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Achieving Mass Customization through Technology Application and Absorptive Capacity – A Customer-Oriented Framework

by

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Submitted as partial fulfillment of the requirements for
the Doctor of Philosophy degree in
Manufacturing Management

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An Abstract of

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The highly uncertain post-industrial environment has presented unprecedented challenges to the U.S. manufacturing firms. To succeed in this turbulent environment characterized by growing global competition, changing customer demand, shortening product life cycle, increasing market diversity, and rapid advances in information technology, the U.S. manufacturers must possess some very distinctive manufacturing system capabilities. Through comprehensive literature review, this research identified three categories of critical capabilities of a successful post-industrial manufacturing firm. They are: 1) Mass customization capability to create superior customer value; 2) The capability to effectively utilize innovative manufacturing technologies and practices, and 3) Absorptive capacity of new knowledge and technologies.

While there have been plenty of anecdotal discussions of these capabilities in the literature, empirical studies to answer the fundamental research question of how manufacturing firms can achieve these capabilities are almost non-existent. The current research is one of the first large-scale empirical efforts to demonstrate that firms can achieve mass customization capability through advanced technology application and innovative manufacturing practices. A comprehensive research framework is proposed and tested using LISREL structural modeling.

A major contribution of this research is the development of measurement instruments for five important constructs, including Absorptive Capacity, Information Systems (IS) Usage, Advanced Manufacturing Technology (AMT) Usage, Modularity-Based Manufacturing Practices and Mass Customization Capability. These instruments should be of great value to both academics and practitioners for further studying and understanding the post-industrial manufacturing system. The instrument development process involved structured interviews and a pilot survey of manufacturing practitioners. The questionnaire was further revised based on the pilot study results. The large-scale survey yielded 303 responses from senior manufacturing managers covering a wide variety of industries and firm sizes. Several statistical methods were then used to assess and validate the instruments, including reliability analysis and exploratory factor analysis.

The empirical results of this research confirmed that superior customer value can be created through mass customization; IS and AMT along with time-based manufacturing practices and modularity-based manufacturing practices are critical antecedents of mass customization capability; absorptive capability ensures the effective usage and implementation of these innovative technologies and practices.

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Last but not least, I wish to dedicate this dissertation to my parents and sister on the other side of the earth. Their love and encouragement always surrounded me and brought me through the most difficult times of my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

One of the most frequently discussed concepts in 1990s is "change". Indeed, all sorts of changes have been witnessed in the business world, such as downsizing, plant closing, reengineering, mergers, acquisitions, and workplace reorganization. The primary reason for the change is that today's chaotic post-industrial environment is fundamentally different from the traditionally more predictable industrial environment. Huber (1984) characterized the nature of post-industrial society as " more and increasing knowledge, more and increasing complexity and more and increasing turbulence". Champlin and Olson (1994) echoed that in today's post-industrial business environment, more than in any preceding era, the only constant is change. They further identified three revolutionary change forces, i.e., global competition, technology advancement, and new managerial practices. The world is changing, and the U.S. manufacturing must meet the challenge.

The challenge comes primarily from the need for a fundamental shift in the managerial thinking of U.S. manufacturing management. The industrial paradigm has dominated U.S. manufacturing for several decades since the origin of Scientific Management (Frederick Taylor, 1911). This industrial mind-set treats the factory as a productivity machine that emphasizes maximum efficiency and stability by buffering the technical core from external changes (Thompson, 1967). Management seeks to maximize profit by reducing cost through process mechanization and high volume mass production. The workers are treated as an annoying and passive factor to be carefully controlled through division of labor and work measurement.

Into the 1980s, the global market emerged and the rate of technological change accelerated. The U.S. manufacturers' inability to respond to these changes caused them to lose market share to global competition (Hayes, Wheelwright and Clark, 1988). In his famous article, "The Taming of Lions", Wickham Skinner stated that U.S. manufacturing is experiencing a severe management problem. A problem caused by an obsolete mind-set rooted in the dominant industrial paradigm that is now becoming dysfunctional in many ways. Doll and Vonderembse (1991) extended Skinner's thoughts and suggested that U.S. manufacturing is entering the post-industrial era characterized by growing global competition, changing customer demand, shorter product life cycles, increased market diversity, and rapid advances in manufacturing and information technology. This shift from industrial to post-industrial paradigm requires corresponding transformation in many aspects of manufacturing systems design and capability development.

1.1. Problem Statement

Recognizing the challenges resulting from the paradigm shift and market change, manufacturers will surely ask the following question: **What are the critical capabilities that we must possess to meet the post-industrial challenges, and how do we achieve those capabilities ?** The current study attempts to answer this question through large-scale empirical investigation to identify the capabilities and their antecedents and consequences.

It has been suggested in the literature (Bowen et al., 1989; Doll and Vonderembse, 1991; Champlin and Olson, 1994; Hayes and Pisano, 1994) that to compete in the highly turbulent post-industrial marketplace, firms must have three distinctive capabilities: 1) The capability to create superior customer value; 2) The capability to use manufacturing technology effectively; and 3) The capability for continuous organizational learning. These manufacturing capabilities characterizes the emerging model of post-industrial manufacturing that will be addressed in the current research.

1.1.1. The capability to create superior customer value

Customer service orientation has become an indispensable component of manufacturing strategy (Bowen, Siehl and Schneider, 1989), and the concept of customer-driven manufacturing has gained popularity worldwide in recent years (Murakoshi, 1994). In fact, the central concern for manufacturers has shifted from an internal focus on efficiency and productivity to an external focus on creating customer value (Doll and Vonderembse, 1991). It is widely accepted that customization of products and services can provide higher value to customers because customers are becoming more demanding about having more choices and getting exactly what they need. Therefore, product customization is increasingly adopted by many manufacturers in an effort to improve product competitiveness in the marketplace.

However, traditional knowledge indicates that product customization lead to higher manufacturing cost due to individualized designs and distinctive equipment setup. According to Skinner's (1974) "focused factory" theory, multiple manufacturing objectives such as greater variety and lower cost could not be achieved at the same time.

Thus manufacturing tradeoffs have to be made. By being focused, manufacturers are expected to achieve maximum economies of scale through mass production. But the reality is that more and more manufacturers no longer have the luxury to stay focused when facing increasing complexity and uncertainty (Parker, 1996; Anderson and Pine, 1997). This dilemma forced manufacturers to search for a valid solution.

The solution turned out to be a seemingly paradoxical concept – mass customization, defined as the mass production of individually customized goods and services (Pine, 1993). The idea of synthesizing "mass production" and "customization" originated from the fact that some manufacturers could achieve high variety, low cost and large volume production simultaneously in their manufacturing systems through technological and managerial innovations (Anderson and Pine, 1997). In fact, more and more manufacturers have come to realize that in a constantly changing marketplace, mass customization capability could be the major source of creating customer value and improving manufacturing performance (Pine, 1995; Duray, 1997).

Recently, academic research has begun to examine the phenomenon of mass customization, but most studies are still anecdotal in nature (Kotha, 1995). The existing literature addresses the market implications of mass customization, but fails to provide operational measures of mass customization (Duray, 1997). This lack of empirical instruments greatly limited our ability to better understand mass customization and to provide useful directions for manufacturers striving to achieve mass customization capability. The current research is one of the first empirical efforts to operationalize the concept of mass customization capability of manufacturing firms.

1.1.2. The capability to use manufacturing technology effectively

We are living in a technology intensive age where technological change presents serious threats and opportunities (Huber, 1996). Therefore, how to effectively utilize emerging technology is yet another critical concern of post-industrial manufacturing.

Computers and information technology are continuously altering the nature of manufacturing competition. Porter and Miller (1985) were among the first to address how information technology can create tremendous competitive advantage by transforming the entire value chain, changing industry structure and spawning new business opportunities. Doll and Vonderembse (1991) described the transformation from industrial to post-industrial manufacturing enterprise as market-driven and technology-enabled. Literature also suggested that mass customization would not be possible without the support of innovative manufacturing technologies (Pine, 1993; Boynton et al., 1993; Kotha, 1995, 1996).

In a broader sense, manufacturing technology not only refers to hardware and software applications such as Information Systems (e.g., MIS, DSS and ES) and Advanced Manufacturing Technologies (e.g., CAD/CAM, FMS and CIM), it is also comprised of innovative manufacturing practices such as Time-Based Manufacturing Practices (e.g., pull production and setup reengineering) (Koufteros et al., 1998) and Modularity-Based Manufacturing Practices (e.g., product and process modularity), an increasingly popular practice for manufacturers to easily customize products (Baldwin and Clark, 1997). This array of new manufacturing technologies together offered firms tremendous strategic opportunities to achieve mass customization. The current research attempts to operationalize the usage level of these representative technologies and practices in U.S. manufacturing firms and study their important impacts on mass customization.

However, while new technologies presented new strategic options (Nemetz and Fry, 1988), the real management challenge lies in how to implement these technologies in a more effective manner that actually improves performance (Boddy, McCalman and Buchanan, 1988). Evidences show that many firms are not gaining the full benefits offered by these new technologies or may even be forced to withdraw them from use (Chen and Small, 1994). For example, an early study by Jaikumar (1986) showed that the U.S. firms were not using Flexible Manufacturing Systems (FMS) effectively comparing with Japan. The FMSs installed in the U.S. showed an astonishing lack of flexibility in terms of machine utilization and the variety of parts produced per system. A more recent study by Mansfield (1993) on 175 Japanese, Western Europe, and U.S. firms also indicated that U.S. firms have been relatively slow in assimilating FMS technologies due to the actual rate of return on this investment being lower in the U.S. than elsewhere.

Huber (1996) indicated that under highly unpredictable environment, lack of organizational learning capacity that transforms experience into knowledge is a major cause for technology-critical organizations to be less effective in assimilating new technologies. Hence there's the need for the third critical capability of a post-industrial manufacturing system - the capability for continuous organizational learning.

1.1.3. The capability for continuous organizational learning

Mansfield (1988) pointed out that a large part of Japan's competitive advantage is due to U.S. industry's apparent lack of ability to match the Japanese in quickly and effectively learning new technologies. Sitkin (1994) also suggested that the new generation of managerial thinking should emphasize continuous learning capability and flexibility. This capability of a firm to exploit and assimilate knowledge and technology, thus generating effective organizational learning is referred to as the firm's absorptive capacity (Cohen and Levinthal, 1990).

Levinson and Asahi (1995) argued that the introduction of any new knowledge or technology involves change, "when it comes to change, the absorptive capacity of an organization is perhaps the most critical factor in determining whether a planned change can be implemented successfully". Therefore, the current study regards a firm's absorptive capacity as the primary determinant of the effectiveness of its technology usage and new manufacturing practice implementation processes. To facilitate the understanding of a firm's absorptive capacity, a measurement instrument is also proposed and validated.

In summary, the current study attempts to answer the research question raised at the beginning of this section by empirically demonstrating the following rationale: To successfully compete in the turbulent post-industrial marketplace, manufacturers must put customers as the first priority. Superior customer value can be created through achieving mass customization capability. Information technologies (e.g., Information Systems and Advanced Manufacturing Technologies) and innovative manufacturing practices (e.g., Time-Based Manufacturing Practices and Modularity-Based Manufacturing Practices) are critical antecedents of achieving mass customization capability. While absorptive capability ensures the effective use and implementation of these technologies and practices through continuous organizational learning.

1.2. Research Objectives and Contributions

The primary objective of this research is therefore to develop and empirically test the emerging model of post-industrial manufacturing management as outlined above. The important relationships to be tested include: (1) the direct impact of firms' absorptive capacity on the effective use of information systems, (2) the direct impact of firms' absorptive capacity on the effective use of advanced manufacturing technologies, (3) the direct impact of firms' absorptive capacity on the effective implementation of time-based manufacturing practices, (4) the direct impact of firms' absorptive capacity on the effective implementation of modularity-based manufacturing practices, (5) the direct impact of information systems usage on firms' mass customization capability, (6) the direct impact of advanced manufacturing technology usage on firms' mass customization capability, (7) the direct impact of time-based manufacturing practices on firms' mass customization capability, (8) the direct impact of modularity-based manufacturing practices on firms' mass customization capability, (9) the direct impact of firms' mass customization capability on creating value to customers, and (10) the direct impact of firms' absorptive capacity on creating value to customers.

As in any empirical study, it won't be possible to correctly test a relationship without valid and reliable measurement instruments for the constructs involved in the relationship. Therefore, a major contribution of the current research is the development of valid and reliable measurement instruments for (1) firm's absorptive capacity for new knowledge and technology, (2) level of information systems usage in a firm, (3) level of advanced manufacturing technology usage in a firm, (4) level of modularity-based manufacturing practices in a firm, and (5) firm's level of mass customization capability.

The measurement instruments for the other constructs in the proposed model are adapted with modification from earlier studies.

From a practitioners' point of view, this research provides important guidelines for firms operating in a turbulent post-industrial environment on what they should do to achieve mass customization and create higher customer value. The measurement instruments developed in this research should be a valuable tool for firms to evaluate and benchmark their current system capabilities. The research findings will also help them identify the factors that most affect a firm's ability to absorb new knowledge and technology, to more effectively use existing technology, and to achieve greater product variety and higher customer satisfaction without sacrificing productivity and profitability.

CHAPTER 2: THEORETICAL FRAMEWORK FOR MASS CUSTOMIZATION AND HYPOTHESES DEVELOPMENT

Hayes and Pisano (1994) suggested that fragmented market and fierce global competition demand greater strategic flexibility of manufacturing firms. The concept of strategic flexibility defies the logic of traditional manufacturing tradeoffs, proposing that firms can be flexible enough to do several things equally well, e.g., increasing variety while lowering cost and improving quality. This is based on the notion of economies of scope defined as economies of scale across multiple products and markets (Goldhar and Jelinek, 1985). The underlying rationale is that greater variety can be more economical due to sharing of technology, knowledge and learning experiences. The new principle of economies of scope becomes the very basis of an entirely new manufacturing strategic paradigm, which has been labeled by many authors as "mass customization" (Pine, 1993; Boynton et al., 1993; Kotha, 1995; Parker, 1996) as oppose to traditional mass production.

The goal of mass customization is to produce customized products on a mass scale without sacrificing efficiency or increasing cost (Pine, 1993; Anderson, 1997). According to Martha Rogers, author of *The One to One Future: Building Relationships One Customer at a Time*, increasing number of customers are shunning mass-produced goods in favor of product and services that are customized to suit their particular needs and situations. Hence mass customization may well become the basis of "the next industrial revolution" (Lau, 1995).

2.1. A Theoretical Model of Mass Customization

To better understand the antecedents and consequences of achieving mass customization, a theoretical framework was developed based on a comprehensive literature review. The theoretical model presented in Figure 2.1 depicts the proposed relationships between the seven major constructs in this research. The numbers next to each arrow correspond to the ten hypotheses to be developed in the following sections.

The seven interrelated constructs in the model include: 1) *Absorptive Capacity*: A firm's ability to identify, assimilate and communicate relevant external and internal knowledge and technology; 2) *Information Systems Usage*: The extent to which information systems are used by the firm to promote integration, support decision making and assist in strategic planning; 3) *Advanced Manufacturing Technology Usage*: The extent to which firms use advanced manufacturing technologies in their product design and manufacturing processes; 4) *Time-Based Manufacturing Practices*: The application of time compression techniques into every aspect of the manufacturing systems design, 5) *Modularity-Based Manufacturing Practices*: The application of modularization principles to product design, production process design and organizational design; 6) *Mass Customization Capability*: The ability of a firm to produce varieties of customized products on a large scale at a cost comparable to non-customized products through technical and managerial innovations; and 7) *Value to Customer Performance*: The extent to which customers perceive firm's product as having higher value and their degree of satisfaction with the products. Table 2.1 summarizes these constructs and their primary literature basis.

Figure 2.1. Theoretical Model

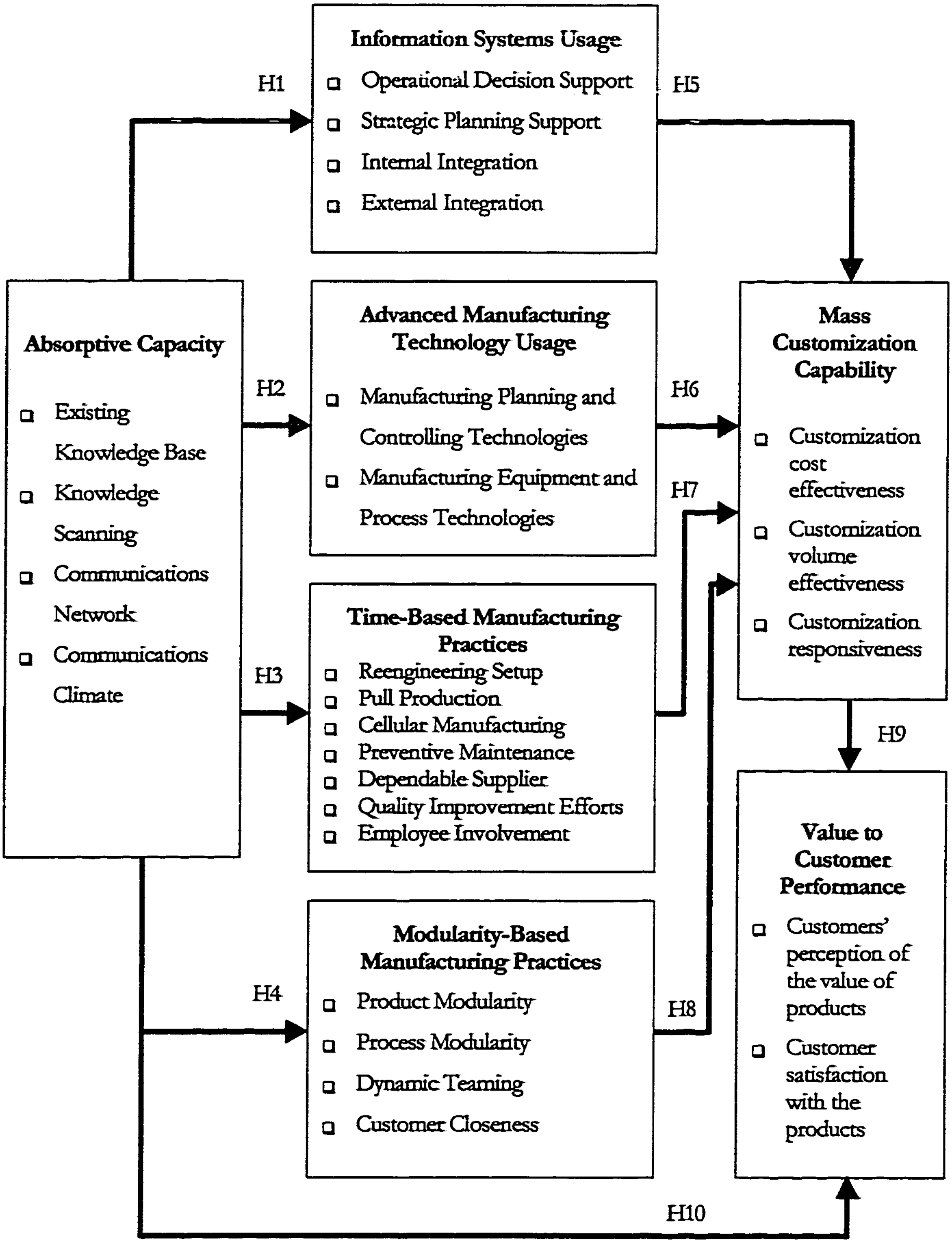


Table 2.1. Construct Definitions and Literature Basis

CONSTRUCT	DEFINITION	LITERATURE
1. Absorptive Capacity	A firm's ability to identify, assimilate and communicate relevant external and internal knowledge and technology	Cohen and Levinthal (1990, 1994); Boynton, Zmud and Jacobs (1994); Brown (1995); Levinson and Asahi, (1995)
2. Information Systems Usage	The extent to which information systems are used by the firm to promote integration, support decision making and assist in strategic planning	Doll and Torkzadeh (1995); Boynton, Zmud and Jacobs (1994); Sethi and King (1994); Raghunathan and Raghunathan (1994)
3. Advanced Manufacturing Technology Usage	The extent to which firms use advanced manufacturing technologies in their product design and manufacturing processes	Small and Chen (1995); Lowe (1995); Vonderembse, Raghunathan and Rao (1997); Cooper and Zmud (1990)
4. Time-Based Manufacturing Practices	The application of time compression techniques into every aspect of the manufacturing system design	Koufterous, Vonderembse and Doll (1998); Blockstette and Shell (1993); Sakakibara, Flynn, Schroeder and Morris (1997); Stalk and Hout (1990)
5. Modularity-Based Manufacturing Practices	The application of modularization principles to product design, production process design and organizational design	Ulrich and Tung (1991); Baldwin and Clark (1997); Feitzinger and Lee (1997); Duray (1997)
6. Mass Customization Capability	The ability of a firm to produce varieties of customized products on a large scale at a cost comparable to non-customized products through technical and managerial innovations	Pine (1993); Kotha (1995, 1996); Boynton, Victor and Pine (1993); Duray (1997)
7. Value to Customer Performance	The extent to which customers perceive a firm's products as having higher value and their degree of satisfaction with the products	Tracey (1996); Garvin (1984); Naumann and Giel (1995)

The rationale underlying this theoretical framework is straightforward. It can be summarized in the following three aspects based on the three phases of the theoretical model.

1) Creating higher value to customers is the ultimate purpose of achieving mass customization.

In the post-industrial environment, customers have really become the ultimate priority of any business. As markets become increasingly segmented and product life cycle gets shorter, firms can no longer satisfy market requirements with a few generic products. They must cater to each individual customer's specific needs. As pointed out by Peppers and Rogers (1997), "Instead of *market share*, businesses are looking at *customer share*. They're shifting the focus from trying to sell as many widgets as they can to trying to get as many customers as they can – and then selling them widgets and other products." One key strategy to increasing customer share is creating customer value through low cost, high volume and responsive product customization. Customer value may include factors such as customer satisfaction with product variety, quality, features, and customers' perception of the worth of the product.

Pine (1995) described how Motorola Paging Products Group successfully created customer value through mass customization of pagers. The sales reps go into customer's office with a laptop computer, and together they design the set of pagers that exactly meet that customer's specification (out of 29 million possibilities). The pager designs are then immediately transmitted through to the factory floor, where a lot-size-of-one flexible manufacturing system can produce them in hours for final shipment.

2) Mass customization requires advanced information technologies and innovative manufacturing practices.

As can be seen from the Motorola case that mass customization is a highly complex technology-intensive process requiring high levels of cooperation from many departments. It involves both technological innovations and structural/cultural changes. Therefore, existing literature indicates that a firm cannot possibly achieve mass customization capability without the support from advanced information technologies and innovative manufacturing practices (Lau, 1995). In fact, new technologies have been a primary enabler of the transition from industrial to postindustrial manufacturing (Doll and Vonderembse, 1991). For example, computer integrated manufacturing (CIM) technology enables firms to efficiently produce multiple products through flexible manufacturing systems (Doll and Vonderembse, 1987), and product modularity makes it feasible to customize products at low cost (Baldwin and Clark, 1997). The current research identifies four important categories of manufacturing technologies and practices as enablers of mass customization. They are:

1. Information systems (IS), such as manufacturing information systems, operational decision support systems, engineering expert systems, and intra-firm computer network systems. IS plays an important role of storing, organizing, processing data and assisting in integrating islands of advanced manufacturing technology units (Rosenthal, 1984).
2. Advanced manufacturing technologies (AMT), such as computer-aided design and manufacturing (CAD/CAM), computer-aided process planning (CAPP), computer

numerically controlled (CNC) machines, and flexible manufacturing systems (FMS) (Gerwin and Kolodny, 1992; Hill, 1994).

3. Time-based manufacturing practices (TBMP), such as setup time reduction, cellular manufacturing, preventive maintenance, quality assurance, and pull production (Koufteros et al., 1998). Lau (1995) pointed out that the manufacturing practices of just-in-time, which has an ideal lot size of one, lays the foundation form of mass customization. These time compression techniques make it economical to quickly changeover to another product line.
4. Modularity-based manufacturing practices (MBMP), such as product modularity and process modularity (Feitzinger and Lee, 1997). Although the principles of product modularization has been discussed for decades (Ulrich and Tung, 1991), it has never been so popular and important to manufacturers in recent years. Baldwin and Clark (1997) argued that modularity has become a very effective manufacturing strategy for firms to cope with rapidly changing customer requirements and increasing technology complexity. Pine (1993) clearly stated that "the best method for achieving mass customization – minimizing costs while maximizing individual customization – is by creating modular components that can be configured into a wide variety of end products and services".

3) Absorptive capacity ensures the effective use and implementation of advanced technologies and manufacturing practices.

Although mass customization requires advanced technologies and innovative manufacturing practices, simple acquisition of technology or copying of practices without proper implementation and assimilation may render the investment fruitless.

Empirical studies have reported the very different manufacturing performance levels from firms using similar technologies, especially U.S. firms' inability to match Japanese firms' in the speed of absorbing flexible technologies (Mansfield, 1993). Thus absorptive capacity may well be the single most important factor for ensuring the successful implementation of new technologies and manufacturing practices.

Markus and Robey's (1988) framework of *Technological Imperative* vs. *Organizational Imperative* can help us better understand the active vs. passive role of technology in organizational change. *Technological Imperative* views technology as an exogenous driving force which determines or strongly constrains the behavior of individuals and organizations, i.e., technology dictates itself; *Organizational Imperative* assumes choices over technological options and control over the consequences, and technology is considered as enabler of achieving the ends.

Doll and Vonderembse (1991) describe the evolution from craft to industrial society as "*technology driven* and market enabled", while the change from industrial to post-industrial manufacturing is "market/customer driven and *technology enabled*". Therefore, the *technology imperative* was applicable in the relatively stable industrial era when firms can achieve technology benefits by simply acquiring new and complex hardware. The unusually high technology investments and proprietary technology served as ideal barriers to new entrants.

Unfortunately, this technology-dictates-itself mindset no longer works under the highly uncertain and competitive post-industrial environment. Clemons and Row (1991) pointed out that, when the same equipment or practice is available to all firms and most applications can be easily duplicated, sustaining technology advantage will not come from whether you have it or not, but from how effectively it is being used. Thus the *organizational imperative* that treats technology as enabler to be properly utilized should be appropriate. As pointed out by Doll and Vonderembse (1991), industrial and post-industrial systems may use the same technologies, but apply them in different ways. The difference lies in the fact that applying technology in post-industrial environment requires a high level of absorptive capacity.

