniques	X	
		The use of preventive maintenance	X	
		JIT supplier deliveries	X	
	Manufacturing Systems	*The use of flexible integrated manufacturing systems*	X	
		The use of CNC technology	X	
		The use of computer aided manufacturing	X	
		The use of robotics		X
		The use of cellular manufacturing and group technology		X

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Mfg. Flex.				
Modification Flex.		*The time required to accommodate minor design changes (rc)*	X	
		The cost required to accommodate minor design changes (rc)	X	
		The extent of new/extra parts required in making minor design changes (rc)	X	
		The extent of new/extra operations involved in making minor design changes (rc)	X	
		The complexity of new/extra operations involved in making minor design changes (rc)		X
Volume Flex.		*The range of aggregate prod. volume over which the firm can run profitably*		X
		The time required to increase prod. volume by 20%		X
		The ease (machine /material avail., willingness to do overtime)of inc. thevolume capacity ofthe system, when needed,without adding new equip.		X
		The stability of unit manufacturing cost over a 20% fluctuation in production volume		X

Table 5.21 (contd.)

Construct	First-order Factors	A-priori Item Measures	Measures Retained	Measures Dropped
Mix Flex.		*The number of products in the product mix*		X
		The time required to change between different products in the product mix	X	
		The cost of changing between different products in the product mix	X	
		The extent of parts commonality in the product mix		X
New Product Flex.		*The time required to introduce (design, prototyping, test and manufacture) new products*	X	
		The cost involved in introducing new products (overtime, production interruptions, lost orders)	X	
		The number of new products introduced in a year		X
		The number of new processes used in new products manufacture		X
		The complexity of new processes used in new product design, prototyping and manufacture		X

Table 5.22
Summary Results of Path Model Analysis

Mfg. Perf. Variable				**Significant Paths (p<.05) and Associated Estimates**					
	CFI	**NNFI**	**NFI**	**Antecedents to Mfg. Flex.**		**Relationships among Mfg. Flex.**		**Antecedents to Mfg Performance**	
				From	**To**	**From**	**To**	**From**	**To**
Mfg Cost Reduct. Perf.	0.978	0.946	0.956	Strat. Sour.	Mix Flex .177	Mix Flex	Mod Flex .432	Mix Flex	Cost Reduction Perf. .111
						Mod Flex	New Prod. Flex .341	Adv. Mfg. Tech.	Cost Reduction Perf. .359
Quality Perf.	0.987	0.951	0.971	Strat. Sour.	Mix Flex. 177	Mix Flex	Mod Flex .439	Adv. Mfg. Tech.	Qual Perf. .334
				Strat. Sour.	New Prod. Flex .118	Mod Flex	New Prod. Flex .342		
Mfg. Cycle Time Reduct. Perf.	0.981	0.965	0.951	Strat. Sour.	Mix Flex .139	Mix Flex	Mod Flex .432	Mix Flex	Mfg. Cycle Time Perf .099
						Mix Flex	New Prod. Flex .121	Adv. Mfg. Tech.	Mfg. Cycle Time Perf .380
						Mod Flex	New Prod. Flex .336		

Table 5.22 (Contd.)

	CFI	NNFI	NFI	Antecedents to Mfg. Flex. From	To	Relationships among Mfg. Flex. From	To	Antecedents to Mfg Performance From	To
New Product Intro. Time Reduct. Perf.	0.947	0.900	0.919	Strat Sour.	Mix Flex .179	Mix Flex	Mod Flex .439	New Prod. Flex	NPIT Perf. .290
				Strat Sour.	New Prod. Flex .142	Mod Flex	New Prod. Flex .411	Adv. Mfg. Tech.	NPIT Perf. .244
Delivery Perf.	0.964	0.922	0.938	Strat Sour.	Mix Flex .152	Mix Flex	Mod Flex .429	Mix Flex	Dely Perf. .173
				Strat Sour.	New Prod. Flex .107	Mod Flex	New Prod. Flex .375	Adv. Mfg. Tech.	Dely Perf. .298
Customization Responsiveness Perf.	0.948	0.902	0.916	Strat Sour.	Mix Flex .174	Mix Flex	Mod Flex .440	New Prod. Flex	Custom Perf. .134
				Strat Sour.	New Prod. Flex .123	Mod Flex	New Prod. Flex .402	Adv. Mfg. Tech.	Custom Perf .229

