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A THEORY OF INTEGRATED MANUFACTURING PRACTICES: RELATING TOTAL QUALITY MANAGEMENT, JUST-IN-TIME AND TOTAL PRODUCTIVE MAINTENANCE

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

KRISTY ONG CUA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Roger G. Schroeder and Kathleen E. McKone, Advisers

July 2000

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Roger G. Schroeder and Kathleen E. McKone
Name of Faculty Adviser(s)

Roger Schroeder Kathleen E. McKone
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ABSTRACT

Manufacturing programs such as Total Quality Management (TQM), Just-in-Time (JIT), and Total Productive Maintenance (TPM) have often been referred to as components of "World-Class Manufacturing". While there are many success stories and much research on TQM, JIT, and TPM, there are also documented cases of failure in the implementation of these programs. There has been insufficient research on the relationships between these programs and their combined impact on manufacturing performance. In this study, we examine the interrelationship between the three programs by proposing a single theoretical framework.

We identify both the common and unique practices of TQM, JIT, and TPM that constitute a set of Integrated Manufacturing Practices. We develop a theoretical framework for understanding the effect of the implementation of Integrated Manufacturing Practices on manufacturing performance that is grounded on the concept of fit, the socio-technical systems theory, and Operations Management theories. The theoretical framework is enriched by information obtained from the case studies of three manufacturing plants. We also use survey data from 163 manufacturing plants to empirically test the theoretical framework and its associated propositions. Multi-item scales are used to measure manufacturing practices and the psychometric properties of these scales are verified using confirmatory methods. The methods of analysis that are used in this study include hierarchical multiple regression analysis, discriminant analysis, and structural equation modeling.

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We find that higher levels of implementation of Integrated Manufacturing Practices are positively associated with manufacturing performance, indicating that manufacturing plants should implement both socially- and technically-oriented practices. We find specific configurations of practices that best support the improvement of particular performance dimensions. Also, while contextual factors affect manufacturing performance, the implementation of Integrated Manufacturing Practices provides a more significant explanation of performance differences.

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CHAPTER 1
INTRODUCTION

1.1. RESEARCH BACKGROUND

The global marketplace has led many companies to implement new manufacturing programs and organizational structures to enhance their competitive position. Among the many manufacturing programs, Total Quality Management (TQM), Just-in-Time (JIT), Total Productive Maintenance (TPM), and Employee Involvement (EI) programs have often been referred to as components of "World-Class Manufacturing" (Schonberger, 1986; Steinbacher and Steinbacher, 1993; Schonberger, 1996). Though there may be some differing notions of what constitutes world-class manufacturing, the cited authors and others recognize that continuous improvement to sustain competitive advantage and profitability is dependent upon the synthesis of several reinforcing world-class manufacturing programs. While some researchers consider EI a separate manufacturing program, the concept of employee involvement permeates TQM, JIT, and TPM, and forms an integral part of their implementation. Hence, EI can also be considered part of the other three programs.

The importance of TQM, JIT, and TPM, cannot be overemphasized. There is an increasing number of organizations that apply some form of TQM, including non-manufacturing organizations in construction (Lurz, 1998), health services (Rouse et al., 1998), and information systems (Ward, 1998) industries to name a few. Firms that

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implement effective TQM, as evidenced by winning the Malcolm Baldrige National Quality Award, are found to have better sales growth and a change in operating income over a 10-year period that is 48% higher than that for non-winning firms (Hendricks and Singhal, 1997).

The success of JIT at the Toyota Motor Company has spread to many firms in the Western industrialized countries and various industries (Inman and Mehra, 1990, 1993). A JIT approach to production has been shown to lead to performance improvements (e.g., Sugimori et al., 1977; Flynn et al., 1995). A number of authors have provided lists of benefits for plants implementing JIT (e.g., Schonberger, 1982; Voss and Robinson, 1987). Some of the benefits cited are lower inventory, improved quality, reduced waste and rework, lower overhead, flexibility, and reduced lead time.

While TPM may not be as commonly implemented as TQM and JIT, the number of plants applying for the TPM/PM awards being given by the Japan Institute of Plant Maintenance (JIPM) has been increasing. In 1999 alone, 150 plants/factories won awards for TPM excellence including 41 non-Japanese plants (Japan Institute of Plant Maintenance, 1999). Constance Dyer, Director of Research and TPM Product Development points out that companies implementing TPM have on average achieved a 50% reduction in breakdown labor rates, a 70% reduction in lost production, a 50-90% reduction in setups, a 25-40% increase in capacity, a 50% increase in labor productivity, and a 60% reduction in costs per maintenance unit (Koelsch, 1993).