The following sections will first present a detailed review of existing literature concerning each of the seven constructs in the theoretical model. Ten research hypotheses are then developed based on the review.

2.2. Absorptive Capacity of Manufacturing Firms

The concept of absorptive capacity originated from macro-economics, in which the term refers to the ability of an economy to utilize and absorb external information and resources (Adler, 1965). Cohen and Levinthal (1990) first adapted this macro-economic level concept to organizations, and defined a firm's absorptive capacity as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends." They argued that absorptive capacity is largely an organizational learning concept, and is thus the cumulative effect of continuous learning. In the current study, a firm's absorptive capacity is defined as the ability to identify, communicate and assimilate relevant external and internal knowledge and technology. It is a function of the firm's existing knowledge base, the effectiveness of systems used to scan the environment, as well as the efficacy of its communication processes.

Since academic research on absorptive capacity has just started, empirical evidence is extremely limited. Thus the current research will frequently refer to the organizational learning and technology implementation literature. In fact, according to Boynton, Zmud and Jacobs (1994), "absorptive capacity theory does appear to offer specific and promising avenues for future research about information technology innovation behavior".

The most comprehensive research so far on absorptive capacity was a case study by Brown (1995). By summarizing the existing literature, she proposed that a firm's absorptive capacity should have three major components: prior relevant knowledge, communication network, and communication climate. While these three dimensions might be adequate for absorbing readily available knowledge, it was deemed necessary to add a fourth dimension, i.e., the firm's knowledge scanning mechanism to explore knowledge unknown but useful to the firm.

Existing Knowledge Base is defined as the existing facts and ideas that individuals in the organization have that can influence the process of implementing organizational innovations. It may include both general employee knowledge and managerial knowledge. Cohen and Levinthal (1990) suggest that prior related-knowledge will be a major determinant of absorptive capacity, just like an individual will learn faster about subjects the individual has been exposed to. Cohen and Levinthal (1994) further suggested that firms with an adequate prior knowledge base will have the ability to proactively envisage future technological advances, thus improving absorptive capacity; while firms where prior knowledge is non-existent may be discouraged by uncertainty to further develop its absorptive capacity.

A longitudinal study by Boer et al. (1990) found that one significant barrier to goal achievement in FMS implementation is technical difficulties. Many companies did not have an appropriate technical knowledge base to assimilate the new technology. Boynton et al. (1994) conceptualized firm's absorptive capacity for information technology (IT) based on management's prior knowledge on IT. Absorptive capacity was found to have significant positive impact on effective use of IT. Kedia and Bhagat's (1988) study on international technology transfer also revealed that the absorptive capacity of the recipient organization depends on the existence of an established technological and managerial knowledge base.

Knowledge Scanning is defined as organizational mechanisms that enable the firm to effectively identify and exploit relevant external and internal knowledge and technology. There are many activities that signify the existence of such a mechanism in an organization. An important dimension of Boynton et al.'s (1994) conceptualization of absorptive capacity is the IT-management-process, i.e., various routines and procedures that embody the pragmatic knowledge to foster appropriate IT use. Cohen and Levinthal (1990) found that investment in basic R&D could significantly improve the firm's ability to exploit external resources. Especially when the new knowledge domain is closely related to the firm's current knowledge base, absorptive capacity is likely to be developed as a byproduct of routine R&D activities.

Employee training such as sending employees for advanced technical training, or encouraging them to monitor and read the technical literature in their areas of expertise, could be another important knowledge scanning activity (Cohen and Levinthal, 1994). When addressing their concept of the "knowledge factory", Roth et al. (1994)

emphasized that training employees to meet technological and business process requirements will be the basis for today's knowledge-based competition. Finally, inter-organizational learning activities, such as benchmarking of best practices, strategic alliances, and customer and supplier surveys may also serve as effective knowledge scanning activities (Levinson and Asahi, 1995).

Communications Network is defined as the scope and strength of structural connections that can bring flows of information and knowledge to different organizational departments. This is frequently referred to in the literature as functional integration. Effective communication and knowledge diversity are considered to be the key generators of a firm's absorptive capacity (Cohen and Levinthal, 1990). Thus the integration and interaction of different functional areas will be critical.

Aletan (1991) stated that functional integration is required for successful CIM implementation. It involves the process of establishing a company-wide environment that requires all functional departments to work together to achieve both business and manufacturing goals. Cross-functional implementation teams are also found to be a major success factor for AMT implementation (Voss, 1988; Beatty, 1990; Goldhar and Lei, 1994). A recent empirical study by Chen and Small (1994) shows that the use of multi-disciplinary implementation teams is the most significant factor that distinguishes successful and unsuccessful AMT adopters. Similarly, Bessant (1994) also suggested that effective implementation of AMT requires a "total integrated manufacturing" organization, which involves several fundamental changes, including changes from vertical communication to network communication, and from sharp line staff boundary to blurred boundaries.

Communications Climate is defined as the cultural factors that form the atmosphere in an organization regarding accepted communication behavior, which may facilitate or hinder the communication processes. This may include such factors as openness, value orientation, support, trust, experimental mindset, and willingness to change. There's general agreement that organizational learning is based on the learning of each individual member (Nicolini and Meznar, 1995). Thus, a firm's absorptive capacity is ultimately realized through each individual's learning performance.

A growing body of literature has confirmed that an open, supportive organizational climate can greatly improve employee's learning experiences. Nevis et al. (1995) regard the "climate of openness" as one of the ten key facilitating factors of organizational learning. Similarly, Levinson and Asahi (1995) pointed out that an open culture that views change as positive can facilitate organizational learning. Another important element of an open climate is "safefailing" that encourages risk-taking (Roth et al., 1994). Learning is in fact a trial and error process that requires an experimental mind-set (Nevis, 1995). Failure is tolerable in an open climate, so that the initial building of absorptive capacity will not be discouraged.

2.3. Information Systems Usage

Information systems (IS) refers to those computer-based systems used to organize, store, retrieve, transfer, and process data and information, and facilitate communication and problem solving, such as office automation systems, electronic mail systems, data conferencing systems, management information systems, decision support systems, expert systems, and other computer network systems. In the current study, IS usage is defined as the extent to which IS is used by the firm to promote integration, support decision making and assist in strategic planning.

Doll and Torkzadeh (1995) developed an instrument for IT usage patterns at the task level. They conceptualize the IT usage pattern into five dimensions: 1) problem solving: the extent that an application is used to analyze cause and effect relationships; 2) customer service: the extent that an applications is used to service customers; 3) decision rationalization: the extent that an application is used to improve the decision making processes or explain/justify the reasons for decisions; 4) vertical integration: the extent that an application is used to coordinate one's work vertically with superiors and subordinates; and 5) horizontal integration: the extent that an application is used to coordinate work activities with others in one's work group. The Doll and Torkzadeh (1995) instrument did offer some useful directions for conceptualizing the IS usage construct. However, since the instrument was developed at the task level, it focused primarily on individual and work group mechanisms. It was determined that the construct of organizational level IS usage in the current study could be re-conceptualized and adapted using Doll and Torkzadeh (1995) dimensions as a starting point.

The re-conceptualization process involved: 1) exclusion of dimensions inappropriate for organizational level analysis such as problem solving, a dimension that reflects individual activities; 2) consolidating dimensions to fit organizational level analysis, such as the merger of vertical integration and horizontal integration to form the organization's Internal Integration dimension; 3) expanding dimensions to reflect organizational level activities, such as the change of customer service dimension to External Integration to incorporate not only customers, but also suppliers and other external relationships; 4) adding new dimensions to address organizational level issues, such as the addition of a Strategic Planning Support dimension to address the issue of strategic IS planning that was not relevant at the task level. Also note that decision rationalization dimension was re-conceptualized as Operational Decision Support.

Further theoretical justification of the operational support vs. strategic support conceptualization can be found from Boynton et al.'s (1994) measure of IT use. This is an organizational level instrument that consists of four dimensions: 1) cost reduction: information systems developed to reduce the cost of business activities; 2) management support: information systems developed to assist in monitoring, controlling, and designing business activities; 3) strategic planning: information systems developed to assist in formulating business strategies; and 4) competitive thrust: information systems developed to establish a competitive advantage in the market. Cost reduction is an outcome of using IS, thus not a valid dimension of IS usage. Management support captures the operational decision support dimension. Strategic planning and competitive thrust can be justifiably combined to form the Strategic Planning Support dimension.

In summary, four major dimensions of organizational-level IS usage were proposed and their definitions are listed below:

Operational Decision Support. The extent that IS is used by the firm to help monitoring, justifying and improving daily operational decision processes (Doll and Torkzadeh - Decision Rationalization; Boynton et al. - Management Support).

Strategic Planning Support. The extent that IS is used by the firm to help formulating, justifying, improving long-term business planning processes and establishing competitive advantage (Boynton et al. – Strategic Planning & Competitive Thrust).

Internal Integration. The extent that IS is used by the firm to facilitate information sharing and coordinate work activities within the organization (Doll and Torkzadeh – Vertical Integration & Horizontal Integration).

External Integration. The extent that IS is used by the firm to service and communicate with external constituencies, such as customers, suppliers, government agencies, research institutions, etc. (Doll and Torkzadeh – Customer Service).

2.3.1. Research Hypothesis 1

Since its origin in macroeconomics, absorptive capacity has long been considered a very positive factor in determining the effectiveness of a nation to disseminate and utilize new technologies (Kedia and Bhagat, 1988). Due to the fact that computer-based information systems are replacing the traditional paper-based information systems in many businesses and organizations, they are often new to organizational members and require significant amount of learning and mutual adjustment (Majchrzak and Cotton, 1988). The major components of absorptive capacity such as existing knowledge base and communications infrastructure can greatly facilitate the individual and organizational learning of new systems (Cohen and Levinthal, 1990), thus improving the level of system usage. For example, a firm with more open communication channels will be more likely to realize the potential of its information systems to integrate functional areas. Boynton et al. (1994) and Brown (1995) found strong empirical evidence that a firm's absorptive capacity has significant positive impact on its level of IT use. Therefore, it is hypothesized that:

Hypothesis 1: There is a positive relationship between a firm's *Absorptive Capacity* and its level of *Information Systems Usage*.

2.4. Advanced Manufacturing Technology Usage

Advanced manufacturing technology (AMT) refers to a family of computer-enabled manufacturing technologies that include computer-aided design and manufacturing (CAD/CAM), computer-aided process planning (CAPP), materials resource planning (MRP), robotics, computer numerically controlled (CNC) machines, flexible manufacturing systems (FMS), and computer integrated manufacturing systems (CIM). A common characteristic of these technologies is the use of micro-computers to plan and control manufacturing operations (Dean et al., 1992). In the current study, AMT usage is defined as the extent to which firms use AMTs in their product design and manufacturing processes.

By reviewing the relevant literature (Small and Chen, 1995; Lowe, 1995), thirteen categories of AMTs were identified. Respondents were asked to indicate the extent of use of a certain AMT in their manufacturing system. These AMTs were further divided into two groups in term of their primary purpose: 1) Manufacturing planning and control technologies, and 2) Manufacturing equipment and process technologies. The thirteen AMTs are listed below:

Manufacturing Planning and Control Technologies

1) Computer-aided manufacturing (CAM)
2) Computer-aided process planning (CAPP)
3) Group technology (GT)

4) Material requirement planning (MRP)

5) Manufacturing resource planning (MRP II)

6) Computer-aided design/engineering (CAD/CAE)

7) Computer-aided rapid prototyping (RP)

Manufacturing Equipment and Process Technologies

8) NC/CNC or DNC machines

9) Automatic storage and retrieval systems (AS/RS)

10) Automated material handling systems (AMHS)

11) Industrial robots

12) Automated inspection and testing equipment

13) Flexible manufacturing systems (FMS)

2.4.1. Research Hypothesis 2

The concept of absorptive capacity contains some important ideas in organizational design such as organizational learning mechanism and communications infrastructure. The impact of organizational design issues on advanced manufacturing technology usage has been a major topic area in the manufacturing management literature. Blumberg and Gerwin (1984) already observed the socio-technical problems that manufacturing firms might encounter during CIM implementation. Zammuto and O'Connor (1992) proposed that firms with organic structure and open communications climate are more likely to gain AMT's productivity and flexibility benefits. They also emphasized the importance of employee knowledge and skills because of the complex nature of AMTs. Dumering et al. (1993) also argued that organizations must be redesigned to ensure effective cross-functional communication before implementing AMTs. Lei, Hitt and Goldhar (1996) further illustrated the positive effects of appropriate organizational learning mechanism on AMT success. Therefore, it is hypothesized that:

***Hypothesis 2*:** There is a positive relationship between a firm's *Absorptive Capacity* and its level of *Advanced Manufacturing Technology Usage*.

2.5. Time-Based Manufacturing Practices

Time, as a manufacturing strategic variable, originated from the evolution process of manufacturing management practices. Frederick Taylor, the father of scientific management, first proposed the use of time study in production operations. Each job was broken up into smaller elements, and each element was to have a fixed standard time set by time study experts (Niebel, 1988). Henry Ford successfully put the techniques of time and motion study into his auto assembly lines and developed the world's most efficient and timely system for producing cars (Bockerstette and Shell, 1993).

In the early 1980s, Toyota developed a system capable of diversified, small quantity production to meet increasing customer demands for variety. The success of this flexible Toyota production system brought about a revolution in manufacturing – the principles of Just-In-Time (JIT) manufacturing (Ohno, 1982). JIT is both a philosophy and a set of tools focusing on not only setup time reduction, but also cycle time reduction, lead time reduction, and the reduction of all sorts of wastes in the production system that do not add value (Sakakibara, Flynn, Schroeder and Morris, 1997). The extension of JIT principles into every aspect of manufacturing system, from new product development, to material purchasing, production, product distribution, and finally customer service, results in the new paradigm of time-based manufacturing (TBM) (Staik and Hout, 1990; Blockstette and Shell, 1993; Koufterous et al.,1995).

Today, time has become a strategic resource in almost every industry. In the current study, Time-Based Manufacturing Practices are defined as the application of time compression techniques into every aspect of the manufacturing system design. Koufteros, Vonderembse and Doll (1998) developed a framework for time-based manufacturing practices. They identified and validated several critical dimensions of TBM. They are briefly discussed below.

Reengineering Setup. Setup time reduction is at the core of the entire chain of time compression efforts. Compressed setup time permits firms to quickly switch between products with minimum penalties, thus enables greater flexibility to respond to changing customer needs (Ohno, 1982).

Pull Production. The traditional production system is usually a push system, in which a high level of work-in-process inventory is kept to buffer production variations. While in a pull system, production is pulled by customer demands at the very end of the production line. By allowing only a small amount of work-in-process inventory in the system, pull systems can greatly reduce the time parts stay in the system, especially the non-value-added waiting time (Monden, 1983; Schonberger, 1986).

Cellular Manufacturing. Using group technology principles, a family of parts with similar design characteristics and processing requirements are grouped together to be produced in a single manufacturing cell. The cell has all the equipment necessary to produce a part. This greatly reduces materials handling time and costs, cuts work-in-process inventory, and shortens throughput time (Hyer and Wemmerlov, 1984).

Preventive Maintenance. Unreliable machines are a major source of shop floor delays and product defects. The result is usually increased throughput time, missed production deadlines, reduced product quality, and increased production costs. Thus scheduling routine preventive maintenance and teaching operators to perform minor maintenance tasks on regular basis should be an integral part of time-base manufacturing practices (Bockerstette and Shell, 1993).

Quality Improvement Efforts. A central theme of total quality management philosophy is to do things right the first time (Dean, 1994). It usually takes much greater time and efforts to rework a defective product. Thus quality improvement efforts can significantly reduce throughput time and reduce costs (Juran, 1989).

Dependable Suppliers. Shortages and quality problems in supplier parts are yet another source of production delay. On-time supplier delivery and high quality supplier parts allow firms to keep inventory low and reduce downtime. Evidence shows that dependable suppliers can help cut throughput time, reduce quality and inventory costs, and improve manufacturing competitiveness (Cusumano and Takeishi, 1991; Blackburn, 1991; Handfield and Pannesi, 1992).

Shop Floor Employee Involvement in Problem Solving. Employee participation in work decision and problem solving has long been an important method of improving performance in various work settings (Cotton et al., 1988). Through employee involvement, management can expect to explore and utilize employee intelligence while improving employee job satisfaction through self-motivation. Therefore, employee involvement in shop floor problem solving and suggestion programs will greatly facilitate the implementation of other time-based manufacturing activities.

2.5.1. Research Hypothesis 3

As can be seen from the above discussions that success of time-based manufacturing practices are heavily dependent upon two essential activities: 1) the exploration and utilization of employee intelligence, such as employee involvement in setup reengineering and quality assurance programs; 2) the effective communication and coordination internally among functional departments and externally with suppliers and customers, so as to ensure smooth operation of the pull production system and just-in-time value chain.

In fact, improved learning and communications are exactly what absorptive capacity is about. Empirical studies have repeatedly verified that absorptive capacity components such as employee technical competence, learning from customers and suppliers, and open communication channels are crucial determinants of just-in-time systems success (Davy et al., 1992; Flynn et al., 1995; Sakakibara et al., 1997). Cooper and Kleinschmidt (1994) also identified several major determinants of product development timeliness, most of which are closely related to the conceptual domain of absorptive capacity, including efficient cross-functional coordination, thorough analyses of market and technical trends, team's technical proficiency, and firm's prior experience in similar products. Therefore, it is hypothesize that:

***Hypothesis 3*:** There is a positive relationship between a firm's *Absorptive Capacity* and its level of *Time-Based Manufacturing Practices*.

2.6. Modularity-Based Manufacturing Practices

Although the concept of modularity is not new to manufacturing practitioners, it has drawn much greater research attention in the recent years due to its definitive advantage in coping with the increasingly turbulent manufacturing environment. Professors Carliss Baldwin and Kim Clark of Harvard Business School are among the many proponents of modularity. Their recent article in Harvard Business Review cited the computer industry as the pioneer in promoting modularity. Through the widespread adoption of modular designs, the computer industry has dramatically increased its rate of innovation. Baldwin and Clark (1997) regard modularity as a strategy for organizing complex products and processes efficiently. They argue that it is modularity, more than any other technology, that makes the rapid developments in computer industry possible. In fact, modularity brings about benefits for both customers and manufacturers. For customers, modular products are much easier to customize, upgrade and repair, thus having greater usability and serviceability (Bowen et al, 1989). For manufacturers, modularity enables them to handle increasingly complex technology. By breaking up a product into modules, designers and producers have gained enormous flexibility (Baldwin and Clark, 1997).

In the current research, Modularity-Based Manufacturing Practices is defined as the application of modularization principles to product design, production process design and organizational design. By summarizing the relevant literature, four categories of common modularity-based manufacturing practices are identified and discussed below.

Product Modularity is the practice to modularize products so that the modules can be easily re-assemble/re-arranged into different forms, or shared across different product lines. Ulrich and Tung (1991) defined several basic types of modularity, including Component Sharing (the same module is used across multiple products), Component Swapping (different components are paired with the same basic product), Mix Modularity (mix different modules to form a new product), and Bus Modularity (new options can be added to a standard base by attaching new modules).

Product modularization has become an inevitable trend in manufacturing. For example, NeoSystems has recently launched a new computer architecture – Modular Digital Architecture (MDA). You can simply stack modules of accessories on a base MDA module for easy hardware installation and upgrade, just like stacking your home stereo system. Baldwin and Clark (1997) highly regard this modularity revolution and wrote, "At the heart of their remarkable advance is modularity – building a complex product or process from smaller subsystems that can be designed independently yet function together as a whole".

Process Modularity is a relatively new concept. It refers to the practice of modularizing production processes so that the modules can be easily re-sequenced or new modules can be added in response to changing product requirements. Feitzinger and Lee (1997) suggest that process modularity is based on three basic principles: 1) *Process standardization*: break down the process into *standard sub-processes* that produce standard base units and *customization sub-processes* that further customize the base units; 2) *Process re-sequencing*: re-sequence the sub-processes so that standard sub-processes occur first while customization sub-processes occur last; 3) *Process postponement*: postpone the customization sub-processes until a customer order is received or put the sub-processes into distribution centers to achieve maximum flexibility. Pine (1993) also points out that the traditional tightly coupled processes should be broken apart and modularized, so that, at its ideal, any process can link to any other process to create the unique end-to-end value chain that will best satisfy each individual customer.

Dynamic Teaming is the practice of easily re-organizing production teams and linking them to necessary resources in response to product / process changes. This is the application of modularity principles to team-building processes. The self-managed production team is not a new concept to most firms. Many firms have experimented with production teams, but the results are not all positive (Adler and Cole, 1993). One reason for this mixed results is that changing manufacturing environment requires a more dynamic team structure that is very different from old-fashioned cross-functional teams (Henke et al., 1993).

Pine et al. (1993) argued that cross-functional teams are usually tightly integrated to improve efficiency and, therefore, lack flexibility. Companies must break apart tightly coupled teams and form loosely coupled networks of modular, flexible working units, so that these units of people, processes and technology can be easily reconfigured to meet the ever changing customer needs. Therefore, the information systems that link these working units and the continuous learning capability of the working units become very crucial. Levinthal and March (1993) suggest that a loosely coupled system is better for error diagnostics, and thus promotes learning. Weick (1990) also indicates that loosely coupled systems are more flexible when facing stochastic events in the post-industrial environment.

Customer Closeness is the practice of keeping direct and frequent contact with customers, to understand customers' individual needs, and to communicate with customers effectively. The increasing utilization of modularity is ultimately driven by changing customer needs. Thus the purpose of modularity is lost without a clear understanding of what customers exactly want. In fact, the proper design of product modules must be based on a thorough analysis of how the product is going to be used by customers. Murakoshi (1994) described several customer-driven manufacturing systems that connect customer requirements on a real-time basis with product design processes and production processes. The system can even help customers clarify their needs if they do not know exactly what they want. Murakoshi (1994) regards this kind of customer-driven system as the most advanced form of manufacturing system evolution. Therefore, staying closer to customers is the fundamental guarantee for the modularity strategy to be successful.

2.6.1. Research Hypothesis 4

As illustrated above, modularity is a very effective strategy for organizing complex products and processes. But why aren't all products and processes modularized? Baldwin and Clark (1997) pointed out that modular systems are much more difficult to design than comparable interconnected systems. A successful modular design requires in-depth knowledge about the inner workings of the overall product and extensive cross-functional communication. Baldwin and Clark (1997) also suggested that, to take full advantage of modularity, firms need knowledgeable leaders, highly skilled workers, and effective communications mechanisms. These are all components of a firm's absorptive capacity. Therefore, it is hypothesized that:

Hypothesis 4: There is a positive relationship between a firm's *Absorptive Capacity* and its level of *Modularity-Based Manufacturing Practices*.

2.7. Mass Customization Capability

The notion of "Mass Customization" (MC) was first proposed by Philip Kotler (1989) from the marketing management point of view. Pine (1993) brought this concept into production and operations management literature through his pioneering book, "Mass Customization: The New Frontier in Business Competition". He defines mass customization as the low-cost, high quality, large volume delivery of individually customized goods and services.

Boynton, Victor and Pine (1993) further clarified the concept of mass customization by comparing Mass Customization with Mass Production, Invention, and Continuous Improvement in a Product/Process Change Grid. The old competitive strategies are either Mass Production or Invention. Under conditions of stable product and stable process change, firms use Mass Production strategy to achieve lowest cost. When faced with both dynamic product and process changes, firms use Invention strategy to generate unique or novel product and process, but this invention design usually creates small volumes of new products at a high cost. Invention organizations often are craft producers, entrepreneurs, and separate R&D units within mass-production organizations.

The new competitive strategies are Continuous Improvement and Mass Customization. In some industries, the nature of product demand is still relatively stable and homogeneous, but firms have to continuously improve their process quality, speed, and cost to meet competition. Thus, Continuous Improvement is mostly a low-cost process differentiation strategy within mature markets. The need for Mass Customization arises when firms face the scenario of dynamic product change but relatively stable process change, which is one of the realities of today's competitive environment. More and more firms are feeling the pressure of customers' constantly changing demands on variety and specifications, but many of these firms also report that the core processes their companies are instituting to meet these demands remain stable. Thus the key question becomes how to use a relatively stable process to generate varied products at low cost. Boynton et al. (1993) also suggest that the correct path of changing from mass production to mass customization is not direct, but rather indirectly through continuous improvement.

Kotha (1995, 1996) conducted an in-depth case study of National Bicycle Industrial Company of Japan, which was a very successful example of mass customization. These cases further verified the practical value and feasibility of mass customization, and also discovered the important role of learning and knowledge creation in achieving mass customization.

The current study is one of the first few attempts to operationalize mass customization. Duray (1997) proposed a measurement instrument for mass customization, but her understanding of Mass Customization focused primarily on the practices of product modularity and customer involvement. The current study adopts a much broader view on Mass Customization. In addition to a more comprehensive array of mass customization practices, the mass customization capability resulted from the practices are also directly measured. Mass Customization Capability is defined as the ability of a firm to produce varieties of customized products on a large scale at a cost comparable to non-customized products through technical and managerial innovations. Based on a comprehensive review of the literature, three basic components of Mass Customization Capability were identified:

Customization Cost Effectiveness. The ability to customize products without increasing production costs. Lowering production costs has been the primary objective of large scale mass production. Thus to achieve customization through higher costs will not be an attractive alternative to manufacturers.

Customization Volume Effectiveness. The ability to increase product variety without sacrificing production volume. Mass production has laid the foundation of high volume output for mass market. When the market becomes more and more segmented but total demand is still increasing, a solution is needed. It's certainly not a desirable situation if customization results in under-utilization of an existing fixed asset base and a decreasing market share. An ideal situation would be turning out individually customized products at a rate similar to mass production rates.

Customization Responsiveness. The ability to reduce the time required to deliver customized products and to quickly reorganize production processes in response to customer's customization requirements. It makes no sense to pursue mass customization if a customized product takes too long to produce. Customers just can't wait. Therefore, the speed of customization should be an indispensable criterion for evaluating mass customization capability.