TABLE 5.23
Test for Industry Effects Among Key Constructs Using ANOVA

Construct		SS	d.f.	Mean Square	F	Sig.	Bonferroni Test
AMT	Treat.	5.69	4	1.423	1.898	.111	
	Error	218.88	292	.750			
Strategic Sourcing	Treat.	3.12	4	.781	2.235	.065	
	Error	102.02	292	.349			
Mix Flex.	Treat.	14.12	4	3.53	4.691	.001	μSIC35 ≠ μSIC36 $p<.001$
	Error	219.74	292	.753			
Modif. Flex.	Treat.	1.10	4	.275	.508	.730	
	Error	158.44	292	.543			
New Product Flex.	Treat.	9.90	4	2.475	3.274	.012	μSIC34 ≠ μSIC35 $p<.018$
	Error	220.74	292	.756			

TABLE 6.1

	Volume Consol V14_2	Parts Bundling V14_3	Contract Rels'hip V15	Trust Develop V16_1	Top Mgt. Committ V16_2	Joint Problem Solving V16_3
V14_2	1.000					
V14_3	.601**	1.000				
V15	.131*	.177**	1.000			
V16_1	.115*	.104	.359**	1.000		
V16_2	.241**	.162**	.489**	.594**	1.000	
V16_3	.266**	.191**	.432**	.527**	.641**	1.000
V16_9	.248**	.184**	.331**	.384**	.441**	.516**
V16_10	.193**	.216**	.326**	.425**	.418**	.478**
V20_5	.079	.150**	.224**	.166**	.188**	.240**
V20_6	.211**	.252**	.165**	.181**	.201**	.271**
V20_7	.207**	.238**	.129*	.116*	.112*	.166**
V20_8	.146**	.244**	.168**	.032	.039	.082
V20_9	.206**	.192**	.144*	.153**	.194**	.202**
V20_10	.201**	.171**	.303**	.237**	.303**	.359**
V20_11	.154**	.145**	.249**	.213**	.262**	.322**
V21A_2	.229**	.148**	.272**	.248**	.279**	.273**
V21A_3	.293**	.231**	.271**	.244**	.245**	.286**
V21A_7	.144**	.091	.110	.127*	.255**	.136*
V21A_8	.206**	.130*	.223**	.168**	.213**	.202**
V21A_9	.195**	.156**	.265**	.182**	.230**	.284**
V21A_11	.163**	.108	.181**	.193**	.223**	.169**

	Prod.Info. shar.w/Supp V16_9	Prod.Info. shar.by/Supp V16_10	Supp.abil. to modify V20_5	Supp resp. dely.chgs V20_6	Supp resp. mix chgs V20_7	SupModul ability V20_8
V16_9	1.000					
V16_10	.648**	1.000				
V20_5	.185**	.207**	1.000			
V20_6	.273**	.298**	.481**	1.000		
V20_7	.247**	.168**	.411**	.649**	1.000	
V20_8	.125*	.164**	.353**	.423**	.475**	1.000
V20_9	.243**	.236**	.386**	.677**	.607**	.483**
V20_10	.244**	.311**	.452**	.440**	.375**	.386**
V20_11	.240**	.260**	.439**	.430**	.367**	.453**
V21A_2	.245**	.351**	.170**	.202**	.100	.146**
V21A_3	.267**	.360**	.174**	.229**	.133*	.255**
V21A_7	.165**	.202**	.186**	.222**	.098	.220**
V21A_8	.200**	.206**	.077	.152**	.131*	.178**
V21A_9	.227**	.211**	.069	.190**	.137*	.228**
V21A_11	.124*	.212**	.125*	.157**	.131*	.172**

TABLE 6.1 (contd.)