Through a comprehensive review of existing literature, the current study propose four major categories of antecedents of Mass Customization Capability, including the use of 1) information systems, 2) advanced manufacturing technologies, 3) time-based manufacturing practices, and 4) modularity-based manufacturing practices. The first two categories represent the technological bases that enable firms to mass customize products, while the last two categories represent the common organizational practices that ensure full realization of mass customization capabilities. The relationships between each of the four antecedents and mass customization capability are discussed below.

2.7.1. Research Hypothesis 5

Computer-based information systems have long been regarded as a critical enabler for transforming and reengineering various business processes (Hammer and Champy, 1993). Similarly, as an entirely new paradigm of doing business, mass customization requires extensive support from computer information systems at all levels to integrate components of the mass customization system (Pine, 1993). For example, the attempts by Levi Strauss & Company to offer 'custom-fit' blue jeans were made possible due to a computer information network system (Rifkin, 1994). Therefore, it is hypothesized that:

***Hypothesis 5*:** There is a positive relationship between the level of *Information Systems Usage* and the level of *Mass Customization Capability*.

2.7.2. Research Hypothesis 6

The benefits of advanced manufacturing technologies have been widely recognized in the manufacturing management literature (Goldhar and Lei, 1994). Flexible manufacturing technologies like CIM and FMS make it possible for firms to switch between product lines with minimum cost penalty, so that they can increase product variety while maintaining high production volume (Doll and Vonderembse, 1987). When describing the successful case of National Bicycle Industrial Company (NBIC), Kotha (1995) pointed out that the CAD/CAM system and various CNC machines are at the heart of NBIC's mass customization system. Therefore, it is hypothesized that:

Hypothesis 6: There is a positive relationship between the level of *Advanced Manufacturing Technology Usage* and the level of *Mass Customization Capability*.

2.7.3. Research Hypothesis 7

Time-based manufacturing practices are definitely indispensable in achieving mass customization. For example, setup time reduction makes it quick and economical to switch between different product lines, while pull production minimizes waste in time and resources, thus achieving customization cost effectiveness, volume effectiveness and responsiveness. Pine (1993) suggests that new manufacturing management methods like Just-In-Time enables firms to pursue mass customization in many industries. Kotha (1995) also observed that NBIC's success in mass customizing bicycles is due in a large part to its ability to deliver the order in considerably shorter time than competitors. Therefore, it is hypothesized that:

Hypothesis 7: There is a positive relationship between the level of *Time-Based Manufacturing Practices* and the level of *Mass Customization Capability*.

2.7.4. Research Hypothesis 8

Modularity-based product and process design is becoming the most effective strategy for coping with changing customer needs and increasing technological complexity (Baldwin and Clark, 1997). Pine (1993) clearly pointed out that the best method of achieving mass customization is by creating modular components that can be configured into a wide variety of end products. Economies of scope are gained by using the modular components over and over in different products. Feitzinger and Lee (1997) detailed HP's success in mass customization through product and process modularity. Kotha (1995) further empirically confirmed that open communication with customers and thorough understanding of customer needs as integral part of modularity strategy are key to mass customization success. Lei et al. (1996) echoed that a modular, open systems approach is essential for realizing the full potential of economies of scope. Therefore, it is hypothesized that:

***Hypothesis 8*:** There is a positive relationship between the level of *Modularity-Based Manufacturing Practices* and the level of *Mass Customization Capability*.

2.8. Value to Customer Performance

As indicated in previous sections, this entire research framework is driven by the constantly changing customer needs. Thus, the real question is: Will mass customization actually create higher value to customers ? To answer this question, "Value to Customer Performance" is included as the final dependent variable in the model.

Value to Customer Performance is defined as the extent to which customers perceive the firm's products as having higher value and their degree of satisfaction with the products. The measurement items used are mainly adopted from Tracey (1996) study. Some more items were added from the customer satisfaction literature (Naumann and Giel, 1995) and customer service quality literature (Garvin, 1984). The items cover such aspects as customer perception of the value of product variety, customer satisfaction to product quality, customer loyalty to products, and customer satisfaction of the firm's ability to customize products, etc.

2.8.1. Research Hypothesis 9

As indicated in previous discussions, the ultimate purpose of mass customization is to create higher customer value. Pine (1993) defines the goal of mass customization as providing enough variety in products and services so that nearly every customer can find exactly what he/she wants at a reasonable price. Gilmore and Pine (1997) further illustrated the basic approaches of using mass customization to provide unique value to customers. Kotha (1995) and Duray (1997) also provided empirical evidence that customers generally consider customized products as having much higher value. Therefore, it is hypothesized that

***Hypothesis 9*:** There is a positive relationship between a firm's *Mass Customization Capability* and its *Value to Customer Performance*.

2.8.2. Research Hypothesis 10

Deschamps and Nayak (1995) advocated that in today's fierce business competition, "fomenting a customer obsession" to increase customer value is the only way to maintain a competitive edge. They further argued that to create a customer obsession, firms must have the capability to learn from customers and watch for new industrial trends. This capability is exactly what absorptive capacity is about, i.e., the ability to identify and assimilate relevant external and internal knowledge and technology. Thus higher absorptive capacity will enable firms to better understand customer needs, easier identify valuable business opportunities, and faster develop new products of high value to customers. Bowen et al. (1989) also suggested that the new type of customer service oriented manufacturing firms rely heavily on climate and cultural mechanisms such as shared norms and values, and an open communications climate, which are critical components of absorptive capacity. Therefore, it is hypothesized that:

Hypothesis 10 : There is a positive relationship between a firm's *Absorptive Capacity* and its *Value to Customer Performance*.

CHAPTER 3: INSTRUMENT DEVELOPMENT (1): ITEM GENERATION AND PILOT STUDY

This research developed the instruments to measure (1) Absorptive Capacity, (2) Information Systems Usage, (3) Advanced Manufacturing Technology Usage, (4) Modularity-Based Manufacturing Practices, and (5) Mass Customization Capability. Instruments to measure Time-Based Manufacturing Practices and Value to Customer Performance were adopted from previous studies (Koufteros, 1995; Tracey, 1996) with minor modifications. Since these two instruments have been tested in previous studies and were found to be valid and reliable, they were not tested again in the pilot study. Instead, they were revalidated in the large-scale analysis.

The instrument development process can be roughly divided into four phases: (1) item generation, (2) pre-pilot study, (3) pilot study, and (4) large-scale data analysis and instrument validation. First, an extensive and comprehensive literature review was done to identify the content domain of major constructs in the current research framework. Initial items and the definitions of each construct were generated from the literature review. The pre-pilot study involved structured interviews with practitioners and academic experts to further refine the definitions and contents of measurement items of each construct. The third phase was a pilot study targeted at senior manufacturing managers. The instruments were then further refined based on the pilot study results. The fourth phase was large-scale questionnaire administration. Research hypotheses were tested based on the large-scale data analysis.

3.1. Item Generation

Proper generation of measurement items of a construct determines the validity and reliability of an empirical research. The very basic requirement for a good measure is content validity, which means the measurement items contained in an instrument should cover the major content domain of a construct (Churchill, 1979). Content validity is usually achieved through comprehensive literature view and interviewing with practitioners and academic research experts. A list of initial items for each construct was generated based on a very comprehensive review of relevant literature. Items were organized into groups to measure a particular dimension of a construct domain. The general literature basis for items in each construct are briefly discussed below.

The items for **Absorptive Capacity** (i.e., Existing Knowledge Base, Knowledge Scanning, Communications Network and Communications Climate) were generated based on the organizational learning literature, especially some of the early works on absorptive capacity by Cohen and Levinthal (1990, 1994), Boynton et al. (1994), and Brown (1995). The items for **Information Systems Usage** (i.e., Operational Decision Support, Strategic Planning Support, Internal Integration, and External Integration) were developed mainly from end user computing literature and strategic information systems planning literature (Doll and Torkzadeh, 1995; Sethi and King, 1994). The items for **Advanced Manufacturing Technology Usage** (i.e., Manufacturing planning and controlling technologies, Manufacturing equipment and process technologies) were primarily based on the review of technology management literature and implementation literature (Cooper and Zmud, 1990; Chen and Small, 1994; Vonderembse et al., 1997). The items for **Modularity-Based Manufacturing Practices** (i.e., Product Modularity, Process Modularity, Dynamic Teaming, and Customer Closeness) were generated mainly from the product development literature and modular manufacturing literature (Ulrich and Tung, 1991; Baldwin and Clark, 1997; Feitzinger and Lee, 1997). Finally, the items for **Mass Customization Capability** (i.e., Customization cost effectiveness, Customization volume effectiveness, and Customization responsiveness) were generated primarily from some early works on mass customization by Pine (1993), Boynton et al. (1993), Kotha (1995, 1996), and Duray (1997).

3.2. Pre-pilot Study

To further ensure content validity, the measurement items generated from literature review were pre-tested with four manufacturing managers in the Midwest region of U.S. and six faculty members at a large state university.

The structured interviews with practitioners consist of two major steps. First, the definition of each research construct was presented to practitioners and some open-ended questions were asked about what they think should be representative questions / sub-dimensions for that construct. In the second step, a "Q-Sort" methodology was applied to the interviews. One 3" by 5" card was printed for each item generated from literature review. The set of cards for each construct were shuffled and given to the practitioners. The definitions of the entire construct and each of its sub-dimensions were also presented. The practitioners were then asked to put each card under each of the sub-dimensions to their best knowledge. Items considered not belong to any of the existing dimensions were taken out and new dimensions were suggested if applicable. If an item falls under a different dimension as previously conceived, questions were asked about why they think so. During the process, the practitioner may also suggest combining two possibly overlapping dimensions. The interview results from all practitioners were then carefully analyzed and a common pattern of thinking was recognized, which forms the basis for further revision of measurement items and construct dimensions.

A copy of the revised definitions and measurement items were then sent to twelve faculty members to solicit their comments on the appropriateness of the measures. They have the opportunity to suggest "Keep", "Drop" or "Modify" each item. They can also suggest new construct dimensions if they feel that the existing dimensions do not cover the entire content domain. Six faculty members responded with comments. The instruments were again revised based on those comments.

3.3. Pilot Study Methodology

Administering a small-scale pilot study prior to the large-scale administration provides valuable preliminary information about the reliability and validity of the measurement scales. It offers a last opportunity to further purify the scales. A pilot study questionnaire was sent out to 1000 manufacturing managers of medium to large size companies nationwide. The mailing list was extracted from the national manufacturers directory published by Manufacturer's News, Inc.. All target respondents have a job title of "VP Manufacturing", "Manufacturing Manager", "Plant Manager", "Manufacturing Director", "Production Manager" or "Plant Operations Manager". The following SIC codes were applied: 25 Furniture and Fixtures; 30 Rubber and Miscellaneous Plastic Products; 34 Fabricated Metal Products; 35 Industrial Machinery and Equipment; 36

Electronic and Other Electric Equipment; 37 Transportation Equipment; 38 Instruments and Related Products. As suggested by previous studies, manufacturing plants within these SIC classifications are more likely to adopt advanced manufacturing technologies and product customization (Parthasarthy and Sethi, 1993; Duray, 1997).

There were 43 responses of which 40 were complete thus usable. This sample can help provide preliminary assessments on the reliability and validity of the pilot study instrument as well as offer clear directions on how to further refine the instrument items.

A major task of the pilot study analysis is item purification to ensure scale reliability. Reliability concerns the extent to which a measurement scale yields the same results on repeated tests. Thus it's a measure of scale consistency. The current study uses the most popular method of evaluating scale reliability, i.e., the internal consistency method which uses Cronbach's alpha (Cronbach, 1951) as indicator of reliability. Alpha values over 0.7 are considered acceptable (Nunnally, 1978). A slightly lower alpha value for a scale with smaller number of items may be considered at this pilot study stage.

For the purpose of item purification, the Corrected Item-Total Correlation (CITC) will be calculated for each item (Kerlinger, 1978). An item will be eliminated if its correlation with the corrected item total is below 0.50. A slightly lower CITC may be acceptable if that item is considered to be important to the construct. With an appropriate sample size, a dimension-level factor analysis may be used to assess the unidimensionality of each measurement scale. Dimension-level factor analysis can also provide useful directions for possible merge or split of existing construct dimensions. If a construct-level factor analysis is not possible due to smaller sample size, correlation coefficients will be checked to ensure discriminant validity of measurement scales.

3.4. Pilot Study Results and Item Modification

The data from the 40 pilot test responses were entered into a SPSS database and then analyzed following the pilot study methodology described above. Sections 3.4.1 through 3.4.5 will present the pilot test results for each of the following constructs: Absorptive Capacity, Information Systems Usage, Advanced Manufacturing Technology Usage, Modularity-Based Manufacturing Practices, and Mass Customization Capability. For each construct, there will be generally three tables to present the results: 1) the initial pilot study items and their corresponding code names; 2) the dimension-level corrected item-total correlation (CITC) scores, alphas if deleted, and Cronbach's alpha scores; 3) Due to the small pilot sample size, construct-level factor analyses are usually very unstable, thus the third table will present the dimension-level factor loading scores to check for the unidimensionality of each construct. Section 3.4.6 will discuss the instruments that were not fully tested in the pilot study.

3.4.1. Absorptive Capacity (AC)

The Absorptive Capacity construct was initially represented by four dimensions and 27 items: Existing Knowledge Base (EK) (4 items), Knowledge Scanning (KS) (9 items), Communications Network (CN) (7 items), and Communications Climate (CC) (7 items). The original 27 items and their corresponding code names are listed in Table 3.4.1.1.

Table 3.4.1. 1. Absorptive Capacity - Pilot Study Items

Code Names	*Questionnaire Items*
Existing Knowledge Base (EK)	
EK1	The general knowledge level of our employees is high
EK2	The knowledge of our managers is adequate when making business decisions
EK3	The technical knowledge of our employees is high
EK4	The knowledge of our managers is adequate when dealing with new technologies
Knowledge Scanning (KS)	
KS1	We track new technological and market trends in our industry
KS2	We search for useful information routinely
KS3	We have regular employee training programs
KS4	We seek to learn from our competitors through benchmarking
KS5	We try out new technologies more often than our competitors
KS6	We seek to learn from our customers and suppliers
KS7	We seek new business opportunities proactively
KS8	We have intensive R&D activities
KS9	We reward our employees for learning new skills
Communications Network (CN)	
CN1	There are frequent and extensive communications among functional areas
CN2	The communications between departments are hindered by clear boundaries
CN3	The information flows tend to be top-down rather than bottom-up
CN4	There are frequent and extensive communications between supervisors and their subordinates
CN5	The communications among different departments tend to be informal
CN6	Ideas from one function or department can be easily communicated to others
CN7	Information has to pass through many hierarchical levels before it reaches its final destination
Communications Climate (CC)	
CC1	Employees tend to trust each other
CC2	Management encourages experimental mind-set and risk-taking
CC3	Employees and functional managers are supportive of each other
CC4	Employees have strong feelings of belonging to our organization
CC5	We have a very open communications environment
CC6	We have no difficulty implementing new ideas in our organization
CC7	Employees share ideas freely with each other

Item Purification. An initial reliability analysis for the Existing Knowledge Base (EK) items showed an alpha score of only 0.48, and CITC scores for all EK items were all below 0.40. This signifies possible multiple underlying dimensions. A dimension-level factor analysis for the EK items revealed two distinctive factors. The results are displayed in Table 3.4.1.2.

Table 3.4.1. 2. Dimension-Level Factor Analysis for Existing Knowledge Base

Item	*Factor Loadings*	
EK1	0.92	
EK3	0.92	
EK2		0.91
EK4		0.91

A closer look at the EK items shows that EK1 and EK3 represent first-line worker knowledge base, while EK2 and EK4 represent management knowledge base. Reliability analysis were then conducted for both sub-dimensions, resulting in an alpha score of 0.81 and 0.78 respectively, and all CITC scores were above 0.60.

Examination of CITC scores for all other dimensions resulted in the elimination of four Knowledge Scanning (KS) items (KS3, KS4, KS6, KS9), four Communications Network (CN) items (CN3, CN4, CN5, CN7), and one Communications Climate (CC) item (CC2) due to their low CITC scores. The CITC scores for all remaining items in CN and CC dimensions were well above 0.50. But for the KS dimension, the CITC scores for some items were still below 0.50 even after purification, and no further improvements could be made. This indicates the need for some major item revisions and rewording in this dimension. The final alphas were 0.61 for KS (5 items), 0.74 for CN (3 items), and 0.81 for CC (6 items). Table 3.4.1.3. presents the item purification results.

Table 3.4.1. 3. Absorptive Capacity - Item Purification Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Existing Knowledge Base (EK)				
EK1	0.34	0.68	NA	α=0.81
EK3	0.38	0.68	NA	
EK2	0.24	0.66	NA	α=0.78
EK4	0.17	0.66	NA	
Knowledge Scanning (KS)				
KS1	0.43	0.53	0.49	α=0.61
KS2	0.36	0.32	0.58	
KS5	0.36	0.44	0.51	
KS7	0.30	0.30	0.59	
KS8	0.45	0.34	0.60	
KS3	0.19	Items dropped after purification		
KS4	0.19			
KS6	0.33			
KS9	0.15			
Communications Network (CN)				
CN1	0.41	0.51	0.71	α=0.74
CN2	0.66	0.61	0.61	
CN6	0.62	0.60	0.63	
CN3	0.27	Items dropped after purification		
CN4	0.20			
CN5	0.17			
CN7	0.29			
Communications Climate (CC)				
CC1	0.56	0.54	0.79	α= 0.81
CC3	0.54	0.54	0.79	
CC4	0.49	0.44	0.82	
CC5	0.71	0.71	0.76	
CC6	0.58	0.62	0.77	
CC7	0.58	0.65	0.77	
CC2	0.34	Item dropped after purification		

Dimension-Level Factor Analysis. To further ensure the unidimensionality of each dimension in the Absorptive Capacity construct, a dimension-level factor analysis was run for each of the four dimensions in Absorptive Capacity. As discussed above, the EK dimension revealed two sub-dimensions with all factor loadings above 0.90. A single factor emerged for all other dimensions with most factor loadings over 0.60. The factor analysis results are displayed in Table 3.4.1.4.

Table 3.4.1. 4. Absorptive Capacity - Dimension-Level Factor Analysis

Items	*Factor Loadings*	
Existing Knowledge Base (EK)		
EK1	Employee Knowledge Base	0.92
EK3		0.92
EK2	Management Knowledge Base	0.91
EK4		0.91
Knowledge Scanning (KS)		
KS1	0.79	
KS2	0.64	
KS5	0.64	
KS7	0.55	
KS8	0.55	
Communications Network (CN)		
CN1	0.77	
CN2	0.84	
CN6	0.83	
Communications Climate (CC)		
CC1	0.68	
CC3	0.68	
CC4	0.61	
CC5	0.84	
CC6	0.77	
CC7	0.78	

Item Revisions. The pilot study results provided some very clear directions on how to further revise the instrument items before large-scale mailing. The EK dimension revealed two sub-dimensions, it was thus determined that EK dimension be split into two dimensions, i.e., First-line Worker Knowledge Base and Management Knowledge Base. Since the two items for each dimension were considered to be insufficient, at least two items will be added to each dimension. A closer examination of the KS items showed that the wording for some items was unclear or even misleading, thus some significant changes and rewording will be necessary. For the CN dimension, although the remaining three items displayed good reliability and unidimensionality, some items considered to be important for this concept domain were dropped due to inappropriate wording. Thus additional items carefully reworded will be designed for CN dimension. The items for CC dimension also require some minor revisions.

3.4.2. Information Systems Usage (ISU)

The Information Systems Usage construct was initially represented by four dimensions and 25 items: Operational Decision Support (ODS) (4 items), Strategic Planning Support (SPS) (5 items), External Integration (EXI) (8 items), and Internal Integration (INI) (8 items). The original 25 items and their corresponding code names are listed in Table 3.4.2.1.

Item Purification. Examination of CITC scores for the four dimensions in Information Systems Usage (ISU) resulted in the elimination of one Operational Decision Support (ODS) item (ODS4) and three Internal Integration (INI) items (INI3, INI4, INI8) due to their relatively low CITC scores. The CITC scores for all remaining items in ODS, SPS and External Integration (EXI) dimensions were above 0.50. But for the INI dimension, the CITC scores for most items were still below 0.50 even after purification, and no further improvements could be made by simply removing items. This indicates the need for some major item revisions and rewording in this dimension. The final alphas were 0.83 for ODS (3 items), 0.86 for SPS (5 items), 0.87 for EXI (8 items), and 0.66 for INI (5 items). Table 3.4.2.2. presents the item purification results.

Dimension-Level Factor Analysis. To further ensure the unidimensionality of each dimension in the Information Systems Usage construct, a dimension-level factor analysis was run for each of the four dimensions. A single factor emerged for all four dimensions with most factor loadings above 0.70. The factor analysis results are displayed in Table 3.4.2.3.

Item Revisions. The ODS measure displayed good reliability and unidimensionality, but consist of only 3 items. A few more items for the ODS dimension are required. No major problem was found in the SPS and EXI instruments, only some minor item rewording was done to further improve their internal consistency. As discussed above, the INI dimension measure scored relatively low on reliability and unidimensionality assessments. A closer examination of the INI items showed that the wording for some items was unclear and respondents sometimes confuse them with the items in the ODS dimension. Thus the INI items underwent major revisions to emphasize their common core of internal information sharing rather than providing decision support.

Table 3.4.2. 1. Information Systems Usage - Pilot Study Items

Code Names	*Questionnaire Items*
Operational Decision Support (ODS)	
ODS1	help justify operational decisions
ODS2	improve the efficiency of our operational decision processes
ODS3	analyze why problems occur in daily operations
ODS4	control or shape the operational decision process
Strategic Planning Support (SPS)	
SPS1	improve the effectiveness of our strategic planning processes
SPS2	help creating new ways of doing business
SPS3	help formulate our long-term business plans
SPS4	be a strategic weapon to generate long-term competitive advantage
SPS5	help justify our long-term business plans
External Integration (EXI)	
EXI1	exchange information with government agencies
EXI2	facilitate supplier involvement in our product design and production processes
EXI3	keep in contact with research institutions
EXI4	keep suppliers informed of our specific requirements
EXI5	collect information about customer requirements
EXI6	keep track of new trends in our industry
EXI7	keep in touch with customers
EXI8	benchmark best practices of our industry
Internal Integration (INI)	
INI1	organize information needed in daily operations
INI2	keep supervisors informed of the work progress of subordinates
INI3	distribute information needed in daily operations
INI4	access information needed in daily operations
INI5	facilitate information sharing between supervisors and subordinates
INI6	help employees get feedback on their performance
INI7	coordinate activities of different departments
INI8	share information among different departments

Table 3.4.2. 2. Information Systems Usage - Item Purification Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Operational Decision Support (ODS)				
ODS1	0.62	0.65	0.80	α=0.83
ODS2	0.72	0.80	0.67	
ODS3	0.70	0.64	0.82	
ODS4	0.49	Item dropped after purification		
Strategic Planning Support (SPS)				
SPS1	0.68	0.68	0.84	α=0.86
SPS2	0.59	0.59	0.86	
SPS3	0.72	0.72	0.83	
SPS4	0.66	0.66	0.84	
SPS5	0.80	0.80	0.81	
External Integration (EXI)				
EXI1	0.64	0.64	0.85	α=0.87
EXI2	0.69	0.69	0.85	
EXI3	0.61	0.61	0.86	
EXI4	0.67	0.67	0.85	
EXI5	0.64	0.64	0.86	
EXI6	0.60	0.60	0.86	
EXI7	0.59	0.59	0.86	
EXI8	0.59	0.59	0.86	
Internal Integration (INI)				
INI1	0.49	.37	.62	α= 0.66
INI2	0.32	.36	.63	
INI5	0.48	.45	.59	
INI6	0.45	.56	.52	
INI7	0.36	.33	.64	
INI3	0.27	Items dropped after purification		
INI4	0.32			
INI8	0.34			

Table 3.4.2. 3. Information Systems Usage - Dimension-Level Factor Analysis

Items	*Factor Loadings*
Operational Decision Support (ODS)	
ODS1	0.86
ODS2	0.93
ODS3	0.81
Strategic Planning Support (SPS)	
SPS1	0.81
SPS2	0.70
SPS3	0.84
SPS4	0.75
SPS5	0.90
External Integration (EXI)	
EXI1	0.68
EXI2	0.79
EXI3	0.66
EXI4	0.79
EXI5	0.76
EXI6	0.64
EXI7	0.76
EXI8	0.72
Internal Integration (INI)	
INI1	0.65
INI2	0.61
INI5	0.77
INI6	0.74
INI7	0.58

3.4.3. Advanced Manufacturing Technology Usage (AMTU)

The Advanced Manufacturing Systems Usage construct was initially represented by two dimensions and 17 items: Manufacturing Equipment and Process Technologies (MEP) (7 items), and Manufacturing Planning and Control Technologies (MPC)

(10 items). The original 17 items and their corresponding code names are listed in Table 3.4.3.1.

Table 3.4.3. 1. Advanced Manufacturing Technology Usage - Pilot Study Items

Code Names	*Questionnaire Items*
Manufacturing Equipment and Process Technologies (MEP)	
MEP1	We use computer numerical controlled machines
MEP2	We use automated inspection and testing equipment
MEP3	We use automated storing and retrieving systems
MEP4	We use conveyors to deliver parts to work centers
MEP5	We use automated guided vehicles to deliver parts and tools
MEP6	We use industrial robots in work centers
MEP7	We use flexible manufacturing systems
Manufacturing Planning and Control Technologies (MPC)	
MPC1	We use computer-aided technology to monitor the production process and provide feedback
MPC2	We use computer-aided technology to determine routings between machines
MPC3	We use computer-based prototyping in product design
MPC4	We use computer-aided technology to facilitate production by classifying parts into families according to similarities
MPC5	We use just-in-time production control system
MPC6	We use product-oriented layout (manufacturing cells) to produce a family of parts
MPC7	We use computer-aided technology to plan machining operations
MPC8	We use computer systems to plan and control material requirements
MPC9	We use computer systems to manage manufacturing resources and the interfaces with marketing and finance
MPC10	We use computer-aided technology to automate parts and tools design processes

Item Purification. Examination of CITC scores for the two dimensions in the Advanced Manufacturing Technology Usage (AMTU) construct resulted in the elimination of one Manufacturing Equipment and Process Technologies (MEP) item (MEP6) and four Manufacturing Planning and Control Technologies (MPC) items (MPC3, MPC5, MPC6, MPC9). The final CITC scores for all remaining items in MEP and MPC dimensions were above 0.50. The final alphas were 0.80 for MEP dimension (6 items), and 0.90 for MPC dimension (6 items). Table 3.4.3.2. presents the item purification results.

Table 3.4.3. 2. Advanced Manufacturing Technology Usage - Item Purification Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Manufacturing Equipment and Process Technologies (MEP)				
MEP1	0.60	0.57	0.77	**α=0.80**
MEP2	0.77	0.70	0.74	
MEP3	0.56	0.53	0.78	
MEP4	0.46	0.50	0.79	
MEP5	0.45	0.51	0.78	
MEP7	0.56	0.57	0.77	
MEP6	0.43	Item dropped after purification		
Manufacturing Planning and Control Technologies (MPC)				
MPC1	0.62	0.72	0.89	**α = 0.90**
MPC2	0.74	0.75	0.89	
MPC4	0.75	0.86	0.87	
MPC7	0.82	0.83	0.87	
MPC8	0.63	0.72	0.89	
MPC10	0.49	0.56	0.90	
MPC3	0.49	Items dropped after purification		
MPC5	0.24			
MPC6	0.11			
MPC9	0.25			

Dimension-Level Factor Analysis. To further ensure the unidimensionality of each dimension in the Advanced Manufacturing Technology Usage construct, a dimension-level factor analysis was run for each of the two dimensions. A single factor emerged for both dimensions with most factor loadings over 0.60. The factor analysis results are displayed in Table 3.4.3.3.

Table 3.4.3. 3. Advanced Manufacturing Technology Usage - Dimension Level Factor Analysis Results

Items	*Factor Loadings*
Manufacturing Equipment and Process Technologies (MEP)	
MEP1	0.55
MEP2	0.70
MEP3	0.69
MEP4	0.71
MEP5	0.66
MEP7	0.58
Manufacturing Planning and Control Technologies (MPC)	
MPC1	0.64
MPC2	0.77
MPC4	0.86
MPC7	0.87
MPC8	0.79
MPC10	0.66

Item Revisions. No major problem was found on the MEP dimension, but rewriting of some items will be necessary to improve consistency across items. Four items were dropped from the MPC dimension, including Just-In-Time Production and Cellular Manufacturing. It appeared that some manufacturing managers do not consider them to be manufacturing technologies, but a philosophy of organizing production. In fact, some of these concepts have already been covered under the construct of Time-Based Manufacturing Practices. It was thus determined that these items could be reasonably dropped from the AMTU construct.

3.4.4. Modularity-Based Manufacturing Practices (MBMP)

The Modularity-Based Manufacturing Practices construct was initially represented by four dimensions and 21 items: Product Modularity (PM) (9 items), Process Modularity (PRM) (4 items), Dynamic Teaming (DT) (4 items), and Customer Closeness (CUC) (4 items). The original 21 items and their corresponding code names are listed in Table 3.4.4.1.

Item Purification. Examination of CITC scores for all dimensions in the Modularity-Based Manufacturing Practices (MBMP) construct resulted in the elimination of three Product Modularity (PM) items (PM3, PM8, PM9), one Process Modularity (PRM) item (PRM3), and one Customer Closeness (CUC) item (CUC1). The final CITC scores for the remaining items in PM, DT and CUC dimensions were all above or very close to 0.50. But for the PRM dimension, the CITC scores for all items were still below 0.50 even after purification, and no further improvements could be made. This indicated the need for some major item revisions and rewriting in this dimension. The final alphas were 0.81 for PM (6 items), 0.61 for PRM (3 items), 0.79 for DT (4 items), and 0.93 for CUC (3 items). Table 3.4.4.2. presents the item purification results.

Dimension-Level Factor Analysis. To further ensure the unidimensionality of each dimension in the Absorptive Capacity construct, a dimension-level factor analysis was run for each of the four dimensions in Absorptive Capacity. A single factor emerged for all dimensions with all factor loadings over 0.60. The factor analysis results are displayed in Table 3.4.4.3.

Table 3.4.4. 1. Modularity-Based Manufacturing Practices - Pilot Study Items

Code Names	*Questionnaire Items*
	Product Modularity (PM)
PM1	Our product features are designed around a standard base unit
PM2	We can add product options to a standard unit
PM3	Our products are designed around common core technology
PM4	Our products are typically designed as detachable modules
PM5	End-users can customize our products by rearranging product components
PM6	We can reassemble product modules into different forms
PM7	Customization features are typically added at the end of our production process
PM8	Our products share common components
PM9	Customization features are usually designed into our products
	Process Modularity (PRM)
PRM1	Our production process can be altered by adding new process modules as needed
PRM2	Our production process is designed as detachable modules
PRM3	Our production process is designed around core sub-processes
PRM4	Our production process can be easily rearranged to meet different product needs
	Dynamic Teaming (DT)
DT1	Production teams are used in our plant
DT2	Our production teams can be reorganized in response to product/process changes
DT3	Our production team members are capable of working under different product and process configurations
DT4	Our production teams have no difficulty accessing necessary resources
	Customer Closeness (CUC)
CUC1	Our manufacturing department communicate with customers directly
CUC2	We monitor changes in customer needs through close contacts
CUC3	We keep close contact with customers
CUC4	We help customers clarify their needs through close contacts

Table 3.4.4. 2. Modularity-Based Manufacturing Practices - Item Purification Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Product Modularity (PM)				
PM1	0.58	0.60	0.78	α=0.81
PM2	0.68	0.70	0.75	
PM4	0.44	0.50	0.80	
PM5	0.51	0.50	0.80	
PM6	0.70	0.70	0.76	
PM7	0.43	0.47	0.80	
PM3	0.15	Item dropped after purification		
PM8	0.30			
PM9	0.19			
Process Modularity (PRM)				
PRM1	0.41	0.38	0.57	α=0.61
PRM2	0.39	0.49	0.42	
PRM4	0.39	0.40	0.54	
PRM3	0.08	Item dropped after purification		
Dynamic Teaming (DT)				
DT1	0.55	0.55	0.77	α=0.79
DT2	0.62	0.62	0.73	
DT3	0.72	0.72	0.68	
DT4	0.52	0.52	0.78	
Customer Closeness (CUC)				
CUC2	0.76	0.84	0.90	α= 0.93
CUC3	0.80	0.86	0.90	
CUC4	0.80	0.88	0.88	
CUC1	0.39	Items dropped after purification		

Table 3.4.4. 3. Modularity-Based Manufacturing Practices - Dimension-Level Factor Analysis Results

Items	*Factor Loadings*
Product Modularity (PM)	
PM1	0.66
PM2	0.70
PM4	0.62
PM5	0.68
PM6	0.83
PM7	0.60
Process Modularity (PRM)	
PRM1	0.63
PRM2	0.76
PRM4	0.78
Dynamic Teaming (DT)	
DT1	0.68
DT2	0.81
DT3	0.87
DT4	0.64
Customer Closeness (CUC)	
CUC2	0.91
CUC3	0.94
CUC4	0.92

Item Revisions. The items in DT and CUC dimensions displayed least problem and best internal consistency, but further literature search showed that the fewer items in these two dimensions were not sufficient. Thus some new items will be designed and added in the large-scale questionnaire. For the PM dimension, slightly low CITC scores for some items (PM4, PM5, PM7) indicated the need for item revisions to eliminate ambiguity. The major problem was found in the PRM dimension with unsatisfactory CITC and reliability scores. The cause for the problem might be twofold. First, Process Modularity is a fairly new concept to most manufacturing managers, and process modularity practices are even less well known. Thus the respondents lack a common understanding of the concept. Second, the conceptualization of process modularity might not be effectively conveyed to respondents due to ambiguity of some items. Therefore, it was decided that the PRM dimension require major revision of existing items and design of new items based on further literature search.

3.4.5. Mass Customization Capability (MCC)

The Mass Customization Capability (MCC) construct was initially represented by only one dimension and 4 items. The original 4 items and their corresponding code names are listed in Table 3.4.5.1.

Item Purification. Examination of CITC scores for the four items in Mass Customization Capability (MCC) construct resulted in the elimination of one item (MCC2). The CITC scores for all remaining items in MCC dimension are above 0.50. The final alpha was 0.75 for the three items. Table 3.4.5.2. presents the item purification results.

Exploratory Factor Analysis. To further ensure the unidimensionality of the Mass Customization Capability construct measurement, exploratory factor analysis was run on the three items. A clear single factor emerged with all factor loadings above 0.70. The factor analysis results are displayed in Table 3.4.5.3.

Item Revisions. Although the MCC items displayed good reliability and unidimensionality, the resulting three items were considered to be insufficient when more literature was gathered on this construct. In addition, these initial items put more emphasis on customization responsiveness while items on customization cost effectiveness and volume effectiveness were relatively weak. Therefore, it was determined that more items will be designed based on an expanded literature search, so that the instrument can reflect a more complete construct domain.

Table 3.4.5. 1. Mass Customization Capability – Pilot Study Items

Code Names	*Questionnaire Items*
MCC1	We can quickly translate customer requirements into technical designs
MCC2	We can quickly reorganize our production processes in response to customization requirements
MCC3	We respond more quickly to customization requirements than our competitors do
MCC4	We can produce customized products with lead time and cost comparable to mass-produced products

Table 3.4.5. 2. Mass Customization Capability - Item Purification Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
MCC1	0.58	0.57	0.69	α=0.75
MCC3	0.63	0.61	0.66	
MCC4	0.58	0.60	0.66	
MCC2	0.49	Item dropped after purification		

Table 3.4.5. 3. Mass Customization Capability - Dimension - Level Factor Analysis

Items	*Factor Loadings*
Mass Customization Capability (MCC)	
MCC1	0.79
MCC3	0.84
MCC4	0.80

3.4.6. Pilot Study Conclusion

The pilot study results provided preliminary reliability and validity information on the survey instrument, which requires further revision. During final revision process, the four manufacturing managers and six faculty members used in the pre-pilot study were again consulted to comment on the items while presenting them with the pilot study results. By integrating the feedback comments, further literature study, and the pilot analysis results, some items were dropped due to low CITC scores or by suggestion, some were reworded to eliminate ambiguity and improve the internal consistency of sub-dimensions, and several new items were also developed in an effort to cover a more complete construct domain. This revision process went on until a satisfactory version of final survey instrument was reached and ready for the large-scale administration.

CHAPTER 4: INSTRUMENT DEVELOPMENT (2) – LARGE-SCALE ADMINISTRATION AND INSTRUMENT VALIDATION

4.1. Large-scale Data Collection Methodology

One important success factor in an empirical study is the quality of respondents. The respondents are expected to have detailed knowledge on multiple topic areas in the survey. In the case of the current study, the respondents are expect to have experience in different levels of manufacturing management. It is also desirable that the respondents are representative of different geographical areas, industries, and firm sizes, so that the results can be generalizable. Based on these thoughts, the large-scale mailing list was obtained from the Society of Manufacturing Engineers (SME), an internationally well-known organization of manufacturing managers and engineers, with 65,000 active members all over the world and in almost every industry.

The initial mailing list contained 4,000 names randomly selected from the SME United States membership database. Priorities were given to members in the following SIC classifications: 25 Furniture and Fixtures; 30 Rubber and Miscellaneous Plastic Products; 34 Fabricated Metal Products; 35 Industrial Machinery and Equipment; 36 Electronic and Other Electric Equipment; 37 Transportation Equipment; 38 Instruments and Related Products. Previous studies indicated that manufacturing plants within these SIC classifications are more likely to adopt advanced manufacturing technologies and product customization (Parthasarthy and Sethi, 1993; Duray, 1997).

This mailing list was then further refined through the following steps: 1) Some names did not have company affiliations, and the mailing addresses were deemed to be home addresses. These names were removed in consideration of home privacy of respondents; 2) If there were multiple names from the same company, the person with the most relevant job title was picked and the others were removed; 3) The names with obviously inappropriate job titles to the current study were removed, such as "Chief Financial Officer" and "Materials Manager". The remaining names mostly have the title of "Manufacturing Manager", "VP of Manufacturing", "Manufacturing Director", "Plant Manager", "Production Manager", or "Operations Manager". These higher level manufacturing managers should have enough experience to respond to the questions. 4) Some obvious errors in names and mailing addresses were also corrected. The refinement resulted in a list of 3109 names. Since the surveys were sent by bulk mail, the mailing addresses had to be filtered again by a post office program to satisfy certain standard. This resulted in the removal of another 278 names. Therefore, the final mailing list contained 2831 names.

The finalized version of questionnaire was administered through large-scale mailing to these 2831 manufacturing managers from SME membership. To ensure a reasonable response rate, the survey was administered in three stages. First, a copy of the questionnaire with a cover letter describing the purpose and significance of the current study was mailed to the 2831 manufacturing managers. Two weeks later, a follow-up letter was mailed to each of the target respondents to remind them of filling out the survey. The names of those who responded were then removed from the original mailing list. After another two weeks, a second follow-up letter with a copy of the questionnaire was sent to those who still had not responded.

There were a total of 320 responses from the mailings. Of these responses, seven letters indicate that the target respondent is no longer an employee at the company. Seven questionnaires were returned empty with notes indicating that the survey does not apply to their specific industry, or they do not have time to fill out the survey. Another three responses were determined to be incomplete or unsuitable for further analysis. Therefore, the final number of complete and usable responses was 303, representing an overall response rate of 10.7%, which is considered to be satisfactory. Detailed demographic information of the 303 respondents, such as industry classification and firm size, is provided in Appendix I.

An important concern in data collection has been whether the sample is representative of the population. Because the original mailing list did not provide demographic information on the target respondents, there is no way to compare the 303 respondents with the non-respondents. However, because the questionnaire was administered in two rounds, it offered a unique opportunity to check for possible non-respondent bias. According to the time log, the 303 responses came in two batches as a result of the two mailings. The first batch has 123 responses and the second batch as 180 responses. The non-respondent bias analysis was done by treating the first batch as respondents and the second batch as non-respondents. The respondents and non-respondents were compared on the basis of firm size, industry type, and sales volume. No significant differences were found. It was thus concluded that non-respondent bias was not a cause for concern. The comparisons were listed in Appendix II.

4.2. Large-scale Instrument Assessment Methodology

The survey instrument used in the large-scale study was then submitted to rigorous reliability and validity assessment using the 303 responses. The reliability assessment process was similar to that of the pilot study. The primary difference lies in the instrument validation process. In the large-scale study, the sample size was large enough for construct level exploratory factor analysis to assess the unidimensionality, convergent validity and discriminate validity of each measurement instrument to be developed. The predictive validity of the measures was also examined by linking the independents variables with their relevant dependent variables.

The statistical package SPSS 8.0 for Windows was used to conduct all the statistical analysis. The instrument items were first purified by examining the Corrected Item-to-Total Correlation (CITC) scores of each item with respect to a specific dimension of a construct. The CITC score is a very good indicator of how well each item contribute to the internal consistency of a particular construct dimension as measured by the Cronbach's Alpha coefficient (Cronbach, 1951). As a general rule, items with an CITC score of lower than 0.50 should be removed. However, a slightly lower CITC score may be acceptable if that particular item is considered to be important to the construct dimension. On the other hand, certain items with CITC score above 0.50 may also be removed if their deletion can improve the overall reliability of the specific dimension. This can be determined by examining the "Alpha if deleted" score. Also, it must be noted that low CITC scores may sometimes indicate multiple underlying factors in the current dimension.

To further ensure the unidimensionality and convergent validity of measurement instrument, the purified items under each construct dimension were submitted as a group to dimension-level exploratory factor analysis. Factor analysis is an important data reduction and summarization method. It analyzes the interrelationships among a large number of variables and then explains these variables in terms of their common underlying dimensions (factors). One of the first decisions in factor analysis is to choose a factor extraction method and the type of input matrix. The widely accepted Principal Component analysis method was selected and the correlation matrix was used as input.

Another important decision in factor analysis is the type of factor rotation. By rotating the factor axes, researchers expect to achieve a simpler, theoretically more meaningful factor pattern. The current study used the most popular VARIMAX factor rotation method. VARIMAX method focuses on simplifying the columns of the factor matrix, thus giving a clearer separation of the factors than any other methods (Hair et al., 1992, pp. 236). The MEANSUB command was used to replace the missing values with the mean score for that item.

A scale with good internal consistency should have all items load on one factor. If multiple factors emerged, the possibility of splitting the items into multiple dimensions was carefully examined, and theoretical justifications were sought.

The entire group of items under each construct was then put into a construct-level exploratory factor analysis to check for their discriminant validity among different dimensions. Once again, Principal Component extraction, VARIMAX rotation, and MEANSUB command were used. As a general rule of thumb, when the sample size is 50 or larger, factor loadings greater than 0.30 are considered to be significant; loadings of

0.40 are considered more important; and loadings of greater than 0.50 are very significant (Hair, et al., 1992, pp. 239). To ensure the high quality of instrument development process in the current study, 0.50 was used as the cutoff score for factor loadings, i.e., items with loadings lower than 0.50 will generally be removed. To streamline the final results, factor loadings below 0.4 were not reported. Items with serious cross-loadings (i.e., an item loaded very close to 0.50 on both factors) were generally dropped.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was calculated for all dimension-level and construct-level factor analysis. This measure ensures that the effective sample size is adequate for the current factor analysis. Generally, a KMO score in the 0.90's is considered outstanding, the 0.80's as very good, the 0.70's as average, 0.60's as tolerable, 0.50's as miserable, and below 0.50 as unacceptable.

Finally, the Cronbach's Alpha reliability coefficient were calculated for each dimension to make sure that they are all above the minimum suggested value. An Alpha score of higher than 0.70 is generally considered to be acceptable (Nunnally, 1978). To check for the predictive validity of the resulting measurement instrument, a composite score for each construct was calculated by taking the average of all remaining items in the construct. Pearson correlation coefficients among these composite construct measures were then calculated to determine the significance of hypothesized relationships.

4.3. Large-scale Study Results

The following sections will present the large-scale instrument validation results on each of the seven major constructs in the current study, including Absorptive Capacity (AC), Information Systems Usage (ISU), Advanced Manufacturing Technology

Usage (AMTU), Time-Based Manufacturing Practices (TBMP), Modularity-Based Manufacturing Practices (MBMP), Mass Customization Capability (MCC), and Value to Customer Performance (VCP). For each construct, the instrument assessment methodology described in the previous section was applied, and tables were provided to present the results: 1) The initial large-scale measurement items for the construct; 2) The dimension-level corrected item-total correlation (CITC) scores and Cronbach's alpha; 3) The dimension-level exploratory factor analysis results; 4) The construct-level factor analysis results; 5) The final Cronbach's alpha reliability coefficients (provided only if the factor analysis result in further modification of items); and 6) The final set of measurement items for the construct (not provided if there is no change in items after instrument validation).

4.3.1. Absorptive Capacity (AC)

The Absorptive Capacity (AC) construct was represented by five dimensions and 29 items in the large-scale questionnaire, including first-line Worker Knowledge (WK) (4 items), Management Knowledge (MK) (4 items), Knowledge Scanning (KS) (7 items), Communications Network (CN) (7 items), and Communications Climate (CC) (7 items). The original 29 items and their corresponding code names are listed in Table 4.3.1.1.

Reliability Analysis. An initial reliability analysis was done for each of the five Absorptive Capacity (AC) dimensions. The Corrected Item-Total Correlation (CITC) scores for all items in WK, MK and CC dimensions were above 0.50. For the KS dimension, item KS7 (We seek to learn from conducting R&D activities) had a CITC score of 0.48, slightly below 0.50. Considering the importance of item KS7 to this dimension, KS7 was kept at this stage. For the CN dimension, items CN6 and CN7 had respective CITC scores of 0.30 and 0.31, far below 0.50. Thus they were removed at this stage. The final Cronbach's Alpha scores were 0.87 for WK, 0.84 for MK, 0.80 for KS, 0.86 for CN, and 0.89 for CC. Table 4.3.1.2. presents the reliability analysis results.

Dimension-Level Exploratory Factor Analysis. To further ensure the unidimensionality and convergent validity of each dimension in the Absorptive Capacity construct, a dimension-level factor analysis was run for each of the five dimensions in Absorptive Capacity construct. A single factor emerged for each of the five dimensions with all factor loadings over 0.60 and most over 0.70. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were all close to or above 0.80. The factor analysis results are displayed in Table 4.3.1.3.

Construct-Level Exploratory Factor Analysis. In this step, all the remaining 27 AC items were submitted to a construct-level exploratory factor analysis to check for discriminant validity of the measurement instrument. Five factors emerged from the factor analysis with most factor loadings above 0.60 (Table 4.3.1.4). Cross-loading was observed on item CC5, thus CC5 was removed and the construct-level factor analysis was performed again. The final construct-level factor analysis results are shown in Table 4.3.1.5. The KMO score of 0.92 indicated outstanding sampling adequacy. The final set of measurement items for the Absorptive Capacity construct organized by factor loadings are shown in Table 4.3.1.6.

Table 4.3.1. 1. Absorptive Capacity - Large-Scale Study Items

Code Names	*Questionnaire Items*
Worker Knowledge (WK)	
WK1	The general knowledge level of our first-line workers is high
WK2	The overall technical knowledge of our first-line workers is high
WK3	The general educational level of our first-line workers is high
WK4	The overall job competence of our first-line workers is high
Management Knowledge (MK)	
MK1	The knowledge of our managers is adequate when making business decisions
MK2	The knowledge of our managers is adequate when dealing with new technologies
MK3	The knowledge of our managers is adequate when managing daily operations
MK4	The knowledge of our managers is adequate when solving technical problems
Knowledge Scanning (KS)	
KS1	We seek to learn from tracking new market trends in our industry
KS2	We seek to learn from routine search of useful information
KS3	We seek to learn from benchmarking best practices in our industry
KS4	We seek to learn from trying out new technologies
KS5	We seek to learn from our customers and suppliers
KS6	We seek to learn from taking new business opportunities
KS7	We seek to learn from conducting R&D activities
Communications Network (CN)	
CN1	The communications between supervisors and their subordinates are extensive
CN2	The communications among functional areas are extensive
CN3	The communications among functional areas are frequent
CN4	The communications between supervisors and their subordinates are frequent
CN5	The communication of new ideas from one department to another is extensive
CN6	The communications between departments are hindered by clear boundaries
CN7	The communications has to pass through many hierarchical levels in our firm
Communications Climate (CC)	
CC1	Our employees tend to trust each other
CC2	Our employees are supportive of each other
CC3	Our employees have strong feelings of belonging to our organization
CC4	Our employees share ideas freely with each other
CC5	Our employees share a very open communications environment
CC6	Our employees have no difficulty accepting new ideas
CC7	Our employees are willing to accept changes

Table 4.3.1. 2. Absorptive Capacity - Large-Scale Reliability Analysis Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Worker Knowledge (WK)				
WK1	0.77	0.77	0.81	α=0.87
WK2	0.79	0.79	0.80	
WK3	0.66	0.66	0.86	
WK4	0.68	0.68	0.85	
Management Knowledge (MK)				
MK1	0.70	0.70	0.77	α=0.84
MK2	0.67	0.67	0.79	
MK3	0.64	0.64	0.81	
MK4	0.67	0.67	0.79	
Knowledge Scanning (KS)				
KS1	0.55	0.55	0.78	α=0.80
KS2	0.55	0.55	0.78	
KS3	0.55	0.55	0.78	
KS4	0.59	0.59	0.77	
KS5	0.51	0.51	0.79	
KS6	0.56	0.56	0.78	
KS7	0.48	0.48	0.79	
Communications Network (CN)				
CN1	0.61	0.69	0.83	α=0.86
CN2	0.67	0.73	0.82	
CN3	0.64	0.69	0.84	
CN4	0.63	0.70	0.83	
CN5	0.60	0.63	0.85	
CN6	0.30	Items dropped after purification		
CN7	0.31			
Communications Climate (CC)				
CC1	0.71	0.71	0.87	α= 0.89
CC2	0.72	0.72	0.87	
CC3	0.65	0.65	0.87	
CC4	0.67	0.67	0.87	
CC5	0.70	0.70	0.87	
CC6	0.66	0.66	0.87	
CC7	0.68	0.68	0.87	

Table 4.3.1. 3. Absorptive Capacity - Large-Scale Dimension-Level Factor Analysis

Items	*Factor Loadings*
Worker Knowledge (WK) KMO = 0.82	
WK1	0.88
WK2	0.89
WK3	0.80
WK4	0.82
Management Knowledge (MK) KMO = 0.79	
MK1	0.84
MK2	0.82
MK3	0.80
MK4	0.82
Knowledge Scanning (KS) KMO = 0.86	
KS1	0.68
KS2	0.67
KS3	0.69
KS4	0.72
KS5	0.64
KS6	0.69
KS7	0.60
Communications Network (CN) KMO = 0.79	
CN1	0.81
CN2	0.84
CN3	0.81
CN4	0.82
CN5	0.76
Communications Climate (CC) KMO = 0.88	
CC1	0.80
CC2	0.81
CC3	0.76
CC4	0.77
CC5	0.79
CC6	0.74
CC7	0.76

Table 4.3.1. 4. Absorptive Capacity - Large-Scale Construct-Level Factor Analysis Results (1)

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.92				
	F1: CC	F2: KS	F3: CN	F4: WK	F5: MK
CC7	0.78				
CC6	0.74				
CC1	0.70				
CC2	0.67				
CC4	0.64				
CC5	0.57		0.47		
CC3	0.55				
KS6		0.69			
KS4		0.68			
KS1		0.65			
KS3		0.64			
KS5		0.56			
KS2		0.54			
KS7		0.51			
CN2			0.76		
CN3			0.74		
CN4			0.73		
CN1			0.71		
CN5			0.54		
WK2				0.83	
WK1				0.83	
WK4				0.70	
WK3				0.70	
MK4					0.78
MK3					0.75
MK1					0.74
MK2					0.63

Table 4.3.1. 5. Absorptive Capacity – Large-Scale Construct-Level Factor Analysis Results (2)

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.92				
	F1: CC	F2: KS	F3: CN	F4: WK	F5: MK
CC7	0.78				
CC6	0.73				
CC1	0.71				
CC2	0.68				
CC4	0.63				
CC3	0.55				
KS6		0.69			
KS4		0.69			
KS1		0.65			
KS3		0.64			
KS5		0.56			
KS2		0.54			
KS7		0.52			
CN2			0.76		
CN3			0.74		
CN4			0.72		
CN1			0.71		
CN5			0.55		
WK2				0.84	
WK1				0.83	
WK4				0.70	
WK3				0.70	
MK4					0.78
MK3					0.75
MK1					0.74
MK2					0.63
Eigen value	9.74	1.98	1.57	1.51	1.34
% of Variance Explained	37.4	7.6	6.0	5.8	5.2
Cumulative % of Variance	37.4	45.0	51.0	56.8	62.0

Table 4.3.1. 6. Absorptive Capacity - Final Construct Measurement Items

Code Names	*Measurement Items*
Communications Climate (CC)	
CC7	Our employees are willing to accept changes
CC6	Our employees have no difficulty accepting new ideas
CC1	Our employees tend to trust each other
CC2	Our employees are supportive of each other
CC4	Our employees share ideas freely with each other
CC3	Our employees have strong feelings of belonging to our organization
Knowledge Scanning (KS)	
KS6	We seek to learn from taking new business opportunities
KS4	We seek to learn from trying out new technologies
KS1	We seek to learn from tracking new market trends in our industry
KS3	We seek to learn from benchmarking best practices in our industry
KS5	We seek to learn from our customers and suppliers
KS2	We seek to learn from routine search of useful information
KS7	We seek to learn from conducting R&D activities
Communications Network (CN)	
CN2	The communications among functional areas are extensive
CN3	The communications among functional areas are frequent
CN4	The communications between supervisors and their subordinates are frequent
CN1	The communications between supervisors and their subordinates are extensive
CN5	The communication of new ideas from one department to another is extensive
Worker Knowledge (WK)	
WK2	The overall technical knowledge of our first-line workers is high
WK1	The general knowledge level of our first-line workers is high
WK4	The overall job competence of our first-line workers is high
WK3	The general educational level of our first-line workers is high
Management Knowledge (MK)	
MK4	The knowledge of our managers is adequate when solving technical problems
MK3	The knowledge of our managers is adequate when managing daily operations
MK1	The knowledge of our managers is adequate when making business decisions
MK2	The knowledge of our managers is adequate when dealing with new technologies

4.3.2. Information Systems Usage (ISU)

The Information Systems Usage (ISU) construct was initially represented by four dimensions comprising 25 items in the large-scale survey, including Operational Decision Support (ODS) (4 items), Strategic Planning Support (SPS) (5 items), External Integration (EXI) (9 items), and Internal Integration (INI) (7 items). The original 25 items and their corresponding code names are listed in Table 4.3.2.1.