	Supp resp. vol.chgs V20_9	ESI in design V20_10	Supp Abil. for NPD V20_11	Pur.part. strategy V21A_2	Pur.impact prod.chgs V21A_3	Purch mkt.anal V21A_7
V20_9	1.000					
V20_10	.452**	1.000				
V20_11	.458**	.745**	1.000			
V21A_2	.204**	.260**	.190**	1.000		
V21A_3	.212**	.405**	.336**	.622**	1.000	
V21A_7	.226**	.220**	.284**	.295**	.299**	1.000
V21A_8	.204**	.312**	.281**	.379**	.510**	.394**
V21A_9	.212**	.336**	.292**	.410**	.513**	.366**
V21A_11	.203**	.274**	.263**	.348**	.399**	.406**

	Pur part. In NPD V21A_8	Pur part. in process Design V21A_9	Pur. m'sured & rewarded on strat. metrics V21A_11
V21A_8	1.000		
V21A_9	.787**	1.000	
V21A_11	.536**	.462**	1.000

* - Signif. LE .05   ** - Signif. LE .01   (2-tailed)

Table 6.2
Correlations among Strategic Sourcing Factors

	Buyer-Supplier Relationship Development	Parts Bundling	Supplier Capability Auditing	Purchasing Integration
Buyer-Supplier Relationship Development	1.000			
Parts Bundling	0.360	1.000		
Supplier Capability Auditing	0.470	0.268	1.000	
Purchasing Integration	0.466	0.396	0.583	1.000

All correlations are significant ($p<0.05$) and significantly different from 1.00

APPENDIX B

APPENDIX B

MEASUREMENT INSTRUMENT

THE CONTRIBUTIONS OF STRATEGIC SOURCING TO MANUFACTURING FLEXIBILITIES & PERFORMANCE

A SURVEY

MICHIGAN STATE UNIVERSITY

FUNDED BY
THE NATIONAL ASSOCIATION OF PURCHASING MANAGEMENT &
THE CENTER FOR INTERNATIONAL BUSINESS EDUCATION AND RESEARCH AT
MICHIGAN STATE UNIVERSITY

MICHIGAN STATE UNIVERSITY
DEPARTMENT OF MARKETING AND SUPPLY CHAIN MANAGEMENT
THE ELI BROAD GRADUATE SCHOOL OF MANAGEMENT
N370 NORTH BUSINESS COMPLEX
EAST LANSING
MICHIGAN 48824-1122, U.S.A.
FAX: 517-432-1112
PHONE: 517-353-6381; ext. 275

GUIDELINES

FOR ALL QUESTIONS, PLEASE REPLY AT THE PLANT LEVEL. IF YOUR COMPANY HAS MULTIPLE PLANTS, PLEASE CHOOSE THE PLANT WHICH EXHIBITS THE MOST PRODUCTION SCHEDULE OR PRODUCT DESIGN/ENGINEERING VOLATILITY.

1. Please Mark (*)questions for which you would like to be Benchmarked On In Your Industry. We shall Customize our feedback to you accordingly.

2. We have pre-tested this questionnaire and feel that it should not take more than 20 minutes of your time to complete it. Please answer all questions since incomplete responses create serious problems in data analysis. If questions are not applicable, please provide a brief explanation.

3. The survey is to be answered by purchasing or materials management executives at a senior level in the company. However, please consult with your manufacturing counterpart (if necessary), for specified areas in the questionnaire.