Reliability Analysis. Initial reliability analysis for each of the four ISU dimensions showed that the CITC scores for all items were above 0.50. However, the "Alpha if deleted" score indicated that removing EXI1 would improve reliability of EXI dimension. Thus item EXI1 was dropped at this stage. The resulting Alphas were 0.81 for ODS (4 items), 0.93 for SPS (5 items), 0.91 for EXI (8 items), and 0.86 for INI (7 items). Table 4.3.2.2. presents the reliability analysis results.

Dimension-Level Exploratory Factor Analysis. To further ensure the unidimensionality of each dimension in the Information Systems Usage construct, dimension-level exploratory factor analysis was performed for each of the four dimensions. The results are displayed in Table 4.3.2.3. A single factor emerged for the ODS, SPS, and EXI dimensions with all factor loadings above 0.70.

Factor analysis of the INI dimension revealed two factors (Factor 1: INI1, INI2, INI3, INI6, INI7 and Factor 2: INI4, INI5). Referring to the contents of each item, Factor 2 does not make too much theoretical sense. It was thus decided that items INI4 and INI5 be removed. Dimension-level factor analysis was again performed on the remaining items of INI dimension. One clear factor emerged with all factor loadings above 0.70. The results are displayed in Table 4.3.2.4.

Table 4.3.2. 1. Information Systems Usage - Large-Scale Study Items

Code Names		*Questionnaire Items*
		Operational Decision Support (ODS)
ODS1	We Use IS to...	help justifying daily operational decisions
ODS2		help improving the efficiency of daily operational decision processes
ODS3		help analyzing why problems occur in daily operations
ODS4		help monitoring the daily operational decision processes
		Strategic Planning Support (SPS)
SPS1	We Use IS to...	help improving the effectiveness of long-term strategic planning processes
SPS2		help formulating long-term business plans
SPS3		help justifying long-term business plans
SPS4		help creating new ways of doing business
SPS5		help generating long-term strategic advantage
		External Integration (EXI)
EXI1	We Use IS to...	exchange information with government agencies
EXI2		collect information about best practices in our industry
EXI3		exchange information with research institutions
EXI4		collect information about customer requirements
EXI5		keep suppliers involved in our product design and production processes
EXI6		exchange information with customers
EXI7		keep suppliers informed of our specific requirements
EXI8		collect information about new technologies in our industry
EXI9		collect information about competitor products
		Internal Integration (INI)
INI1	We Use IS to...	facilitate information distribution throughout the organization
INI2		facilitate information sharing among employees
INI3		facilitate information sharing between different management levels
INI4		facilitate information feedback on employee work performance
INI5		facilitate reporting of employee work progress
INI6		facilitate information sharing among different departments
INI7		facilitate cross-functional cooperation within the organization

Table 4.3.2. 2. Information Systems Usage - Large-Scale Reliability Analysis Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Operational Decision Support (ODS)				
ODS1	0.62	0.62	0.77	α=0.81
ODS2	0.71	0.71	0.73	
ODS3	0.60	0.60	0.78	
ODS4	0.60	0.60	0.77	
Strategic Planning Support (SPS)				
SPS1	0.84	0.84	0.92	α=0.93
SPS2	0.82	0.82	0.92	
SPS3	0.85	0.85	0.91	
SPS4	0.77	0.77	0.93	
SPS5	0.84	0.84	0.92	
External Integration (EXI)				
EXI2	0.73	0.71	0.90	α=0.91
EXI3	0.75	0.71	0.90	
EXI4	0.67	0.67	0.91	
EXI5	0.75	0.76	0.90	
EXI6	0.66	0.67	0.91	
EXI7	0.69	0.72	0.90	
EXI8	0.76	0.77	0.90	
EXI9	0.73	0.74	0.90	
EXI1	0.50	Item dropped after purification		
Internal Integration (INI)				
INI1	0.62	0.62	0.84	α= 0.86
INI2	0.69	0.69	0.83	
INI3	0.65	0.65	0.84	
INI4	0.54	0.54	0.85	
INI5	0.56	0.56	0.85	
INI6	0.73	0.73	0.82	
INI7	0.63	0.63	0.84	

Table 4.3.2. 3. Information Systems Usage - Large-Scale Dimension-Level Factor Analysis Results (1)

Items	*Factor Loadings*	
Operational Decision Support (ODS) KMO = 0.75		
ODS1	0.80	
ODS2	0.85	
ODS3	0.77	
ODS4	0.77	
Strategic Planning Support (SPS) KMO = 0.89		
SPS1	0.89	
SPS2	0.89	
SPS3	0.91	
SPS4	0.85	
SPS5	0.90	
External Integration (EXI) KMO = 0.90		
EXI2	0.77	
EXI3	0.76	
EXI8	0.75	
EXI9	0.81	
EXI4	0.74	
EXI5	0.77	
EXI6	0.83	
EXI7	0.79	
Internal Integration (INI) KMO = 0.84		
INI1	0.75	
INI2	0.83	
INI3	0.84	
INI6	0.75	
INI7	0.62	
INI4		0.85
INI5		0.86

Table 4.3.2. 4. Information Systems Usage - Large-Scale Dimension-Level Factor Analysis Results (2)

Items	*Factor Loadings*
Internal Integration (INI) KMO = 0.83	
INI1	0.76
INI2	0.84
INI3	0.82
INI6	0.84
INI7	0.74

Construct-Level Exploratory Factor Analysis. In this step, all the remaining 22 ISU items were submitted to construct-level exploratory factor analysis to check for discriminant validity of the measurement instrument. The results were presented in Table 4.3.2.5. Four factors emerged from the factor analysis with all factor loadings above 0.50 and most above 0.60. Serious cross-loading occurred on item INI7. Hence item INI7 was dropped.

The remaining 21 items were again put into construct-level exploratory factor analysis. This time four clear factors emerged with all items loaded correctly on the expected dimensions. Most factor loadings were above 0.60. No cross-loading was observed. The KMO measure of 0.93 indicated outstanding sampling adequacy. The final construct-level factor analysis results are shown in Table 4.3.2.6.

Table 4.3.2. 5. Information Systems Usage - Large-Scale Construct-Level Factor Analysis Results (1)

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.93			
	F1: EXI	F2: SPS	F3: INI	F4: ODS
EXI8	0.78			
EXI9	0.75			
EXI5	0.75			
EXI2	0.71			
EXI3	0.71			
EXI7	0.71			
EXI4	0.69			
EXI6	0.68			
SPS3		0.86		
SPS2		0.83		
SPS1		0.82		
SPS5		0.80		
SPS4		0.71		
INI7		0.53	0.49	
INI3			0.83	
INI2			0.81	
INI6			0.71	
INI1			0.66	
ODS1				0.85
ODS2				0.81
ODS3				0.57
ODS4				0.53

Table 4.3.2. 6. Information Systems Usage - Large-Scale Construct-Level Factor Analysis Results (2)

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.93			
	F1: EXI	F2: SPS	F3: INI	F4: ODS
EXI8	0.78			
EXI9	0.75			
EXI5	0.75			
EXI2	0.72			
EXI3	0.71			
EXI7	0.71			
EXI4	0.69			
EXI6	0.68			
SPS3		0.86		
SPS2		0.84		
SPS1		0.82		
SPS5		0.79		
SPS4		0.70		
INI3			0.84	
INI2			0.81	
INI6			0.69	
INI1			0.67	
ODS1				0.85
ODS2				0.82
ODS3				0.56
ODS4				0.52
Eigen value	9.18	2.18	1.84	1.13
% of Variance Explained	43.7	10.4	8.8	5.4
Cumulative % of Variance	43.7	54.1	62.9	68.3

Due to further item purification after the initial reliability analysis, a final reliability analysis was done for the INI dimension to make sure that the final CITC scores and Alphas meet the suggested criteria. The results are presented in Table 4.3.2.7. All CITC scores were greater than 0.80, and the final Alphas was 0.85.

Table 4.3.2. 7. Information Systems Usage - Final Reliability Analysis Results

Items	CITC	Alpha if deleted	Alpha Score
Internal Integration (INI)			
INI1	0.64	0.83	α= 0.85
INI2	0.73	0.80	
INI3	0.74	0.79	
INI6	0.68	0.82	

The final set of measurement items for the Information Systems Usage construct organized by factor loadings are shown in Table 4.3.2.8.

Table 4.3.2. 8. Information Systems Usage - Final Construct Measurement Items

Code Names		*Questionnaire Items*
Factor 1: External Integration (EXI)		
EXI8	We Use IS to...	collect information about new technologies in our industry
EXI9		collect information about competitor products
EXI5		keep suppliers involved in our product design and production processes
EXI2		collect information about best practices in our industry
EXI3		exchange information with research institutions
EXI7		keep suppliers informed of our specific requirements
EXI4		collect information about customer requirements
EXI6		exchange information with customers
Factor 2: Strategic Planning Support (SPS)		
SPS3	We Use IS to...	help justifying long-term business plans
SPS2		help formulating long-term business plans
SPS1		help improving the effectiveness of long-term strategic planning processes
SPS5		help generating long-term strategic advantage
SPS4		help creating new ways of doing business
Factor 3: Internal Integration (INI)		
INI3	We Use IS to...	facilitate information sharing between different management levels
INI2		facilitate information sharing among employees
INI6		facilitate information sharing among different departments
INI1		facilitate information distribution throughout the organization
Factor 4: Operational Decision Support (ODS)		
ODS1	We Use IS to...	help justifying daily operational decisions
ODS2		help improving the efficiency of daily operational decision processes
ODS3		help analyzing why problems occur in daily operations
ODS4		help monitoring the daily operational decision processes

4.3.3. Advanced Manufacturing Technology Usage (AMTU)

The Advanced Manufacturing Technology Usage (AMTU) construct was initially represented by two dimensions comprising 14 items in the large-scale survey, including Manufacturing Equipment and Process technology usage (MEP) (7 items), and Manufacturing Planning and Control technology usage (MPC) (7 items). The original 14 items and their corresponding code names are listed in Table 4.3.3.1.

Table 4.3.3.1. Advanced Manufacturing Technology Usage - Large-Scale Study Items

Code Names	*Questionnaire Items*
Manufacturing Equipment and Process Technologies (MEP)	
MEP1	Automatic numerically controlled machines
MEP2	Automated inspection and testing equipment
MEP3	Automated storing and retrieving systems
MEP4	Automated conveyors that deliver parts to work centers
MEP5	Automated guided vehicles that deliver parts and tools
MEP6	Automatic industrial robots
MEP7	Automated flexible manufacturing systems
Manufacturing Planning and Control Technologies (MPC)	
MPC1	Computer-aided technology that monitors the production process and provides feedback
MPC2	Computer-aided technology that determines routings between machines
MPC3	Computer-aided technology that facilitates production by classifying parts into families according to similarities
MPC4	Computer-aided technology that plans machining operations
MPC5	Computer-aided technology that plans and controls shop floor material requirements
MPC6	Computer-aided technology that automates parts and tools design processes
MPC7	Computer-aided technology that provides rapid prototyping in product design process

Reliability Analysis. Initial reliability analysis was done for each of the two dimensions of the AMTU construct. Examination of CITC scores along with checking for the contents and importance of each item in the MEP dimension resulted in the elimination of three MEP items (MEP3, MEP4, and MEP5). The CITC scores for the remaining MEP items were all above 0.50 except for MEP6 (CITC = 0.42). Considering the importance of MEP6 (Industrial Robots) to the entire construct, it was thus retained. Two MPC items (MPC6, MPC7) were dropped due to their relatively low CITC scores. The CITC scores for all remaining MPC items were above 0.50. The final Alphas were 0.71 for the MEP dimension (4 items) and 0.80 for the MPC dimension (5 items), all above the minimum recommended value of 0.70. Table 4.3.3.2. presents the item purification results.

Table 4.3.3. 2. Advanced Manufacturing Technology Usage - Large-Scale Reliability Analysis Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Manufacturing Equipment and Process Technologies (MEP)				
MEP1	0.43	0.50	0.65	**$\alpha = 0.71$**
MEP2	0.56	0.56	0.61	
MEP6	0.35	0.42	0.69	
MEP7	0.65	0.52	0.64	
MEP3	0.42	Items dropped after purification		
MEP4	0.44			
MEP5	0.49			
Manufacturing Planning and Control Technologies (MPC)				
MPC1	0.52	0.50	0.78	**$\alpha = 0.80$**
MPC2	0.58	0.67	0.73	
MPC3	0.57	0.60	0.75	
MPC4	0.70	0.57	0.76	
MPC5	0.54	0.55	0.77	
MPC6	0.49	Items dropped after purification		
MPC7	0.44			

Dimension-Level Exploratory Factor Analysis. To further ensure the unidimensionality and convergent validity of each dimension in the Advanced Manufacturing Technology Usage construct, dimension-level factor analysis was conducted for each of the two dimensions. A clear single factor emerged for both MEP and MPC dimensions with all factor loadings over 0.60. The factor analysis results are displayed in Table 4.3.3.3.

Table 4.3.3. 3. Advanced Manufacturing Technology Usage - Large-Scale Dimension-Level Factor Analysis Results

Items	*Factor Loadings*
Manufacturing Equipment and Process Technologies (MEP) KMO = 0.68	
MEP1	0.72
MEP2	0.76
MEP6	0.63
MEP7	0.71
Manufacturing Planning and Control Technologies (MPC) KMO = 0.80	
MPC1	0.65
MPC2	0.81
MPC3	0.75
MPC4	0.72
MPC5	0.70

Construct-Level Exploratory Factor Analysis. All the remaining AMTU items were then submitted to construct-level exploratory factor analysis to check for discriminant validity of the measurement instrument. Two clear factors emerged with all factor loadings close to or above 0.60. No cross-loadings were observed. Thus no items were dropped in this step. The KMO score of 0.82 indicated very good sampling adequacy. The final construct-level factor analysis results are shown in Table 4.3.3.4. The final set of measurement items for the Absorptive Capacity construct organized by factor loadings are shown in Table 4.3.3.5.

Table 4.3.3. 4. Advanced Manufacturing Technology Usage - Large-Scale Construct-Level Factor Analysis Results

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.82	
	F1: MPC	**F2: MEP**
MPC3	0.78	
MPC2	0.78	
MPC5	0.70	
MPC4	0.65	
MPC1	0.59	
MEP2		0.75
MEP6		0.69
MEP1		0.64
MEP7		0.64
Eigen value	3.43	1.31
% of Variance Explained	38.1	14.5
Cumulative % of Variance	38.4	52.6

Table 4.3.3. 5. Advanced Manufacturing Technology Usage - Final Construct Measurement Items

Code Names	*Questionnaire Items*
Factor 1: Manufacturing Planning and Control Technologies (MPC)	
MPC3	Computer-aided technology that facilitates production by classifying parts into families according to similarities
MPC2	Computer-aided technology that determines routings between machines
MPC5	Computer-aided technology that plans and controls shop floor material requirements
MPC4	Computer-aided technology that plans machining operations
MPC1	Computer-aided technology that monitors the production process and provides feedback
Factor 2: Manufacturing Equipment and Process Technologies (MEP)	
MEP2	Automated inspection and testing equipment
MEP6	Automatic industrial robots
MEP1	Automatic numerically controlled machines
MEP7	Automated flexible manufacturing systems

4.3.4. Time-Based Manufacturing Practices (TBMP)

The measurement instrument for Time-Based Manufacturing Practices (TBMP) was directly adopted from Koufteros et al. (1998). The current study revalidated the instrument through reliability analysis and factor analysis using a different data set. The TBMP construct was originally represented by seven dimensions and 25 items, including Reengineering Setup (RS) (4 items), Pull Production (PP) (4 items), Cellular Manufacturing (CM) (4 items), Preventive Maintenance (PR) (3 items), Quality Assurance (QA) (3 items), Dependable Suppliers (DS) (4 items), and Employee Involvement (EI) (3 items). The 25 items and their corresponding code names are listed in Table 4.3.4.1.

Reliability Analysis. Reliability analysis for each of the seven TBMP dimensions indicated that CITC scores for all 25 items were greater than 0.50. Thus no items were dropped at this stage. The Cronbach's Alphas were 0.84 for RS (4 items), 0.85 for PP (4 items), 0.79 for CM (4 items), 0.88 for PR (3 items), 0.81 for QA (3 items), 0.83 for DS (4 items), and 0.76 for EI (3 items). Table 4.3.4.2. presents the reliability analysis results.

Dimension-Level Exploratory Factor Analysis. To further check the unidimensionality and convergent validity of the TBMP instrument, dimension-level factor analysis was run for each of the seven dimensions. A single factor emerged for all seven dimensions with all factor loadings greater than 0.70. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were all close to or above 0.70, indicating good sampling adequacy. The factor analysis results are displayed in Table 4.3.4.3.

Table 4.3.4. 1. Time-Based Manufacturing Practices - Large-Scale Study Items

Code Names	*Questionnaire Items*
	Reengineering Setup (RS)
RS1	We use special tools to shorten setup time
RS2	Our employees are trained to reduce setup time
RS3	Employees work on setup improvement
RS4	We redesign or reconfigure equipment to shorten setup time
	Pull Production (PP)
PP1	Production at stations is "pulled" by the current demand of the next stations
PP2	Production is "pulled" by the shipment of finished goods
PP3	We use a "pull" production system
PP4	Production is "pulled" by an open kanban / bin position
	Cellular Manufacturing (CM)
CM1	Products are classified into groups with similar routing requirements
CM2	Products are classified into groups with similar processing requirements
CM3	Equipment is grouped to produce families of products
CM4	Families of products determine our factory layout
	Preventive Maintenance (PR)
PR1	We maintain our equipment regularly
PR2	We emphasize good preventive maintenance
PR3	Records of routine maintenance are kept
	Quality Assurance (QA)
QA1	We use fishbone type diagrams to identify causes of quality problems
QA2	Our employees use quality control charts
QA3	We conduct process capability studies
	Dependable Suppliers (DS)
DS1	We receive parts from suppliers on time
DS2	We receive the correct number of parts from suppliers
DS3	We receive high quality parts from suppliers
DS4	We receive the correct type of parts from suppliers
	Employee Involvement (EI)
EI1	Shop-floor employees are involved in improvement efforts
EI2	Shop-floor employees are involved in problem solving teams
EI3	Shop-floor employees are involved in suggestion programs

Table 4.3.4. 2. Time-Based Manufacturing Practices - Large-Scale Reliability Analysis Results

Items	CITC	Alpha if deleted	Alpha Score
Reengineering Setup (RS)			
RS1	0.62	0.83	α=0.84
RS2	0.73	0.78	
RS3	0.71	0.79	
RS4	0.67	0.81	
Pull Production (PP)			
PP1	0.71	0.79	α=0.85
PP2	0.61	0.83	
PP3	0.79	0.76	
PP4	0.63	0.83	
Cellular Manufacturing (CM)			
CM1	0.61	0.73	α=0.79
CM2	0.67	0.71	
CM3	0.58	0.74	
CM4	0.55	0.76	
Preventive Maintenance (PR)			
PR1	0.75	0.83	α=0.88
PR2	0.81	0.78	
PR3	0.73	0.85	
Quality Assurance (QA)			
QA1	0.57	0.83	α=0.81
QA2	0.70	0.69	
QA3	0.71	0.68	
Dependable Suppliers (DS)			
DS1	0.68	0.78	α=0.83
DS2	0.67	0.78	
DS3	0.60	0.81	
DS4	0.70	0.77	
Employee Involvement (EI)			
EI1	0.63	0.68	α= 0.76
EI2	0.63	0.65	
EI3	0.57	0.73	

Table 4.3.4. 3. Time-Based Manufacturing Practices - Large-Scale Dimension-Level Factor Analysis Results

Items	*Factor Loadings*
Reengineering Setup (RS) KMO = 0.80	
RS1	0.77
RS2	0.86
RS3	0.85
RS4	0.81
Pull Production (PP) KMO = 0.79	
PP1	0.83
PP2	0.77
PP3	0.88
PP4	0.78
Cellular Manufacturing (CM) KMO = 0.69	
CM1	0.82
CM2	0.85
CM3	0.73
CM4	0.73
Preventive Maintenance (PR) KMO = 0.73	
PR1	0.89
PR2	0.92
PR3	0.88
Quality Assurance (QA) KMO = 0.68	
QA1	0.78
QA2	0.88
QA3	0.88
Dependable Suppliers (DS) KMO = 0.77	
DS1	0.83
DS2	0.82
DS3	0.78
DS4	0.84
Employee Involvement (EI) KMO = 0.69	
EI1	0.85
EI2	0.85
EI3	0.80

Construct-Level Exploratory Factor Analysis. In this step, all the 25 TBMP items were submitted to a construct-level exploratory factor analysis to check for discriminant validity of the measurement instrument. Seven clear factors emerged from the factor analysis with all items loaded correctly on the intended factor. All factor loadings were above 0.60. KMO measure of 0.90 indicated very good sampling adequacy. Therefore, there's no need to revise the TBMP instrument. The original instrument was valid and reliable. The final construct-level factor analysis results are shown in Table 4.3.4.4.

Table 4.3.4. 4. Time-Based Manufacturing Practices - Large-Scale Construct-Level Factor Analysis Results

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.90						
	F1: PP	F2: DS	F3: PR	F4: CM	F5:RS	F6: EI	F7: QA
PP3	0.84						
PP1	0.74						
PP4	0.72						
PP2	0.67						
DS4		0.82					
DS2		0.80					
DS1		0.78					
DS3		0.69					
PR2			0.83				
PR3			0.80				
PR1			0.80				
CM2				0.81			
CM1				0.80			
CM3				0.62			
CM4				0.62			
RS1					0.84		
RS2					0.71		
RS3					0.68		
RS4					0.62		
EI1						0.78	
EI2						0.75	
EI3						0.68	
QA2							0.76
QA3							0.76
QA1							0.66
Eigen value	8.77	2.02	1.96	1.42	1.26	1.36	1.07
% of Variance Explained	35.1	8.1	7.8	5.7	5.0	4.5	4.3
Cumulative % of Variance	35.1	43.2	51.0	56.7	61.7	66.2	70.5

4.3.5. Modularity-Based Manufacturing Practices (MBMP)

The Modularity-Based Manufacturing Practices (MBMP) construct was initially represented by four dimensions comprising 27 items: Product Modularity (PM) (7 items), Process Modularity (PRM) (6 items), Dynamic Teaming (DT) (7 items), and Customer Closeness (CUC) (7 items). The original 27 items and their corresponding code names are listed in Table 4.3.5.1.

Reliability Analysis. Initial reliability analysis was performed for each of the four dimensions of MBMP. Examination of CITC scores resulted in the elimination of two Product Modularity (PM) items (PM4, PM7), one Process Modularity (PRM) item (PRM6), two Dynamic Teaming (DT) items (DT4, DT7), and one Customer Closeness (CUC) item (CUC2). For items DT4 and CUC2, although their CITC scores were above 0.50, the "Alpha if deleted" score indicated that Alpha could be improved if they were deleted. Thus DT4 and CUC2 were designated for removal. The CITC scores for the remaining 21 items were all above 0.50. The final alphas were 0.83 for PM (5 items), 0.82 for PRM (5 items), 0.88 for DT (5 items), and 0.92 for CUC (6 items). Table 4.3.5.2. presents the reliability analysis results.

Dimension-Level Exploratory Factor Analysis. To further ensure the unidimensionality of each dimension in the MBMP construct, dimension-level factor analysis was performed for each of the four dimensions in MBMP. A single factor emerged for all dimensions with all factor loadings over 0.60 and most above 0.70. The factor analysis results are displayed in Table 4.3.5.3.