4. Responses will be kept strictly confidential. Research findings shall be presented in aggregate form only.

5. Please complete and return this survey at your earliest convenience in the enclosed return envelope.

6. In case of any questions, please contact PROF. RAM NARASIMHAN or AJAY DAS at(517)-353-6381; Fax(517)-432-1112.

7. Personal Information (Optional): ***(Or please attach your card)***

Name:____________________________Title:

Telephone:______________________Fax #:________________Company name:

Address:

THANK YOU FOR YOUR TIME AND THOUGHTFULNESS. YOUR REPLIES ARE CONFIDENTIAL.
WE SHALL BE GLAD TO SEND YOU THE RESEARCH RESULTS. PLEASE CHECK HERE ( ) IF YOU WISH US TO DO SO.

ABOUT YOUR PLANT, COMPANY AND INDUSTRY.

1. Please describe your plant's **major selling product/product line?** ________________________ 4 digit SIC code (if known)

2. What was the total company and plant(all products) sales(U.S.$-million)last year?

	Company	Plant		Company	Plant
Below $1m	( )	( )	>$50m - 100m	( )	( )
$1m - $10m	( )	( )	>$100m -500m	( )	( )
>$10m - 50m	( )	( )	Above $500m	( )	( )

Overseas sales as a proportion of total sales: Company______%
Plant______%

3. How many people are employed in your plant?

4a. Your company's **primary** strategic focus for your **major product/product line** is on :

( )Being *the* lowest cost seller( ) Product/Service differentiation

( )Using either of the above strategies in a specific market segment

b. **Distribute a total of 100 points among the items** below, to reflect the relative importance of each in your manufacturing strategy:

Quality____ Cost____ Innovation ___
Delivery____ Flexibility____

Total 100

5. How would you **primarily** characterize your **major product/product line (choose one)**?

( )Make to stock ( )Engineer to order
( )Make to order ( )Assemble to order ( ) Other

6. The production process which accounts for the most time in the manufacture of your major **product/product line** is:

( )Job shop ( )Batch ( )Repetitive ( )Continuous process

7. What stage of the product market life cycle is your major **product/product line** in?

( )Growth ( )Maturity ( )Decline

8. What was your company's performance, relative to your primary competitor(s), based on most recent data

	VERY LOW 1	2	3	4	VERY HIGH 5
a) Net profits	( )	( )	( )	( )	( )
b) Unit growth rate in Sales	( )	( )	( )	( )	( )
c) ROA	( )	( )	( )	( )	( )
d) Market share of major product/product line?	( )	( )	( )	( )	( )

9. In your **major** product/product line:

	VERY LOW 1	2	3	4	VERY HIGH 5
The cost of delay in meeting customer orders is	( )	( )	( )	( )	( )
The intensity of competition in the U.S. market is	( )	( )	( )	( )	( )
The intensity of competition in global markets (if any) is	( )	( )	( )	( )	( )
The intensity of competition from overseas manufacturers is	( )	( )	( )	( )	( )
The degree of stability of market volume is	( )	( )	( )	( )	( )
The degree of stability of market design is	( )	( )	( )	( )	( )

10. On what proportion of production orders do changes occur after start of production:

	<10%	10-30%	31-60%	61-80%	>80%
Volume changes	( )	( )	( )	( )	( )
Design changes	( )	( )	( )	( )	( )

ABOUT MANUFACTURING FLEXIBILITY AT YOUR PLANT. <u>Please check here</u> ☐ <u>to confirm IF you have consulted with manufacturing for your responses to this set of questions</u>.

11. (*Product-mix refers to different products within your major product line/family)*

	VERY LOW 1	2	3	4	VERY HIGH 5
The cost (job interruptions, set-ups etc. <u>not</u> cost of manufacturing) of changing between different products in the product mix is	( )	( )	( )	( )	( )
The number of products in the product mix is (relative to industry)	( )	( )	( )	( )	( )
The extent of parts commonality between different products in the product mix is	( )	( )	( )	( )	( )
The time required to change between different products in the product mix is	( )	( )	( )	( )	( )
The time required to accommodate minor design changes is	( )	( )	( )	( )	( )
The cost of accommodating minor design changes is	( )	( )	( )	( )	( )
The extent of new/extra parts required in making minor design changes is	( )	( )	( )	( )	( )
The number of new/extra operations required in making minor design changes is	( )	( )	( )	( )	( )
The complexity of new/extra operations in making minor design changes is	( )	( )	( )	( )	( )
The ease(machine/material availability, willingness to do overtime)of increasing the volume capacity of the system when needed, without adding new equipment, is	( )	( )	( )	( )	( )

Time needed to increase production volume by 20% is	( )	( )	( )	( )	( )
The range of aggregate production volume over which the firm can run profitably i.e., is BEP high/low relative to industry?)is	( )	( )	( )	( )	( )
The stability of unit manufacturing cost over a 20% fluctuation in production volume is	( )	( )	( )	( )	( )
The time required to introduce (design, prototyping, test and manufacture) new* products is	( )	( )	( )	( )	( )
The cost(overtime, production interruptions,delayed or lost orders <u>not</u> cost of new machines/material/regular labor)involved in introducing new* products is	( )	( )	( )	( )	( )
The number of new* products introduced per year (relative to)industry) is	( )	( )	( )	( )	( )
Extent of standard parts used in new* products is	( )	( )	( )	( )	( )
Number of new processes used in new* products manufacturing	( )	( )	( )	( )	( )
The complexity of new processes used in new* product design, prototyping and manufacturing is	( )	( )	( )	( )	( )

**New: New to the plant, not re-packaged or modified product*

ABOUT STRATEGIC SOURCING AT YOUR PLANT - For your responses to this set of questions, please choose from your major product/product line, a high value, critical 'A' type item(s) which is/are subject to frequent engineering or volume changes. ***(Mark N/A for non-applicable/not-in-use issues)***

Supply-base Optimization

12. On average, how many suppliers are there per purchased item for these 'A' type critical items?

( )1 ( )2 ( )3 or more

13. For these 'A' items, the number of suppliers/item you have currently is:

( )Low ( )Appropriate ( )Too Many

14.	VERY LOW 1	2	3	4	VERY HIGH 5
The extent to which such suppliers are tiered into 1st/2nd tier suppliers for these 'A' items, with 1st tier suppliers managing lower tiers is	( )	( )	( )	( )	( )
The extent of volume consolidation for these 'A' items is	( )	( )	( )	( )	( )
The extent of parts bundling for these 'A' items is	( )	( )	( )	( )	( )

Buyer-Supplier Relationship Development - Please answer for the **major supplier** of these 'A' items

15. How would you describe your company's outsourcing relationship with **the major supplier**?

( )Short-term contracts ( )Long term contracts with little investment and information sharing

( )Partnerships - sharing technology, information, resources and gains

16. In your relationships with the **major supplier of these 'A' items;**

	VERY LOW 1	2	3	4	VERY HIGH 5
The degree of mutual trust is	( )	( )	( )	( )	( )
Top management commitment to relationship development is	( )	( )	( )	( )	( )
Joint problem-solving with the supplier is	( )	( )	( )	( )	( )
Joint investments (in specialized machy/ materials/bldgs/trg.)is	( )	( )	( )	( )	( )
Financial assistance to the supplier is	( )	( )	( )	( )	( )
Technological assistance to the supplier is	( )	( )	( )	( )	( )
Training in quality issues to supplier personnel is	( )	( )	( )	( )	( )
Use of buyer-supplier councils /similar mechanisms is	( )	( )	( )	( )	( )
Timely production schedule information sharing with the supplier	( )	( )	( )	( )	( )
Timely production schedule information sharing by the supplier	( )	( )	( )	( )	( )
Direct communications between production schedulers at the buyers and supplier plants is	( )	( )	( )	( )	( )
Cost information sharing with the supplier is	( )	( )	( )	( )	( )
Cost information sharing by the supplier is	( )	( )	( )	( )	( )
The use of 'total costs' (pre-ordering to field failure costs associated with supplier product) to cost supplier products is	( )	( )	( )	( )	( )