Table 4.3.5. 1. Modularity-Based Manufacturing Practices – Large-Scale Study Items

Code Names	*Questionnaire Items*
	Product Modularity (PM)
PM1	Our products use modularized design
PM2	Our products share common modules
PM3	Our product features are designed around a standard base unit
PM4	Our products can be customized by adding feature modules as requested
PM5	Product modules can be reassembled into different forms
PM6	Product feature modules can be added to a standard base unit
PM7	Product modules can be rearranged by end-users to suit their needs
	Process Modularity (PRM)
PRM1	Our production process is designed as adjustable modules
PRM2	Our production process can be adjusted by adding new process modules
PRM3	Production process modules can be adjusted for changing production needs
PRM4	Our production process can be broken down into standard sub-processes that produce standard base units and customization sub-processes that further customize the base units
PRM5	Production process modules can be re-arranged so that customization sub-processes occur last
PRM6	Production process modules can be re-arranged so that customization sub-processes be carried out later at distribution centers
	Dynamic Teaming (DT)
DT1	Production teams that can be re-organized are used in our plant
DT2	Production teams can be re-organized in response to product / process changes
DT3	Production teams can be re-assigned to different production tasks
DT4	Production teams are not permanently linked to a certain production task
DT5	Production team members can be re-assigned to different teams
DT6	Production team members are capable of working on different teams
DT7	Production teams have no difficulty accessing necessary resources
	Customer Closeness (CUC)
CUC1	We keep close contact with customers
CUC2	We keep close contact with customers through all functional departments
CUC3	We monitor changes in customer needs through close contacts
CUC4	We try to understand customers' exact needs through close contacts
CUC5	We help customers clarify their needs through close contacts
CUC6	We involve customers in the customization processes through close contacts
CUC7	We have a well designed system to ensure close contact with customers

Table 4.3.5. 2. Modularity-Based Manufacturing Practices – Large-Scale Reliability Analysis Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
Product Modularity (PM)				
PM1	0.59	0.64	0.79	α=0.83
PM2	0.67	0.70	0.77	
PM3	0.53	0.56	0.81	
PM5	0.59	0.53	0.82	
PM6	0.75	0.71	0.77	
PM4	0.47	Items dropped after purification		
PM7	0.41			
Process Modularity (PRM)				
PRM1	0.57	0.58	0.79	α=0.82
PRM2	0.67	0.70	0.76	
PRM3	0.63	0.66	0.77	
PRM4	0.58	0.56	0.80	
PRM5	0.63	0.56	0.80	
PRM6	0.43	Item dropped after purification		
Dynamic Teaming (DT)				
DT1	0.66	0.66	0.87	α=0.88
DT2	0.75	0.74	0.85	
DT3	0.77	0.78	0.84	
DT5	0.71	0.74	0.85	
DT6	0.67	0.69	0.87	
DT4	0.52	Items dropped after purification		
DT7	0.49			
Customer Closeness (CUC)				
CUC1	0.68	0.67	0.91	α= 0.92
CUC3	0.79	0.79	0.90	
CUC4	0.83	0.84	0.89	
CUC5	0.71	0.72	0.91	
CUC6	0.79	0.81	0.90	
CUC7	0.79	0.78	0.90	
CUC2	0.59	Item dropped after purification		

Table 4.3.5. 3. Modularity-Based Manufacturing Practices – Large-Scale Dimension-Level Factor Analysis Results

Items	*Factor Loadings*
Product Modularity (PM) KMO = 0.75	
PM1	0.79
PM2	0.83
PM3	0.70
PM5	0.68
PM6	0.80
Process Modularity (PRM) KMO = 0.75	
PRM1	0.75
PRM2	0.84
PRM3	0.81
PRM4	0.70
PRM5	0.69
Dynamic Teaming (DT) KMO = 0.83	
DT1	0.77
DT2	0.81
DT3	0.87
DT5	0.84
DT6	0.80
Customer Closeness (CUC) KMO = 0.91	
CUC1	0.77
CUC3	0.86
CUC4	0.87
CUC5	0.80
CUC6	0.87
CUC7	0.85

Construct-Level Exploratory Factor Analysis. All the resulting 21 MBMP item were then submitted together to a construct-level factor analysis. Four clear factors emerged from the factor analysis and all factor loadings were above 0.60. No cross-loading was observed, thus there's no need for further item revision. The KMO score of 0.87 indicated very good sampling adequacy. The final construct-level factor analysis results are shown in Table 4.3.5.4. The final set of measurement items for the Modularity-Based Manufacturing Practices construct organized by factor loadings are shown in Table 4.3.5.5.

Table 4.3.5. 4. Modularity-Based Manufacturing Practices – Large-Scale Construct-Level Factor Analysis Results

Questionnaire Items	Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy = 0.87			
	F1: CUC	F2: DT	F3: PM	F4: PRM
CUC4	0.85			
CUC6	0.84			
CUC3	0.83			
CUC7	0.82			
CUC1	0.77			
CUC5	0.77			
DT5		0.86		
DT3		0.81		
DT6		0.81		
DT2		0.70		
DT1		0.68		
PM2			0.81	
PM1			0.79	
PM6			0.76	
PM3			0.71	
PM5			0.62	
PRM2				0.78
PRM3				0.74
PRM5				0.67
PRM4				0.66
PRM1				0.66
Eigen value	6.80	3.15	2.19	1.47
% of Variance Explained	32.4	15.0	10.4	7.0
Cumulative % of Variance	32.4	47.4	57.8	64.8

Table 4.3.5. 5. Modularity-Based Manufacturing Practices – Final Construct Measurement Items

Code Names	*Questionnaire Items*
Factor 1: Customer Closeness (CUC)	
CUC4	We try to understand customers' exact needs through close contacts
CUC6	We involve customers in the customization processes through close contacts
CUC3	We monitor changes in customer needs through close contacts
CUC7	We have a well designed system to ensure close contact with customers
CUC1	We keep close contact with customers
CUC5	We help customers clarify their needs through close contacts
Factor 2: Dynamic Teaming (DT)	
DT5	Production team members can be re-assigned to different teams
DT3	Production teams can be re-assigned to different production tasks
DT6	Production team members are capable of working on different teams
DT2	Production teams can be re-organized in response to product / process changes
DT1	Production teams that can be re-organized are used in our plant
Factor 3: Product Modularity (PM)	
PM2	Our products share common modules
PM1	Our products use modularized design
PM6	Product feature modules can be added to a standard base unit
PM3	Our product features are designed around a standard base unit
PM5	Product modules can be reassembled into different forms
Factor 4: Process Modularity (PRM)	
PRM2	Our production process can be adjusted by adding new process modules
PRM3	Production process modules can be adjusted for changing production needs
PRM5	Production process modules can be re-arranged so that customization sub-processes occur last
PRM4	Our production process can be broken down into standard sub-processes that produce standard base units and customization sub-processes that further customize the base units
PRM1	Our production process is designed as adjustable modules

4.3.6. Mass Customization Capability (MCC)

In the large-scale study, the Mass Customization Capability (MCC) construct was initially represented by one dimension comprising 9 items. The original 9 items and their corresponding code names are listed in Table 4.3.6.1.

Reliability Analysis. SPSS reliability analysis showed that the CITC scores for all 9 items in MCC dimension are above 0.50. The final Alpha was 0.89. Table 4.3.6.2 presents the reliability analysis results.

Exploratory Factor Analysis. To further check for the unidimensionality and convergent validity of Mass Customization Capability instrument, an exploratory factor analysis was performed on the 9 items. A clear single factor emerged with all factor loadings above 0.60. The KMO score of 0.87 indicated very good sampling adequacy. The factor analysis results are displayed in Table 4.3.6.3.

Table 4.3.6. 1. Mass Customization Capability - Large-Scale Study Items

Code Names	*Questionnaire Items*
MCC1	Our capability of customizing products at low cost is high
MCC2	Our capability of customizing products on a large scale is high
MCC3	Our capability of translating customer requirements into technical designs quickly is high
MCC4	Our capability of adding product variety without increasing cost is high
MCC5	Our capability of customizing products while maintaining a large volume is high
MCC6	Our capability of setting up for a different product at low cost is high
MCC7	Our capability of responding to customization requirements quickly is high
MCC8	Our capability of adding product variety without sacrificing overall production volume is high
MCC9	Our capability of changeover to a different product quickly is high

Table 4.3.6. 2. Mass Customization Capability - Large-Scale Reliability Analysis Results

Items	CITC	Alpha if deleted	Alpha Score
MCC1	0.69	0.87	α=0.89
MCC2	0.71	0.87	
MCC3	0.53	0.88	
MCC4	0.64	0.87	
MCC5	0.65	0.87	
MCC6	0.59	0.88	
MCC7	0.66	0.87	
MCC8	0.67	0.87	
MCC9	0.59	0.88	

Table 4.3.6. 3. Mass Customization Capability - Large-Scale Factor Analysis Results

Items	*Factor Loadings*
Mass Customization Capability (MCC) KMO = 0.87	
MCC2	0.78
MCC8	0.76
MCC1	0.75
MCC7	0.74
MCC5	0.73
MCC4	0.71
MCC6	0.68
MCC9	0.66
MCC3	0.62

4.3.7. Value to Customer Performance (VCP)

The initial items (VCP5, VCP6, VCP7 and VCP8) of VCP construct were adopted from Tracey (1996), and some more items (VCP1, VCP2, VCP3 and VCP4) were added based on the customer satisfaction literature. The VCP instrument in the large-scale study contained one dimension comprising 8 items. The original 8 items and their corresponding code names are listed in Table 4.3.7.1.

Table 4.3.7. 1. Value to Customer Performance - Large-Scale Study Items

Code Names	*Questionnaire Items*
VCP1	Our customers are satisfied with our ability to customize products
VCP2	Our customers are satisfied with the variety of our products
VCP3	Our customers are satisfied with the quality of our products
VCP4	Our customers are satisfied with the features that our products provide
VCP5	Our customers are loyal to our products
VCP6	Our customers refer new customers to purchase our products
VCP7	Our customers feel that we offer products with high value
VCP8	Our customers perceive that they receive their money's worth when they purchase our products

Reliability Analysis. Initial reliability analysis was performed on the 8 VCP items. Items VCP1 and VCP2 were dropped due to their CITC scores of below 0.50. The CITC scores of all remaining items were greater than 0.50 except for VCP4 (CITC = 0.49). Considering the importance of this item, it was retained. The final Alpha was 0.84. Table 4.3.7.2 presents the reliability analysis results.

Table 4.3.7. 2. Value to Customer Performance – Large-Scale Reliability Analysis Results

Items	Initial CITC	Final CITC	Alpha if deleted	Alpha Score
VCP3	0.57	0.57	0.82	**α=0.84**
VCP4	0.54	0.49	0.84	
VCP5	0.62	0.68	0.80	
VCP6	0.64	0.66	0.81	
VCP7	0.67	0.72	0.80	
VCP8	0.63	0.62	0.81	
VCP1	0.37	Items dropped after purification		
VCP2	0.45			

Exploratory Factor Analysis. To further check for the unidimensionality and convergent validity of Value to Customer Performance instrument, an exploratory factor analysis was performed on the remaining 6 VCP items. A clear single factor emerged with all factor loadings above 0.60. The KMO score of 0.82 indicated very good sampling adequacy. The factor analysis results are displayed in Table 4.3.7.3. The final set of measurement items for VCP organized by factor loadings are presented in Table 4.3.7.4.

Table 4.3.7. 3. Value to Customer Performance – Large-Scale Factor Analysis Results

Items	*Factor Loadings*
Value to Customer Performance (VCP) KMO = 0.82	
VCP7	0.81
VCP8	0.77
VCP5	0.77
VCP6	0.73
VCP3	0.70
VCP4	0.65

Table 4.3.7. 4. Value to Customer Performance – Final Construct Measurement Items

Code Names	*Questionnaire Items*
VCP7	Our customers feel that we offer products with high value
VCP8	Our customers perceive that they receive their money's worth when they purchase our products
VCP5	Our customers are loyal to our products
VCP6	Our customers refer new customers to purchase our products
VCP3	Our customers are satisfied with the quality of our products
VCP4	Our customers are satisfied with the features that our products provide

4.3.8. Summary of Large-Scale Analysis Results

Table 4.3.8.1 presents a summary of the large-scale instrument validation results. For each construct dimension, the number of final measurement items, Cronbach's Alpha score, and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy are displayed. It can be seen from the table that the final Alpha scores for all construct dimensions are greater than the minimum required value of 0.70, and most of the Alphas are over 0.80. The dimension-level KMO scores range from 0.68 to 0.91, indicating average to outstanding sampling adequacy. The construct-level KMO measures are all above 0.80, indicating excellent sampling adequacy. Overall, the final measurement instrument for all seven constructs in the current study were found to be valid and reliability.

Table 4.3.8. 1. Summary of Large-Scale Analysis Results

Construct-Level Analysis Results	Dimension-Level Analysis Results			
	Dimension Name	# of Items	Alpha (α)	KMO
Absorptive Capacity (AC) 26 items KMO = 0.92	Communications Climate (CC)	6	0.89	0.88
	Knowledge Scanning (KS)	7	0.80	0.86
	Communications Network (CN)	5	0.86	0.79
	Worker Knowledge (WK)	4	0.87	0.82
	Management Knowledge (MK)	4	0.84	0.79
Information Systems Usage (ISU) 21 items KMO = 0.93	External Integration (EXI)	8	0.91	0.90
	Strategic Planning Support (SPS)	5	0.93	0.89
	Internal Integration (INI)	4	0.85	0.83
	Operational Decision Support (ODS)	4	0.81	0.75
Advanced Manufacturing Technology Usage (AMTU) 9 items KMO = 0.82	Manufacturing Planning and Control Technology (MPC)	5	0.80	0.80
	Manufacturing Process and Equipment Technology (MEP)	4	0.71	0.68
Time-Based Manufacturing Practices (TBMP) 25 items KMO = 0.90	Pull Productions (PP)	4	0.85	0.79
	Dependable Suppliers (DS)	4	0.83	0.77
	Cellular Manufacturing (CM)	4	0.79	0.69
	Preventive Maintenance (PR)	3	0.88	0.73
	Reengineering Setup (RS)	4	0.84	0.80
	Employee Involvement (EI)	3	0.76	069
	Quality Assurance (QA)	3	0.81	0.68
Modularity-Based Manufacturing Practices (MBMP) 21 items KMO = 0.87	Customer Closeness (CUC)	6	0.92	0.91
	Dynamic Teaming (DT)	5	0.88	0.83
	Product Modularity (PM)	5	0.83	0.75
	Process Modularity (PRM)	5	0.82	0.75
Mass Customization Capability	Mass Customization Capability (MCC)	9	0.89	0.87
Value to Customer Performance	Value to Customer Performance (VCP)	6	0.84	0.82

4.4. Construct-Level Correlation Analysis

To check for the preliminary statistical validity of the 10 hypotheses presented in Chapter 2, the Pearson correlation coefficients of the 10 hypothesized relationships were calculated using a composite score for each construct. The composite score was computed by taking the average score of all items in a specific construct. The results are presented in Table 4.4.1. As can be seen from the table, all correlations are significant at the 0.01 level. Thus all hypothesized relationships of interest are statistically supported by the Pearson correlation. Further hypotheses testing using LISREL structural equation causal modeling will be discussed in the next chapter.

Table 4.4. 1. Construct-Level Correlation Analysis Results

Hypothesis	Independent Variable	Dependent Variable	Pearson Correlation
H1	Absorptive Capacity (AC)	Information Systems Usage (ISU)	0.549**
H2	Absorptive Capacity (AC)	Advanced Manufacturing Technology Usage (AMTU)	0.461**
H3	Absorptive Capacity (AC)	Time-Based Manufacturing Practices (TBMP)	0.669**
H4	Absorptive Capacity (AC)	Modularity-Based Manufacturing Practices (MBMP)	0.486**
H5	Information Systems Usage (ISU)	Mass Customization Capability (MCC)	0.211**
H6	Advanced Manufacturing Technology Usage (AMTU)	Mass Customization Capability (MCC)	0.156**
H7	Time-Based Manufacturing Practices (TBMP)	Mass Customization Capability (MCC)	0.486**
H8	Modularity-Based Manufacturing Practices (MBMP)	Mass Customization Capability (MCC)	0.345**
H9	Mass Customization Capability (MCC)	Value to Customer Performance (VCP)	0.352**
H10	Absorptive Capacity (AC)	Value to Customer Performance (VCP)	0.485**
** Correlation is significant at the 0.01 level			

CHAPTER 5: STRUCTURAL EQUATION MODELING AND HYPOTHESES TESTING

Although the bivariate correlations are statistically significant for all hypothesized relationships, it may not be true when all the relationships are put together in a multivariate complex model due to the interactions among variables. The hypotheses can be tested in a much more rigorous manner using path analysis within the LISREL (Joreskog and Sorbom, 1989) structural equation modeling (SEM) framework.

A major methodological breakthrough in the study of complex interrelations among variables has been the development and application of SEM (Joreskog, 1977). SEM is widely recognized as a powerful methodology for capturing and explicating complex multivariate relations in social science data. It represents the unification of two methodological traditions: factor analysis originating from psychology and psychometrics, and simultaneous equations (path analytic) modeling originating from econometrics (Kaplan and Elliot, 1997). Therefore, the standard SEM is composed of two parts – the *measurement model* (a sub-model in SEM that specifies the indicators of each construct and assess the reliability of each construct for later use in estimating the causal relationships) and the *structural model* (The set of dependence relationships linking the model constructs). Since the measurement properties of each instrument in the current study have already been evaluated through comprehensive reliability analysis and factor analysis, the SEM model described in this chapter will focus on path analysis using the LISREL *structural model*. The significance of each path in the proposed structural model will be tested and the overall goodness-of-fit of the entire structural equation model will be assessed as well.

The general *structural model* can be expressed as follows:

$$\eta = B\eta + \Gamma\xi + \zeta$$

Where, η is an $m \times 1$ random vector of latent dependent or endogenous variables.

ξ is an $n \times 1$ random vector of latent independent, or exogenous variables.

B is an $m \times m$ matrix of coefficients of the η-variables in the structural model.

Γ is an $n \times n$ matrix of coefficients of the ξ-variables in the structural model.

ζ is an $m \times 1$ vector of random errors in the structural relationships.

5.1. The Proposed Structural Model

The proposed structural model depicted in Figure 5.1. is a replication of the theoretical framework presented in Figure 2.1 using the mathematical expression presented above. There are seven variables in the model: Absorptive Capacity (AC) - ξ_1, Information Systems Usage (ISU) - η_1, Advanced Manufacturing Technology Usage (AMTU) - η_2, Time-Based Manufacturing Practices (TBMP) - η_3, Modularity-Based Manufacturing Practices (MBMP) - η_4, Mass Customization Capability (MCC) - η_5, and Value to Customer Performance (VCP) - η_6. AC is regarded as independent (exogenous) ξ-variable, and all others are dependent (endogenous) η-variables.

The 10 hypotheses proposed in Chapter 2 are represented by the 10 causal relationships in the model. Hypothesis 1 is represented in Figure 5.1 by the relationship γ_{11} (AC $\rightarrow$ ISU); Hypothesis 2 is represented by the relationship γ_{21} (AC $\rightarrow$ AMTU);

Hypothesis 3 is represented by the relationship γ_{31} (AC → TBMP); Hypothesis 4 is represented by the relationship γ_{41} (AC → MBMP); Hypothesis 5 is represented by the relationship β_{51} (ISU → MCC); Hypothesis 6 is represented by the relationship β_{52} (AMTU → MCC); Hypothesis 7 is represented by the relationship β_{53} (TBMP → MCC); Hypothesis 8 is represented by the relationship β_{54} (MBMP → MCC); Hypothesis 9 is represented by the relationship β_{65} (MCC → VCP); Hypothesis 10 is represented by the relationship γ_{61} (AC → VCP).

5.2. LISREL Structural Modeling Methodology

Before proceeding to the LISREL structural model testing of the hypotheses, the LISREL structural equation modeling methodology and some major model evaluation indices will be discussed.

Unlike the traditional statistical methods that can examine only a single relationship at a time, structural equation modeling (SEM) method greatly expanded the researchers capability to study a set of interrelated relationships simultaneously. The first and most difficult steps in SEM are to specify the two components: *Measurement Model* and *Structure Model*. It is difficult because SEM model specification must always be based on sound theory from existing literature. The need for theoretical justification in SEM is very important for the specification of dependence relationships, modifications to the proposed relationships, and many other aspects of model estimation (Hair, et al., 1992, pp. 434).

Once the measurement and structure models are specified, the researcher must choose a computer program for model estimation and evaluation. The most widely used program is LISREL (Linear Structural Relations) by Joreskog and Sorbom (1989). There is no single statistical test that best describes the strength of a model. Instead, researcher have developed a number of goodness-of-fit measure to assess the results from three perspectives: 1) overall fit, 2) comparative fit to a base model, and 3) model parsimony. The LISREL algorithm provides several such statistics that can be used to evaluate the hypothesized model and also suggest ways in which the model might be modified given sufficient theoretical justification.

Overall Fit Measures.

The most fundamental measure of overall fit is the chi-square statistic (χ^2). Low values, which results in significance levels greater than 0.05, indicate that the actual and predicted input matrices are not statistically different, hence a good fit. However, the χ^2 measure is often criticized for its over-sensitivity to sample size, especially in cases where the sample size exceeds 200 respondents (Hair et al., 1992, pp. 490). As sample size increases, this measure has a greater tendency to indicate significant differences for equivalent models. Thus the current study will not use the χ^2 measure.

A second measure of overall fit is the **Goodness-of-fit index (GFI)** provided by LISREL. GFI represents the overall degree of fit (the squared residuals from prediction compared to the actual data), but is not adjusted for the degrees of freedom. GFI ranges in value from 0 (poor fit) to 1 (perfect fit). Generally, a GFI value of greater than 0.90 is considered as acceptable (Segars and Grover, 1993).

Another measure of overall fit is the **Root Mean Square Residual (RMSR)** – an average of the residuals between observed and estimated input matrices. A smaller value of RMSR represents a better model fit. The recommended maximum value of RMSR is 0.1 (Chau, 1997).

Comparative Fit Measures.

This class of measures compare the proposed model to some baseline model (null model) – some realistic model that all other models should be expected to exceed. In most cases, the null model is a single construct model with all indicators perfectly measuring the construct. One of the most popular measure of this kind is the **Normed Fit Index (NFI)**, which ranges from 0 (no fit at all) to 1 (perfect fit). A commonly recommended value is 0.90 or greater (Hair et al., 1992).

Parsimonious Fit Measures.

These type of measures relate the goodness-of-fit of the model to the number of estimated coefficients required to achieve this level of fit. The basic objective is to diagnose whether model fit has been achieved by "overfitting" the data with too many coefficients. The most widely used measure of parsimonious fit is **Adjusted Goodness-of-Fit Index (AGFI)** provided by LISREL. AGFI is an extension of GFI but adjusted by the ratio of degrees of freedom for the proposed model to the degrees of freedom for the null model. A recommended acceptance value of AGFI is 0.80 or greater (Segars and Grover, 1993).

Finally, the LISREL program also provides modification indices that suggest possible ways of improving model fit, such as uncovering new relationships among constructs. However, one has to bear in mind that the modifications must have sufficient theoretical justification.

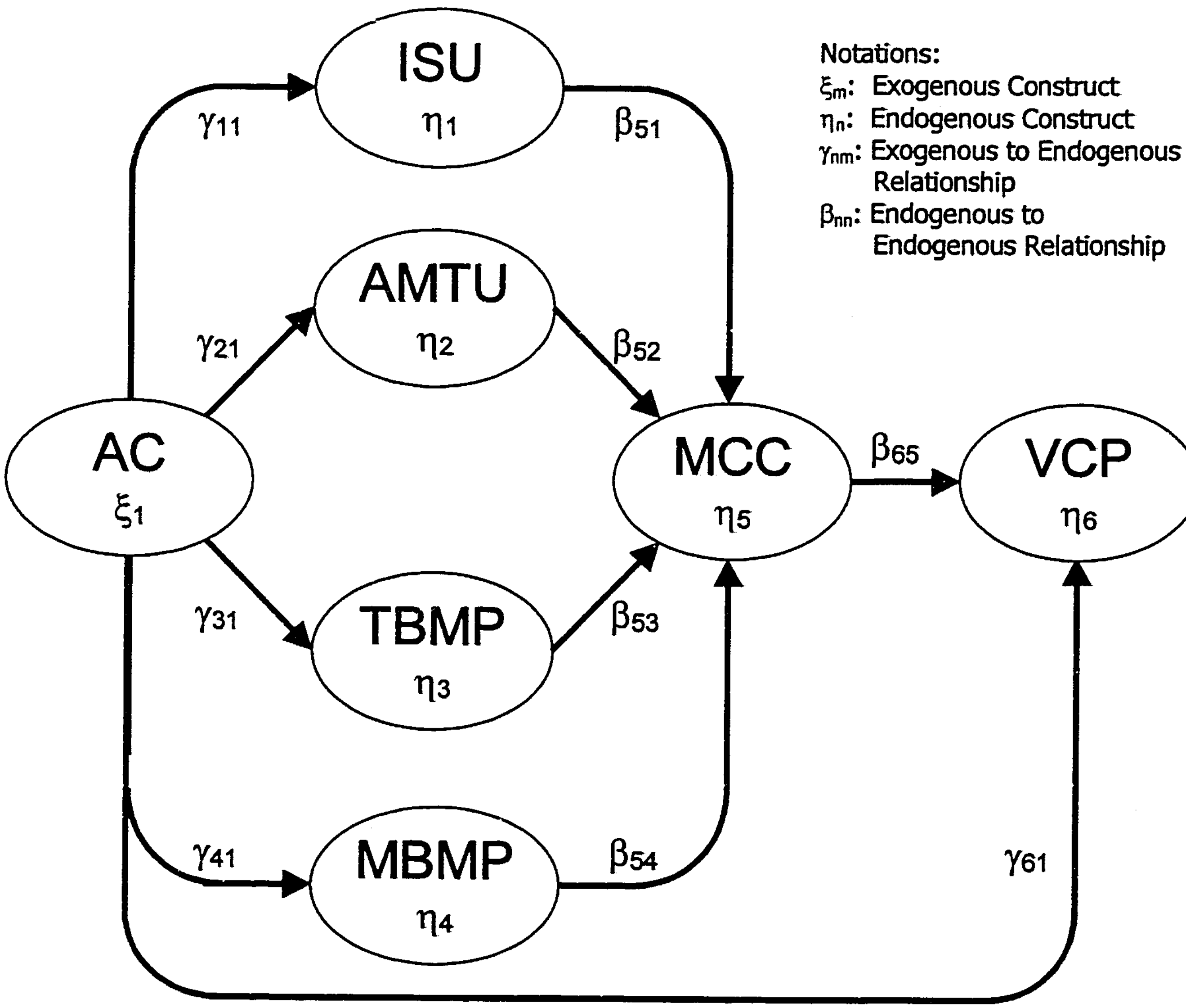
5.3. LISREL Structural Model Testing Results

The hypothesized relationships are now ready to be tested based on the LISREL structural model specified in Figure 5.1 and the model fit properties are evaluated using the fit statistics discussed above. The composite score computed for each construct at the end of Chapter 4 will be used as input to the LISREL structural modeling process.

5.3.1. Initial LISREL Structural Modeling Results

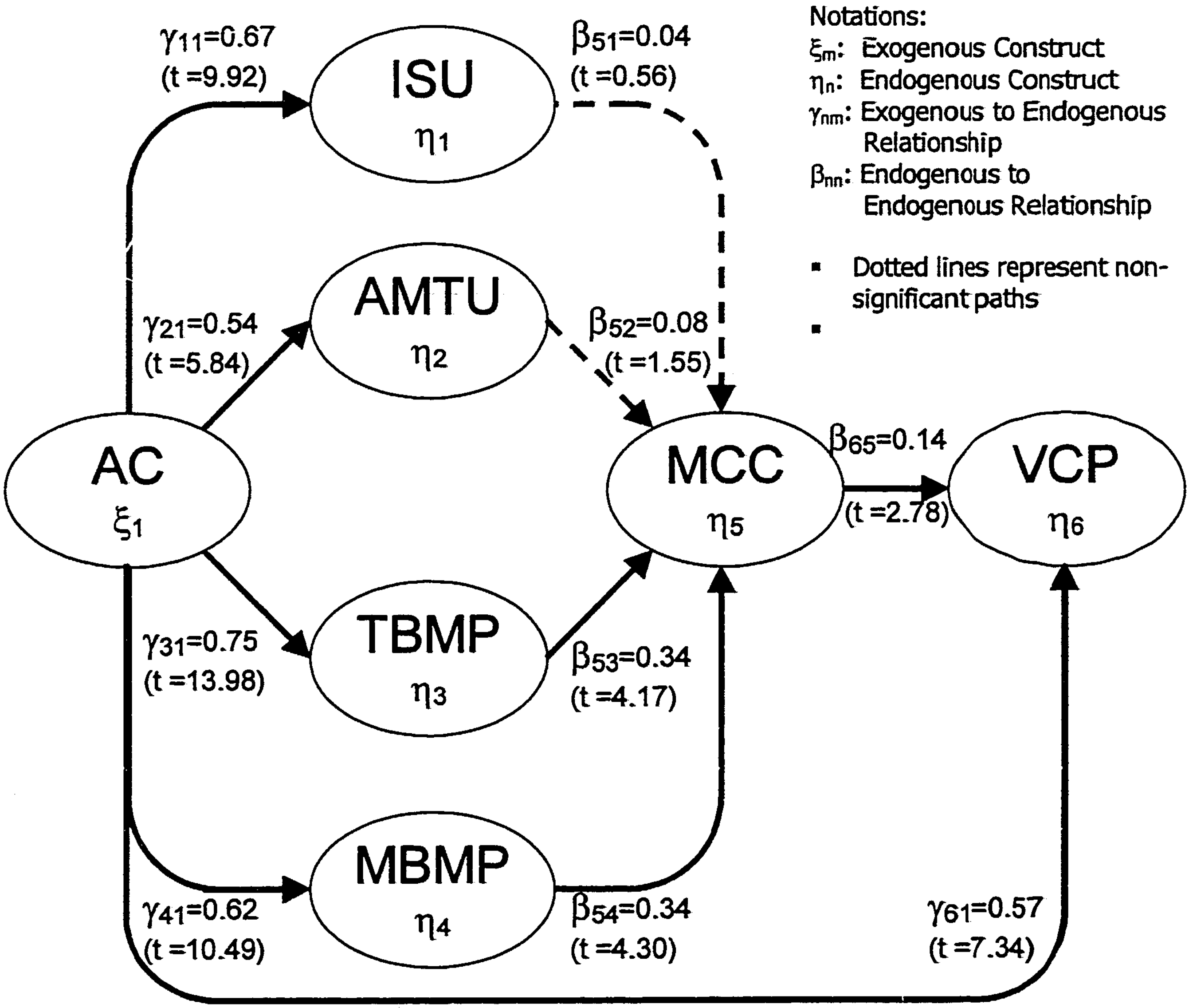
Figure 5.2 displays the path diagram resulted from the LISREL structural modeling analysis. More detailed results are presented in Table 5.3.1. Out of the 10 hypothesized relationships, 8 were found to be significant. Hypotheses 1, 2, 3, 4, 7, 8, 9 and 10 all had a t-value of greater than 2.00, indicating the relationships are significant at the 0.05 level. The t-value for Hypotheses 5 and 6 are 0.56 and 1.56 respectively, which is not significant at the 0.05 level. Therefore, all research hypotheses except Hypotheses 5 and 6 are supported by the LISREL structural modeling results. The initial model fit measures are: GFI = 0.93, RMSR = 0.037, NFI = 0.89, AGFI = 0.84. GFI was above the recommended minimum value of 0.90; RMSR was below the suggested maximum value of 0.05; AGFI was above the recommended minimum value of 0.80; Only the NFI (0.89) is slightly below the recommended 0.90 level. These results present initial good fit of the proposed model to the data. The implications of the two insignificant relationships will be discussed later in this chapter.

Figure 5.1. Proposed Structural Equation Model



AC – Absorptive Capacity
ISU – Information Systems Usage
AMTU – Advanced Manufacturing Technology Usage
TBMP – Time-Based Manufacturing Practices
MBMP – Modularity-Based Manufacturing Practices
MCC – Mass Customization Capability
VCP – Value to Customer Performance

Figure 5.2. Initial LISREL Structural Modeling Results



AC – Absorptive Capacity
ISU – Information Systems Usage
AMTU – Advanced Manufacturing Technology Usage
TBMP – Time-Based Manufacturing Practices
MBMP – Modularity-Based Manufacturing Practices
MCC – Mass Customization Capability
VCP – Value to Customer Performance

Model Fit Indices:

GFI = 0.93
AGFI = 0.84
NFI = 0.89
RMSR = 0.037

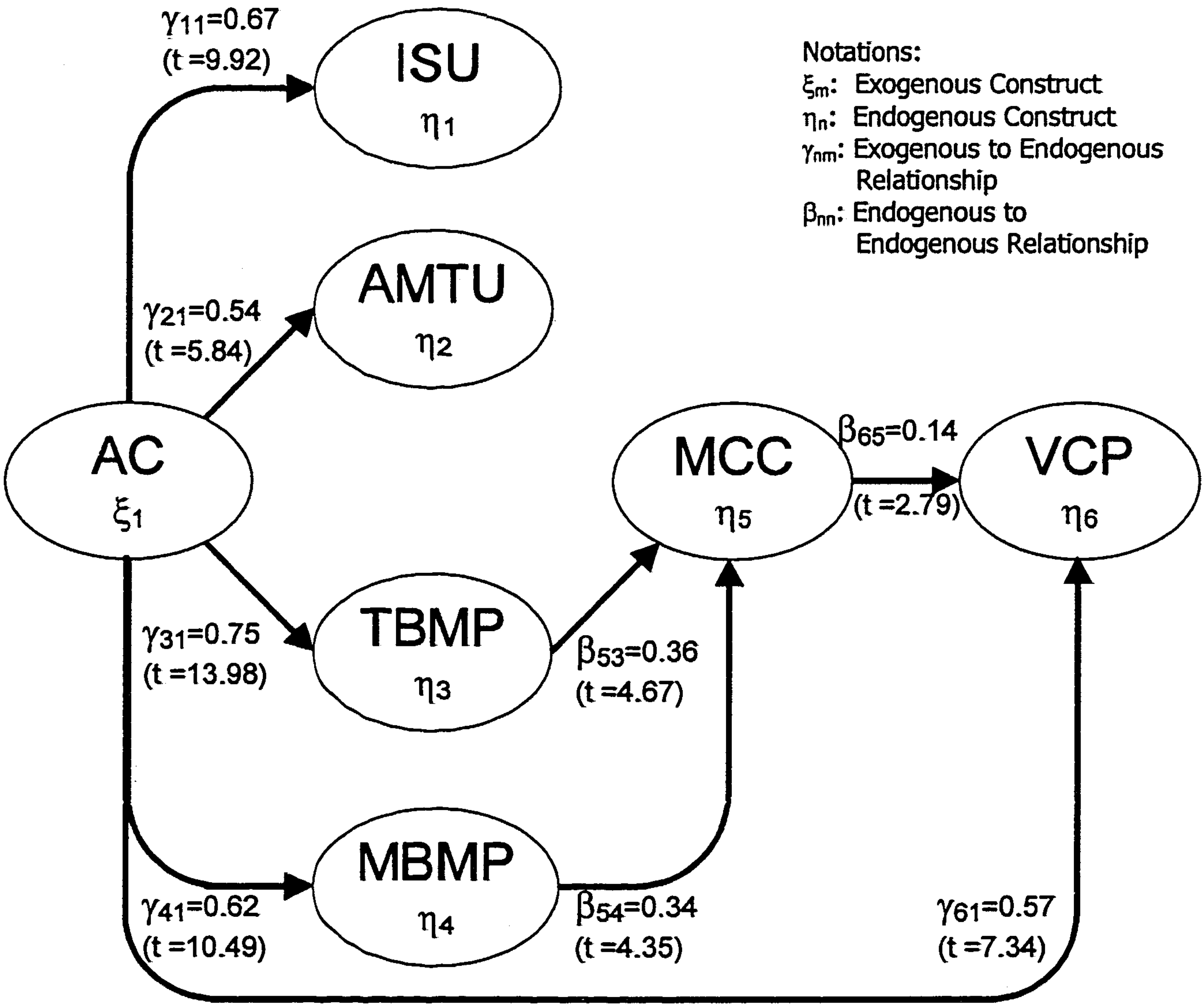
Table 5.3. 1. Initial LISREL Structural Modeling Results

Hypotheses	Relationship	LISREL Coefficients	t-value	Significant ?
H1	AC → ISU	0.67	9.92	Yes
H2	AC → AMTU	0.54	5.84	Yes
H3	AC → TBMP	0.75	13.98	Yes
H4	AC → MBMP	0.62	10.49	Yes
H5	ISU → MCC	0.04	0.56	No
H6	AMTU → MCC	0.08	1.55	No
H7	TBMP → MCC	0.34	4.17	Yes
H8	MBMP → MCC	0.34	4.30	Yes
H9	MCC → VCP	0.14	2.78	Yes
H10	AC → VCP	0.57	7.34	Yes
GFI = 0.93 RMSR = 0.037 NFI = 0.89 AGFI = 0.84				

5.3.2. Revised LISREL Structural Model

After revising the structural model by removing the two insignificant relationships (H5 and H6), the model was tested again using LISREL. The results are presented in Figure 5.3 and Table 5.3.2. As can be seen from the figure and table, all paths have a t-value of greater than 2.0 and significant at the 0.05 level. The fit measures of the revised model also indicated good fit: GFI = 0.93 was greater than the minimum 0.90 level; RMSR = 0.039 was below the maximum 0.05 level; NFI = 0.88 was slight lower than the recommended 0.90 level but acceptable; and AGFI = 0.86 was above the minimum 0.80 level.

Figure 5.3. Revised LISREL Structural Modeling Results



AC – Absorptive Capacity
ISU – Information Systems Usage
AMTU – Advanced Manufacturing Technology Usage
TBMP – Time-Based Manufacturing Practices
MBMP – Modularity-Based Manufacturing Practices
MCC – Mass Customization Capability
VCP – Value to Customer Performance

Model Fit Indices:

GFI = 0.93
AGFI = 0.86
NFI = 0.88
RMSR = 0.039

Table 5.3. 2. Revised LISREL Structural Modeling Results

Hypotheses	Relationship	LISREL Coefficients	t-value	Significant ?
H1	AC → ISU	0.67	9.92	Yes
H2	AC → AMTU	0.54	5.84	Yes
H3	AC → TBMP	0.75	13.98	Yes
H4	AC → MBMP	0.62	10.49	Yes
H7	TBMP → MCC	0.36	4.67	Yes
H8	MBMP → MCC	0.34	4.35	Yes
H9	MCC → VCP	0.14	2.79	Yes
H10	AC → VCP	0.57	7.34	Yes
GFI = 0.93 RMSR = 0.039 NFI = 0.88 AGFI = 0.86				

5.3.3. Final LISREL Structural Model

Although the model fit indices were generally acceptable in the revised structural model, they were not good enough from a higher standard of research. Especially the NFI was still a little lower than the suggested minimum value of 0.90. This might indicate some other undiscovered relationships in the model. After checking the modification indices provided by LISREL structural modeling, two interesting new paths not proposed in the original model were found, which made very good theoretical sense. The two new paths were 1) the direct positive effects of Information Systems Usage (ISU) on Time-Based Manufacturing Practices (TBMP), and 2) the direct positive effects of Advanced Manufacturing Technology Usage (AMTU) on Time-Based Manufacturing Practices (TBMP). In other word, although the direct effects of ISU and AMTU on MCC (H5 and H6) were not significant, they indirectly affect MCC through TBMP.

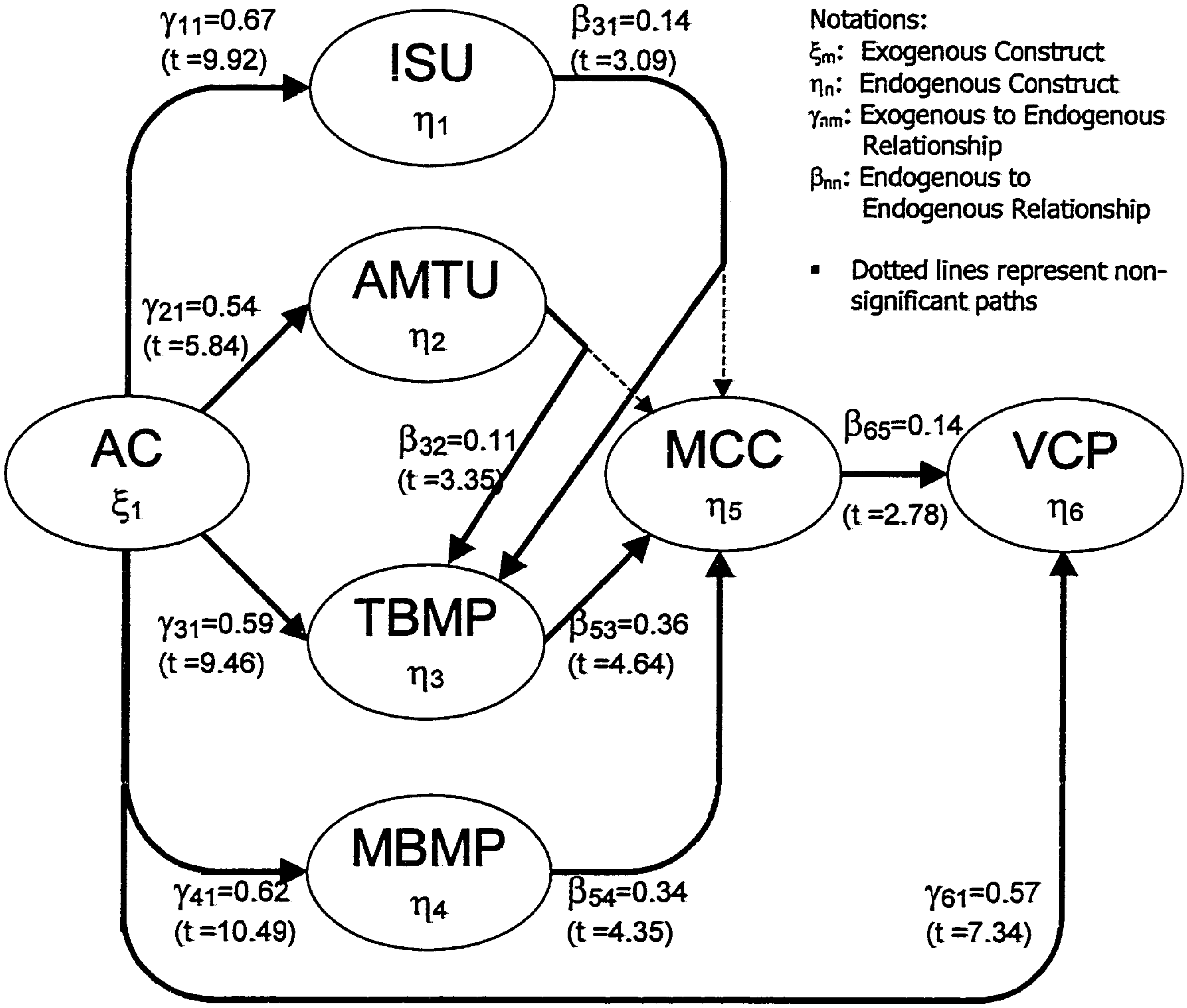
These are very interesting and meaningful findings. The implications and theoretical justifications of these two new relationships will be provided in the next section.

After adding these two new paths, the structural model was estimated again using LISREL. The final results are presented in Figure 5.4 and Table 5.3.3. All relationships have a t-value of greater than 2.0 and significant at the 0.05 level. The model fit indices have also greatly improved. GFI = 0.96 and AGFI = 0.91 were both well above the recommended minimum value of 0.90 and 0.80. RMSR = 0.031 was far below the maximum 0.05 level. Note that NFI has improve significantly from 0.88 to 0.93, greater than the suggested lower limit of 0.90.

Table 5.3. 3. Final LISREL Structural Modeling Results

Hypotheses	Relationship	LISREL Coefficients	t-value	Significant ?
H1	AC → ISU	0.67	9.92	Yes
H2	AC → AMTU	0.54	5.84	Yes
H3	AC → TBMP	0.59	9.46	Yes
H4	AC → MBMP	0.62	10.49	Yes
H7	TBMP → MCC	0.36	4.64	Yes
H8	MBMP → MCC	0.34	4.35	Yes
H9	MCC → VCP	0.14	2.78	Yes
H10	AC → VCP	0.57	7.34	Yes
H5a	ISU → TBMP	0.14	3.09	Yes
H6a	AMTU → TBMP	0.11	3.35	Yes
GFI = 0.96 RMSR = 0.031 NFI = 0.93 AGFI = 0.91				

Figure 5.4. Final LISREL Structural Model



AC – Absorptive Capacity
ISU – Information Systems Usage
AMTU – Advanced Manufacturing Technology Usage
TBMP – Time-Based Manufacturing Practices
MBMP – Modularity-Based Manufacturing Practices
MCC – Mass Customization Capability
VCP – Value to Customer Performance

Model Fit Indices:

GFI = 0.96
AGFI = 0.91
NFI = 0.93
RMSR = 0.031

5.3.4. Discussion of LISREL Structural Modeling and Hypotheses Testing Results

The previous sections reported the LISREL structural modeling and hypotheses testing results on the proposed model. To summarize, 8 out of 10 of the hypothesized relationships (Hypotheses 1, 2, 3, 4, 7, 8, 9, 10) were significant at the 0.05 level, and the final LISREL structural model displayed very good fit to the data. For the two non-significant direct relationships (Hypotheses 5 and 6), two new indirect paths (H5a and H6a) were found.

However, statistical significance and model fit are not the ultimate objectives of academic research. They are just the means to achieve the end, which is better understanding of the subject under investigation and discovery of new relationships. The results from the research will be of great value both to practitioners in terms of assisting their business decision making processes, and to researchers in terms of providing some new instruments for further academic research. Therefore, the practical and theoretical implications of the LISREL structural model testing results on each hypothesis will be discussed as follows.

Hypothesis 1: *There is an overall positive relationship between a firm's Absorptive Capacity (AC) and its level of Information Systems Usage (ISU).*

This relationship was found to be significant. Computer based information systems has evolved from the traditional back office support to a strategic resource for most firms in the past two decades. This is made possible by the rapidly decreasing cost and drastically improving power of computers. Along with it, the Internet and World Wide Web technology have brought about a revolution in information networking systems. The new generations of information systems such as Electronic Data Interchange (EDI) and Electronic Commerce (EC) have become a strategic necessity for many firms to stay ahead of competition. But to effectively utilize these new information systems technology is not as simple as purchasing and installing hardware and software. It requires overall improvements in the knowledge level and learning capability of both workers and managers to accommodate the new technology. It may even require a complete change in the firm's communications structure and culture when the new technologies totally reengineered the traditional working processes and relationships.

Hypothesis 2: *There is an overall positive relationship between a firm's Absorptive Capacity (AC) and its level of Advanced Manufacturing Technology Usage (AMTU).*

This relationship was found to be significant. Similar to the computer-based information systems, various advanced manufacturing technologies (AMT) enabled by computer technology has established their strategic role in many industries, especially in the hi-tech electronics and auto manufacturing section. Many firms can now achieve the level of manufacturing flexibility and technical complexity that will otherwise be impossible without using AMTs. However, many other firms also found that the AMT system that they invested heavily had not achieve the expected level of performance (Mansfield, 1993). The important finding from hypothesis 2 empirically confirmed the proposition by several prominent researchers (Duimering et al., 1993; Lei et al, 1996; Zammuto and O'Connor, 1992; Maffei and Meridith, 1993; Chung, 1991), that the structural and cultural redesign of an organization to improve its absorptive capacity of new technologies is a fundamental requirement before implementing flexible technology.

For practitioners, the detailed items of absorptive capacity actually provided very useful guidelines for their organizational redesign efforts.

Hypothesis 3: *There is an overall positive relationship between a firm's Absorptive Capacity (AC) and its level of Time-Based Manufacturing Practices (TBMP).*

This relationship was found to be significant. Needless to say, time has become a decisive factor of manufacturing performance in today's increasingly turbulent business environment. But many of the time-based manufacturing practices, such as pull production, reengineering setup, and dependable suppliers, requires a highly cooperative and well informed manufacturing operations system. In fact, the Toyota experience has proved that in a true Just-In-Time system, water (inventory buffer) level has been minimized, thus rocks (problems) may easily surface if the entire supply chain were not well coordinated. Building absorptive capacity can help firms to achieve the desired harmony along the manufacturing supply chain through improved communications infrastructure and partnership with suppliers and customers. Hypothesis 3 clearly indicates to manufacturing managers ways of improving absorptive capacity, such as fostering an open communications climate and knowledge scanning, are valid measures of facilitating time-based manufacturing practices in a firm.

Hypothesis 4: *There is an overall positive relationship between a firm's Absorptive Capacity (AC) and its level of Modularity-Based Manufacturing Practices (MBMP).*

This relationship was found to be significant. As suggested by Baldwin and Clark (1997), manufacturing strategies based on modularity are the best way to deal with today's fast-paced change and growing technological complexity. However, modularity is still rare in many industries other than the computer industry, because modular products and processes are much more difficult to design and implement, and they requires a much higher level of knowledge and expertise. Further, designers must not only focus on individual modules of products, processes or teams, but also ensure that the modules will work together harmoniously. Many industries today are modeling after the successful modularity strategy set forth by the computer industry. The significant positive relationship between absorptive capacity and modularity-based manufacturing practices empirically demonstrated to manufacturing managers, that upgrading the firm's knowledge base and technical expertise, and promoting company-wide systems thinking are key to successful modularity-based manufacturing strategy.

Hypothesis 5 and 6: *There is an overall positive relationship between the level of Information Systems Usage (ISU) and the level of Mass Customization Capability (MCC). There is an overall positive relationship between the level of Advanced Manufacturing Technology Usage (AMTU) and the level of Mass Customization Capability (MCC).*

Although the bivariate Pearson correlations of these two relationships were significant at 0.01 level, they were found to be non-significant in the LISREL structural model. Instead, two new indirect paths were found through Time-Based Manufacturing Practices (TBMP). That is, Information Systems Usage and Advanced Manufacturing Technology Usage affects firms' Mass Customization Capability indirectly through TBMP. This finding is very valuable because it signifies to manufacturing managers that use of IS and AMT alone will not necessarily result in a flexible manufacturing system. Extensive use of IS and AMT may produce a highly automated and computerized manufacturing system. But to realize its potential for mass customization, automation must be accompanied by other organizational practices such as TMBP to achieve a highly integrated system.

In fact, the level of integration could be a much more important issue. According to Cooper and Zmud's (1990) technology implementation stage model, routinization of technology usage is not the final stage. It is at the infusion stage that a certain technology is used to its fullest potential and increased organizational effectiveness is obtained by using the technology in a more comprehensive and integrated manner. Vonderembse, Raghunathan and Rao (1997) conducted some in-depth case studies concerning the issue of automation versus integration. They found that, under the industrial paradigm of thinking, firms tend to automate specific tasks to solve local problems, which often results in "islands of automation" that are not capable of responding quickly to rapidly changing customer needs. Thus firms operating in the post-industrial environment should focus first on integration across the value chain, then automate the activities that add value to customers.

Hypothesis 7: *There is an overall positive relationship between the level of Time-Based Manufacturing Practices (TBMP) and the level of Mass Customization Capability (MCC).*

This relationship was found to be statistically significant. This finding is consistent with Koufteros (1995) conclusion that there is a significant positive relationship between TBMP and a firm's competitive capabilities. The focus of the current study is on the firms' capability to customize products on a large-scale at time and cost comparable to general purpose products. The significance of hypothesis 7 confirmed that TBM practices such as reengineering setup, cellular manufacturing, pull production and dependable suppliers could indeed help manufacturers cut down costs and improve response time when switching between different products.