The use of formal supplier evaluation and feedback procedures is	( )	( )	( )	( )	( )
Granting supplier performance awards and rewards is	( )	( )	( )	( )	( )
Your concern for the supplier earning a fair profit is	( )	( )	( )	( )	( )
Your supplier's concern for your earning a fair profit is	( )	( )	( )	( )	( )
Initial search costs for locating the supplier were	( )	( )	( )	( )	( )
Supplier info. gathering, monitoring and evaluations costs are	( )	( )	( )	( )	( )
Contracting costs(complexity ,freq. etc.) are	( )	( )	( )	( )	( )
Performance enforcement (if needed) costs are	( )	( )	( )	( )	( )

Buyer-Supplier Relationship Outcomes ***Pl mark 'N/A' for non-applicable/not-in-use items***

17. What percentage of the total manufacturing cost of your major product/product line is outsourced?

_______%

18. For your major **product/product line,** you primarily (most $ expenditure) outsource:
( ) Components ( ) Sub-assemblies ( ) Major Systems
( ) Processes

19. The degree to which you choose to outsource (in preference to possible internal manufacture), relative to your industry is:

VERY LOW VERY HIGH
1-----2-----3-----4-----5
( ) ( ) ( ) ( ) ( )

20. Please indicate the performance of the **major supplier you had chosen** while answering the preceding section on buyer-supplier relationship development, in the following areas:

	VERY LOW 1	2	3	4	VERY HIGH 5
Lower costs (compared to target costs)	( )	( )	( )	( )	( )

Lower costs (compared to probable cost of) internal mfg.is	( )	( )	( )	( )	( )
Better quality of conformance to specifications	( )	( )	( )	( )	( )
Ability for complex manufacturing	( )	( )	( )	( )	( )
Ability to modify product to meet our needs without excessive cost or time penalties	( )	( )	( )	( )	( )
Responsiveness to our schedule delivery changes without excessive cost penalties	( )	( )	( )	( )	( )
Ability to accept late 'mix' changes in orders	( )	( )	( )	( )	( )
Modularization of supplier products (to enable optionality deferral and enable quick response to our design changes)	( )	( )	( )	( )	( )
Responsiveness to our schedule volume changes without excessive cost penalties	( )	( )	( )	( )	( )
Assistance in our product/process design and innovation	( )	( )	( )	( )	( )
Ability to design and supply new products to meet our needs, without excessive time/cost penalties	( )	( )	( )	( )	( )
Making(and bearing risks of) investments specific to buyer's firm	( )	( )	( )	( )	( )

Internal Purchasing Environment ***Pl mark 'N/A' for non-applicable/not-in-use activities***

21-a.
The extent to which Purchasing:

	VERY LOW 1	2	3	4	VERY HIGH 5
And manufacturing jointly establish major goals is	( )	( )	( )	( )	( )

Regularly attends corporate strategy meetings is	( )	( )	( )	( )	( )
Recommends (and impacts) changes in end products and inputs based on supplier market analysis is	( )	( )	( )	( )	( )
Participates in cross-functional teams/integration is	( )	( )	( )	( )	( )
Primarily (proportion of total personnel who spends time in routine actions(expediting, order generation, record keeping)is	( )	( )	( )	( )	( )
Primarily spends time in supplier development and certification	( )	( )	( )	( )	( )
Primarily spends time in market and price/cost analysis	( )	( )	( )	( )	( )
Participates in new product design	( )	( )	( )	( )	( )
Participates in process design and improvements	( )	( )	( )	( )	( )
Participates in developing major sales bids	( )	( )	( )	( )	( )
Is measured/rewarded on strategic contributions to the company (new products /technology etc. vs. cost & efficiency metrics <u>alone</u>)	( )	( )	( )	( )	( )

21-b. The average annual \$ purchases per purchasing employee (mgt, buyers, lawyers, support staff) is ('000):

<\$50	\$50-\$100	\$100-\$250	\$250-\$500	\$500-\$1000	>\$1mill
( )	( )	( )	( )	( )	( )

ABOUT ADVANCED MANUFACTURING TECHNOLOGY APPLICATIONS AT YOUR PLANT. Please check here [ ] to confirm IF you have consulted with manufacturing for your responses to this set of questions.