Hypothesis 8: *There is an overall positive relationship between the level of Modularity-Based Manufacturing Practices (MBMP) and the level of Mass Customization Capability (MCC).*

This relationship was found to be significant. It empirically confirmed the theoretical notion that modularity could be a major form of mass customization. Moreover, the study results also show that modularity practices are not limited to product modularity. The newer practices of production process modularity and team modularity are both very effective ways of achieving mass customization. To manufacturing managers, recognizing these new opportunities and put them to everyday practice can actually become a real long term asset to the firm.

Hypothesis 9: *There is an overall positive relationship between a firm's Mass Customization Capability (MCC) and its Value to Customer Performance (VCP).*

This relationship was found to be significant. This finding is important because there has been doubt among researchers and practitioner about investment in product customization capability. There are some firms still surviving on a few mass market products, but the statistical significance of hypothesis 9 verifies that customers indeed think customized products have higher value, and are more satisfied with the features customized products provide. Although improving mass customization capability may incur some investments, it will finally pay off in the long run through a loyal customer base and sustaining market share.

Hypothesis 10: *There is an overall positive relationship between a firm's Absorptive Capacity (AC) and its Value to Customer Performance (VCP).*

This relationship was found to be significant. This is a very valuable finding in that many firms are not putting enough emphasis on improving individual and organizational continuous learning capability. They think the knowledge level of employees and communications culture within the firm has little to do with their customers. Hypothesis 10 clearly signifies that this is not the case. A firm's capability to learn and absorb new knowledge and technology directly affects its ability to create customer value. It is hard to imagine that a firm with obsolete knowledge base and limited communication among functional areas can come up with innovative products.

CHAPTER 6: FUTURE RESEARCH DIRECTIONS AND CONCLUSION

The constantly changing global marketplace, rapidly advancing information technology and emerging managerial practices offer U.S. manufacturers unprecedented strategic opportunities and also present many management challenges. One of the biggest challenges is how to achieve distinctive manufacturing capabilities, such as mass customization capability and absorptive capacity, to support new strategic initiatives aimed at creating higher value to customers. A customer-oriented manufacturing strategy eventually determines a firm's growth in the increasingly competitive global market.

The current research represents one of the first large-scale cross-disciplinary empirical efforts to systematically investigate the interrelationships among a manufacturing firm's absorptive capacity of knowledge and technology, level of advanced information technology usage, level of innovative manufacturing practices, mass customization capability and value to customer performance. The major contribution of this research is the development of valid and reliable measurement instruments for the following constructs: 1) Absorptive Capacity; 2) Information Systems Usage; 3) Advanced Manufacturing Technology Usage; 4) Modularity Based Manufacturing Practices; and 5) Mass Customization Capability. From a researcher's point of view, the development and validation of these important measurement instruments provided valuable tools to greatly facilitate future interdisciplinary studies in manufacturing management and information technology management fields.

The second major contribution of the current research is the development and testing of a comprehensive theoretical framework of mass customization. LISREL structural modeling was used to test the relationships among the major research constructs. The relationships were represented by Hypotheses 1 to 10 in this research. The empirical results supported Hypotheses 1, 2, 3, 4, 7, 8, 9 and 10, while Hypotheses 5 and 6 were not supported. That is, the direct impact of a firm's information systems usage and advanced manufacturing technology usage on mass customization capability was not found. However, an interesting finding was that information systems usage and advanced manufacturing technology usage indirectly affect mass customization capability through time-based manufacturing practices. The empirical findings on these relationships added significantly to the current body of knowledge in manufacturing management and technology management.

From a practitioner's point of view, the third major contribution of the current research is that the measurement instruments and structural models developed in this research provide a set of valuable tools to 1) evaluate a firm's level of absorptive capacity, level of information systems and advanced manufacturing technology usage, use of various manufacturing practices, and degree of mass customization capability; 2) understand the impact of a firm's absorptive capacity on the effective usage of information technology and successful implementation of innovative manufacturing practices; 3) understand the joint impact of information technology and manufacturing practices on a firm's mass customization capability; and 4) understand the mechanism of creating higher customer value through absorptive capacity and mass customization capability.

While the current research made significant contributions from both a theoretical and practical point of view, it also posed some interesting directions for future research. One immediate direction will be to collect new data set for comfirmatory factor analysis of the measurement instruments developed in the current research. This will provide further evidence for the validity and reliability of the instruments.

Future studies can also examine the proposed relationships in a contingent manner by bringing some contextual variables into the model, such as level of market turbulence, industry type, and firm size. For example, it will be very interesting to examine the relationships proposed in Hypotheses 5 and 6 across different industries. While these two relationships were found to be non-significant in the general structural model, they may become significant in some industry-specific models. It will also be intriguing to investigate how market turbulence affects the role of absorptive capacity. The need for absorptive capacity should be more significant under more turbulent environment where high level of organizational learning is required to deal with uncertainties.

Future research can also expand on the current theoretical framework by adding new constructs or studying new relationships. For example, the impact of absorptive capacity and mass customization capability on overall firm performance can be examined. The construct of manufacturing strategy can be introduced to check for its relationship with the constructs in this study. The issue of manufacturing system automation vs. integration (Vonderembse, Raghunathan and Rao, 1997) can be empirically studied using the Advanced Manufacturing Technology Usage instrument developed in the current research. Finally, the relationships among sub-dimensions of different constructs will also be worthwhile to explore.

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Appendix I: Demographic Information of Large-Scale Respondents

Firm Size

Number of Employees	Frequency	Percent
Less than 100	5	1.7%
100 to 499	208	68.6%
500 to 1000	41	13.5%
More than 1000	48	15.8%
Unspecified	1	0.3%
Total	303	100%

Sales Volume

Annual Sales ($)	Frequency	Percent
Less than 10 million	12	4.0%
10 to 50 million	148	48.8%
50 to 100 million	54	17.8%
100 to 250 million	26	8.6%
250 to 500 million	26	8.6%
500 to 1000 million	9	3.0%
1000 million and above	12	4.0%
Unspecified	16	5.3%
Total	303	100%

Industry Type

Industry	Frequency	Percent
Automotive or parts	40	13.2%
Fabricated metal products	85	28.1%
Electronics	26	8.6%
Electrical equipment	21	6.9%
Furniture and fixtures	7	2.3%
Appliances	11	3.6%
Rubber and plastic products	9	3.0%
Industrial machinery and equipment	52	17.2%
Transportation equipment	9	3.0%
Instruments and related products	20	6.6%
Other	23	7.6%
Total	303	100%

Plant Type

Type of Operations	Frequency	Percent
Job Shop	77	25.4%
Assembly line	42	13.9%
Batch processing	40	13.2%
Projects (one-of-a-kind)	15	5.0%
Continuous flow process	22	7.3%
Flexible manufacturing	37	12.2%
Manufacturing cells	68	22.4%
Unspecified	2	0.7%
Total	303	100%

Appendix II: Analysis of Non-respondent Bias

Firms Size Comparison

Number of Employees	Batch 1		Batch 2	
	Frequency	Percent	Frequency	Percent
Less than 100	1	0.8%	4	2.2%
100 to 499	88	71.5%	120	66.7%
500 to 1000	18	14.6%	23	12.8%
More than 1000	16	13.0%	32	17.8%
Unspecified	0	0%	1	0.6%
Total	123	100%	180	100%

Sales Volume Comparison

Annual Sales ($)	Batch 1		Batch 2	
	Frequency	Percent	Frequency	Percent
Less than 10 million	4	3.3%	8	4.4%
10 to 50 million	63	51.2%	85	47.2%
50 to 100 million	24	19.5%	30	16.7%
100 to 250 million	11	8.9%	15	8.3%
250 to 500 million	9	7.3%	17	9.4%
500 to 1000 million	3	2.4%	6	3.3%
1000 million and above	5	4.1%	7	3.9%
Unspecified	4	3.3%	12	6.7%
Total	123	100%	180	100%

Industry Type Comparison

Industry	Batch 1		Batch 2	
	Frequency	Percent	Frequency	Percent
Automotive or parts	16	13.0%	24	13.3%
Fabricated metal products	35	28.5%	50	27.8%
Electronics	8	6.5%	18	10.0%
Electrical equipment	10	8.1%	11	6.1%
Furniture and fixtures	3	2.4%	4	2.2%
Appliances	4	3.3%	7	3.9%
Rubber and plastic products	5	4.1%	4	2.2%
Industrial machinery and equipment	18	14.6%	34	18.9%
Transportation equipment	3	2.4%	6	3.3%
Instruments and related products	11	8.9%	9	5.0%
Other	10	8.1%	13	7.2%
Total	123	100%	180	100%

Appendix III: Large-Scale Mail Survey Questionnaire

1998 Survey of Manufacturing Practices of Product Customization, Infrastructure Building and Technology Application

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GENERAL INSTRUCTIONS

This questionnaire is part of a nationwide study underway to document manufacturing practices of product customization, infrastructure building, technology application and their impact on creating higher value to customers.

The questionnaire is divided into eight sections. Each question requires that you choose the alternative that best fits your views on that topic. We estimate that it should take you approximately 25 minutes to fill out this questionnaire. No additional file search is needed to answer the questions. There are no right or wrong answers. We are interested only in your perceptions. **The information provided by you will be treated in the strictest confidence.** Your responses will be entered in a coded format and only be used for aggregated statistical analyses.

Thank you for your cooperation. We believe that, with your assistance, this study can help clarify a number of issues pertaining to manufacturing management effectiveness that have only been addressed so far at a theoretical level. A business-reply envelope is enclosed for your convenience.

Section 1. The following statements describe typical manufacturing practices of flexible **product customization** through product modularity, process modularity, dynamic teaming and customer involvement. Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your organization.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable, or Do Not Know
Our products use modularized design	1	2	3	4	5	NA
Our products share common modules	1	2	3	4	5	NA
Production teams that can be re-organized are used in our plant	1	2	3	4	5	NA
Our product features are designed around a standard base unit	1	2	3	4	5	NA
We keep close contact with customers	1	2	3	4	5	NA
Production teams can be re-organized in response to product / process changes	1	2	3	4	5	NA
Our products can be customized by adding feature modules as requested	1	2	3	4	5	NA
We keep close contact with customers through all functional departments	1	2	3	4	5	NA
Our product modules can be reassembled into different forms	1	2	3	4	5	NA
We monitor changes in customer needs through close contacts	1	2	3	4	5	NA
Production teams can be re-assigned to different production tasks	1	2	3	4	5	NA
We try to understand customers' exact needs through close contacts	1	2	3	4	5	NA
Production teams are not permanently linked to a certain production task	1	2	3	4	5	NA
Our product feature modules can be added to a standard base unit	1	2	3	4	5	NA
Production team members can be re-assigned to different teams	1	2	3	4	5	NA
We involve customers in the customization processes through close contacts	1	2	3	4	5	NA
Our product modules can be rearranged by end-users to suit their needs	1	2	3	4	5	NA
We help customers clarify their needs through close contacts	1	2	3	4	5	NA
Production team members are capable of working on different teams	1	2	3	4	5	NA
Production teams have no difficulty accessing necessary resources	1	2	3	4	5	NA
We have a well designed system to ensure close contact with customers	1	2	3	4	5	NA
Our production process is designed as adjustable modules	1	2	3	4	5	NA
Our production process can be adjusted by adding new process modules	1	2	3	4	5	NA
Our production process modules can be adjusted for changing production needs	1	2	3	4	5	NA
Our production process can be broken down into standard sub-processes that produce standard base units and customization sub-processes that further customize the base units	1	2	3	4	5	NA
Our production process modules can be re-arranged so that customization sub-processes occur last	1	2	3	4	5	NA
Our production process modules can be re-arranged so that customization sub-processes be carried out later at distribution centers	1	2	3	4	5	NA

Section 2. The following statements describe typical characteristics of a firm's **capacity to absorb new knowledge and technology.** Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your organization.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable, or Do Not Know
The general knowledge level of our first-line workers is high	1	2	3	4	5	NA
The communications between supervisors and their subordinates are extensive	1	2	3	4	5	NA
We seek to learn from tracking new market trends in our industry	1	2	3	4	5	NA
The communications among functional areas are extensive	1	2	3	4	5	NA
We seek to learn from routine search of useful information	1	2	3	4	5	NA
The overall technical knowledge of our first-line workers is high	1	2	3	4	5	NA
We seek to learn from benchmarking best practices in our industry	1	2	3	4	5	NA
The communications among functional areas are frequent	1	2	3	4	5	NA
We seek to learn from trying out new technologies	1	2	3	4	5	NA
The communications between supervisors and their subordinates are frequent	1	2	3	4	5	NA
The general educational level of our first-line workers is high	1	2	3	4	5	NA
The communication of new ideas from one department to another is extensive	1	2	3	4	5	NA
The overall job competence of our first-line workers is high	1	2	3	4	5	NA
We seek to learn from our customers and suppliers	1	2	3	4	5	NA
The communications between departments are hindered by clear boundaries	1	2	3	4	5	NA
We seek to learn from taking new business opportunities	1	2	3	4	5	NA
The communications has to pass through many hierarchical levels in our firm	1	2	3	4	5	NA
Our employees tend to trust each other	1	2	3	4	5	NA
We seek to learn from conducting R&D activities	1	2	3	4	5	NA
Our employees are supportive of each other	1	2	3	4	5	NA
Our employees have strong feelings of belonging to our organization	1	2	3	4	5	NA
The knowledge of our managers is adequate when making business decisions	1	2	3	4	5	NA
Our employees share ideas freely with each other	1	2	3	4	5	NA
The knowledge of our managers is adequate when dealing with new technologies	1	2	3	4	5	NA
Our employees share a very open communications environment	1	2	3	4	5	NA
Our employees have no difficulty accepting new ideas	1	2	3	4	5	NA
The knowledge of our managers is adequate when managing daily operations	1	2	3	4	5	NA
The knowledge of our managers is adequate when solving technical problems	1	2	3	4	5	NA
Our employees are willing to accept changes	1	2	3	4	5	NA
Overall, our organization has high capacity to explore and assimilate new ideas	1	2	3	4	5	NA

Section 3. The following statements describe various **advanced manufacturing technologies.** Please circle the appropriate number that best indicates your firm's **extent of use of each technology** (column 1) AND **level of integration of each technology** (column 2) with other components of your manufacturing system. **Please answer both columns**. The measurement scale to be used are explained below.

1 - Very Low, **2** - Low, **3** - Moderate, **4** - High, **5** - Very High, **NA** - Not Applicable or Do Not Know

	Extent of use of this technology in your company	Level of integration of this technology with others
Automatic numerically controlled machines	1 2 3 4 5 NA	1 2 3 4 5 NA
Automated inspection and testing equipment	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that monitors the production process and provides feedback	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that determines routings between machines	1 2 3 4 5 NA	1 2 3 4 5 NA
Automated storing and retrieving systems	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that facilitates production by classifying parts into families according to similarities	1 2 3 4 5 NA	1 2 3 4 5 NA
Automated conveyors that deliver parts to work centers	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that plans machining operations	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that plans and controls shop floor material requirements	1 2 3 4 5 NA	1 2 3 4 5 NA
Automated guided vehicles that deliver parts and tools	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that automates parts and tools design processes	1 2 3 4 5 NA	1 2 3 4 5 NA
Automatic industrial robots	1 2 3 4 5 NA	1 2 3 4 5 NA
Automated flexible manufacturing systems	1 2 3 4 5 NA	1 2 3 4 5 NA
Computer-aided technology that provides rapid prototyping in product design process	1 2 3 4 5 NA	1 2 3 4 5 NA

Please circle your level of agreement to the following overall statement about your manufacturing system on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree).

Overall, our manufacturing system is highly automated	1 2 3 4 5 NA
Overall, the components of our manufacturing system are highly integrated	1 2 3 4 5 NA

Section 4. The following statements describe the typical **usage of information systems (IS)** in a firm. *Typical IS may include office automation systems, order entry systems, electronic mail and conferencing systems, intranet and internet systems, executive decision support systems, expert systems, and other computer-based networking systems.* Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your organization.

We use IS to ...	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable, or Do Not Know
help justifying daily operational decisions	1	2	3	4	5	NA
help improving the efficiency of daily operational decision processes	1	2	3	4	5	NA
facilitate information distribution throughout the organization	1	2	3	4	5	NA
help analyzing why problems occur in daily operations	1	2	3	4	5	NA
facilitate information sharing among employees	1	2	3	4	5	NA
facilitate information sharing between different management levels	1	2	3	4	5	NA
help monitoring the daily operational decision processes	1	2	3	4	5	NA
facilitate information feedback on employee work performance	1	2	3	4	5	NA
help improving the effectiveness of long-term strategic planning processes	1	2	3	4	5	NA
facilitate reporting of employee work progress	1	2	3	4	5	NA
help formulating long-term business plans	1	2	3	4	5	NA
facilitate information sharing among different departments	1	2	3	4	5	NA
help justifying long-term business plans	1	2	3	4	5	NA
help creating new ways of doing business	1	2	3	4	5	NA
facilitate cross-functional cooperation within the organization	1	2	3	4	5	NA
help generating long-term strategic advantage	1	2	3	4	5	NA
exchange information with government agencies	1	2	3	4	5	NA
collect information about best practices in our industry	1	2	3	4	5	NA
exchange information with research institutions	1	2	3	4	5	NA
collect information about customer requirements	1	2	3	4	5	NA
keep suppliers involved in our product design and production processes	1	2	3	4	5	NA
exchange information with customers	1	2	3	4	5	NA
keep suppliers informed of our specific requirements	1	2	3	4	5	NA
collect information about new technologies in our industry	1	2	3	4	5	NA
collect information about competitor products	1	2	3	4	5	NA

Section 5. The following statements describe a firm's typical shop floor **production practices.** Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your organization.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable, or Do Not Know
Shop-floor employees are involved in improvement efforts	1	2	3	4	5	NA
We use special tools to shorten setup time	1	2	3	4	5	NA
Our employees are trained to reduce setup time	1	2	3	4	5	NA
We receive parts from suppliers on time	1	2	3	4	5	NA
Products are classified into groups with similar routing requirements	1	2	3	4	5	NA
Products are classified into groups with similar processing requirements	1	2	3	4	5	NA
We maintain our equipment regularly	1	2	3	4	5	NA
Equipment is grouped to produce families of products	1	2	3	4	5	NA
Production at stations is "pulled" by the current demand of the next stations	1	2	3	4	5	NA
Families of products determine our factory layout	1	2	3	4	5	NA
Shop-floor employees are involved in problem solving teams	1	2	3	4	5	NA
We use fishbone type diagrams to identify causes of quality problems	1	2	3	4	5	NA
Production is "pulled" by the shipment of finished goods	1	2	3	4	5	NA
We receive the correct number of parts from suppliers	1	2	3	4	5	NA
Employees work on setup improvement	1	2	3	4	5	NA
We receive high quality parts from suppliers	1	2	3	4	5	NA
Our employees use quality control charts	1	2	3	4	5	NA
We conduct process capability studies	1	2	3	4	5	NA
Shop-floor employees are involved in suggestion programs	1	2	3	4	5	NA
We use a "pull" production system	1	2	3	4	5	NA
We emphasize good preventive maintenance	1	2	3	4	5	NA
Records of routine maintenance are kept	1	2	3	4	5	NA
We redesign or reconfigure equipment to shorten setup time	1	2	3	4	5	NA
We receive the correct type of parts from suppliers	1	2	3	4	5	NA
Production is "pulled" by an open kanban / bin position	1	2	3	4	5	NA

Section 6. The following statements measure your firm's **capability to customize products** inexpensively and quickly. Please circle the appropriate number which best indicates your perception of <u>the relative capabilities of your firm as compared to the industry average</u>.

	Much Below Average	Below Average	About Average	Above Average	Much Above Average	Not Applicable, or Do Not Know
Our capability of customizing products at low cost is	1	2	3	4	5	NA
Our capability of customizing products on a large scale is	1	2	3	4	5	NA
Our capability of translating customer requirements into technical designs quickly is	1	2	3	4	5	NA
Our capability of adding product variety without increasing cost is	1	2	3	4	5	NA
Our capability of customizing products while maintaining a large volume is	1	2	3	4	5	NA
Our capability of setting up for a different product at low cost is	1	2	3	4	5	NA
Our capability of responding to customization requirements quickly is	1	2	3	4	5	NA
Our capability of adding product variety without sacrificing overall production volume is	1	2	3	4	5	NA
Our capability of changeover to a different product quickly is	1	2	3	4	5	NA
Our capability of producing customized products with lead time and cost comparable to mass-produced products is	1	2	3	4	5	NA

Section 7. The following statements indicate the **value of your products to customers**. Please circle the appropriate number to indicate the extent to which you agree or disagree with each statement as applicable to your organization.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable, or Do Not Know
Our customers are satisfied with our ability to customize products	1	2	3	4	5	NA
Our customers are satisfied with the variety of our products	1	2	3	4	5	NA
Our customers are satisfied with the quality of our products	1	2	3	4	5	NA
Our customers are satisfied with the features that our products provide	1	2	3	4	5	NA
Our customers are loyal to our products	1	2	3	4	5	NA
Our customers refer new customers to purchase our products	1	2	3	4	5	NA
Our customers feel that we offer products with high value	1	2	3	4	5	NA
Our customers perceive that they receive their money's worth when they purchase our products	1	2	3	4	5	NA

Section 8. General Information

Please provide the following information for statistical purpose.

1. Your job title:____

2. How many employees does you company have?
   ▯ Less than 100 ▯ 100 to 499 ▯ 500 to 1000 ▯ More than 1000

3. Please indicate annual sales of your firm/division
   ▯ Less than 10 million ▯ 10 to <50 million ▯ 50 to <100 million
   ▯ 100 to <250 million ▯ 250 to <500 million ▯ 500 to <1000 million
   ▯ 1000 million and above

4. Please indicate the category that best describe your primary business:
   ▯ Automotive or parts ▯ Fabricated metal products ▯ Electronics
   ▯ Electrical equipment ▯ Furniture and fixtures ▯ Appliances
   ▯ Rubber and plastic products ▯ Industrial machinery and equipment
   ▯ Transportation equipment ▯ Instruments and related products
   ▯ Other (Please specify): ____________________________________

5. What percentage of your end products are customized to specific customer orders ? ______%
   What percentage of your end products are general purpose products for the mass market ? ______%

6. Please select the type of manufacturing operation that best describe your company / division:
   ▯ Job shop ▯ Assembly line ▯ Batch processing
   ▯ Projects (one-of–a-kind production) ▯ Continuous flow process
   ▯ Flexible manufacturing ▯ Manufacturing cells

7. What quality certification have you attained ?
   ▯ ISO 9000 ▯ QS 9000 ▯ Other (please specify) ________________

8. What is the Standard Industrial Classification (SIC) code of your primary business ? __________

Thank you for your assistance in this research ! Your time and effort to answer this survey is greatly appreciated. If you wish to receive a summary of the research findings, please enter your name and address below or attach a business card.

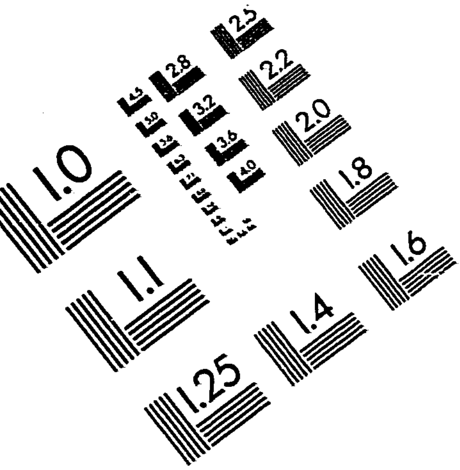
Name ______________________________ Phone ____________

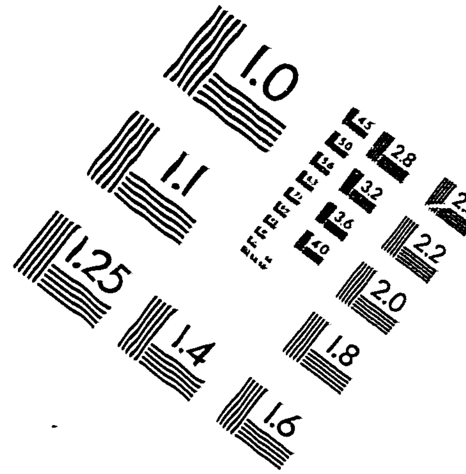
Firm Name ____

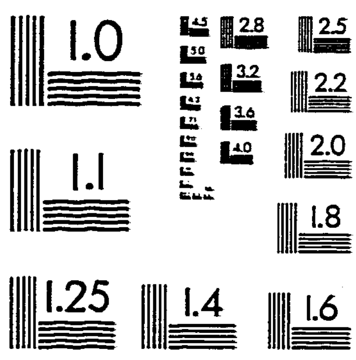
Address ____

____

IMAGE EVALUATION TEST TARGET (QA-3)







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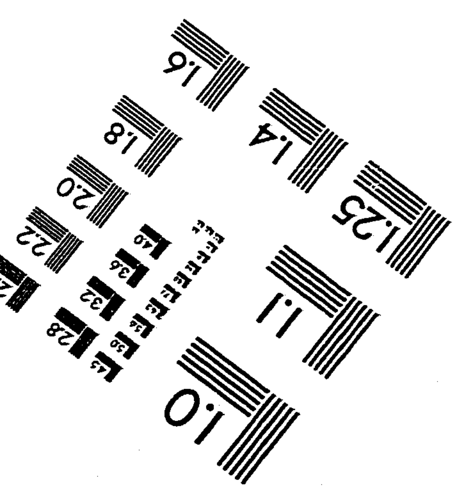

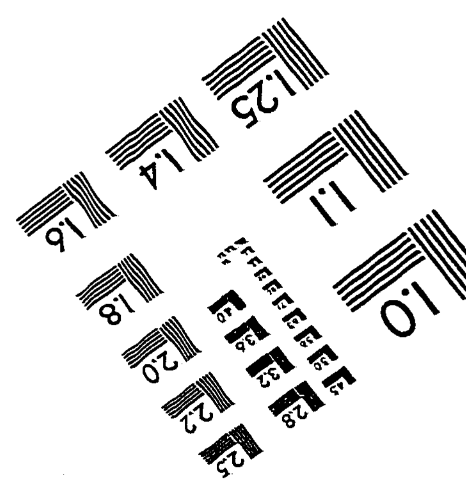

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