22. Your plant's **use** of the following for your **major product/product line** has been(***Pl mark 'N/A' for non-applicable/not-in-use activities)***:

	# Years in Use			Extent of Actual Use				
				VERY LOW				VERY HIGH
	1	2	3&>	1	2	3	4	5
Automated Material Handling Systems	( )	( )	( )	( )	( )	( )	( )	( )
Robotics	( )	( )	( )	( )	( )	( )	( )	( )
CNC Technology	( )	( )	( )	( )	( )	( )	( )	( )
Computer aided manufacturing	( )	( )	( )	( )	( )	( )	( )	( )
Flexible Integrated Manufacturing to the(Computer integrated CNC machine-material handling-CAD/ CAM systems)	( )	( )	( )	( )	( )	( )	( )	( )
Computer aided engineering	( )	( )	( )	( )	( )	( )	( )	( )
Computer aided design	( )	( )	( )	( )	( )	( )	( )	( )
Computer aided testing	( )	( )	( )	( )	( )	( )	( )	( )
Modularization in design	( )	( )	( )	( )	( )	( )	( )	( )
Cellular Manufacturing	( )	( )	( )	( )	( )	( )	( )	( )
Group Technology (parts grouping for manufacture based on process /specs. similarity)	( )	( )	( )	( )	( )	( )	( )	( )

Bar coding/ automatic identification Systems	( )	( )	( )	( )	( )	( )	( )	( )
Real-time process control systems	( )	( )	( )	( )	( )	( )	( )	( )
In-plant electronic data interchange Systems	( )	( )	( )	( )	( )	( )	( )	( )
Kanban/other WIP inventory control systems	( )	( )	( )	( )	( )	( )	( )	( )
Carry safety stock for only unique components in your **major** product-line bills of materials	( )	( )	( )	( )	( )	( )	( )	( )
Set-up time reduction techniques (e.g., SMED)	( )	( )	( )	( )	( )	( )	( )	( )
Preventive maintenance (e.g., TPM)	( )	( )	( )	( )	( )	( )	( )	( )
JIT supplier deliveries	( )	( )	( )	( )	( )	( )	( )	( )
Cross-trained employees	( )	( )	( )	( )	( )	( )	( )	( )
Operator teams in manufacturing	( )	( )	( )	( )	( )	( )	( )	( )
Decentralized decision-making/ (operator teams individuals)for (micro)production scheduling	( )	( )	( )	( )	( )	( )	( )	( )
Decentralized decision-making for choosing or distributing operator tasks for the day	( )	( )	( )	( )	( )	( )	( )	( )

ABOUT MANUFACTURING PERFORMANCE AT YOUR PLANT. **Please check here ☐ to confirm IF you have consulted with manufacturing for your responses to this set of questions.**

23. The overall extent to which your plant has been able to meet its current performance goals in the following areas is:

	VERY LOW 1	2	3	4	VERY HIGH 5
Manufacturing Cost reduction performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
# Of Defects/product reduction performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
Manufacturing Cycle-Time reduction performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
New Product Introduction Time reduction performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
Increased Delivery Speed performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
Increased Delivery Dependability performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )
Increased Responsiveness to Customization Requests performance:					
Relative to internal goals	( )	( )	( )	( )	( )
Relative to primary competition	( )	( )	( )	( )	( )

ABOUT THE UNION ENVIRONMENT IN YOUR PLANT

24. Do labor unions in your plant have a strong influence on management decisions?

( ) Yes ( ) No

THANK YOU VERY MUCH!

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