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Academic research on TQM and JIT abounds. A total of 226 TQM-related articles was identified from 44-refereed management journals and reviewed by Ahire et al. (1995). There are over 700 JIT-related articles published between 1985 and 1990 (Inman and Mehra, 1990). While there are few academic articles that specifically address TPM, there are numerous books and articles in trade journals that espouse the benefits of TPM implementation (e.g., Nakajima, 1988; Suzuki, 1992; Teresko, 1992; Tsuchiya, 1992; Koelsch, 1993; Mahmudar, 1996; Patterson et al., 1996). However, the literature primarily considers the TQM, JIT, and TPM programs in isolation and mostly ignores the investigation of simultaneous implementation and combined benefits of interrelated and complementary manufacturing programs.

While there are many success stories and much research on TQM, JIT, and TPM, there are also documented cases of failure in the implementation of these programs. For instance, Wallace Company, a Malcolm Baldrige National Quality Award winner, filed for bankruptcy protection; and Florida Power and Light, the winner of Deming Prize for Quality Management, slashed its quality department staff from 85 to three since management feared that the "quality improvement process had become a tyrannical bureaucracy" (Choi and Behling, 1997). The widespread use of JIT also has mixed success and failure (Safayeni et al., 1991). Only 5% of companies surveyed by Giffi et al. (1990) that have some kind of maintenance program believed that their program was effective.

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Many authors have tried to explain why failures and undesirable effects occur. Some of the suggested reasons for failure of TQM include partial implementation of TQM (Becker, 1993), overly optimistic expectations (Doyle, 1992), lack of a well-defined routine for attaining quality (Westphal et al., 1997), and implementation of TQM to conform to societal norms rather than for its instrumentality (Campbell, 1994).

Crawford et al. (1988) point out several problems faced by JIT implementation, such as: cultural resistance of change, lack of training and education, lack of organizational communication, use of inappropriate performance measurement, and poor quality. Moreover, Safayeni et al. (1991) contend that failure of JIT implementation is partly due to confusion over what exactly constitutes JIT and its implementation within an existing organization structure that does not provide the necessary support. Many of the problems of JIT implementation cited by Crawford et al. (1988) are also observed as hindrances to the successful implementation of TPM (Patterson et al., 1995). The major barrier that will possibly affect TPM implementation is the inability of a company to coordinate its human resource practices, management policies and technology (Fredendall et al., 1997). Together, these problems reflect the lack of a system that supports the implementation of world-class manufacturing programs such as TQM, JIT, and TPM.

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1.2. RESEARCH PROBLEMS

The mixed evidence of success and failure from the different manufacturing programs calls for more in-depth study. The goal of this study is to understand the drivers of improved manufacturing performance. Rather than considering TQM, JIT, and TPM as distinct programs, we seek to identify both their common and unique practices that constitute a set of Integrated Manufacturing Practices.

This study considers strategic and human resource related practices common to TQM, JIT, and TPM as the common strategic- and human resource-oriented practices of the set of Integrated Manufacturing Practices. This set of common practices is similar to Rehder's (1989) notion of building manufacturing competitiveness with a synergy between the strategy, structure, culture, and human resources subsystems of varying manufacturing practices. This is also consistent with Hayes and Wheelwright's (1984) emphasis on the human elements of organization in their discussion of the infrastructure category of manufacturing strategy decisions. The other core procedures and practices of TQM, JIT, and TPM that are unique to each of these programs and that are technical or process oriented are considered the basic techniques in the set of Integrated Manufacturing Practices. Following are the questions that this research attempts to delineate.

1. What are the theoretical and historical foundations for studying manufacturing programs such as TQM, JIT, and TPM within a single framework?

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2. What constitutes the common strategic- and human resource-oriented practices and basic techniques of TQM, JIT, and TPM?
3. How does the development of the common strategic- and human resource-oriented practices directly affect manufacturing performance and enhance or constrain the effect of implementation of basic TQM, JIT, and TPM techniques on manufacturing performance?

1.3. RESEARCH METHOD

The goal of this research is to build and test a theory that explains the effect of the implementation of a set of Integrated Manufacturing Practices on manufacturing performance. Therefore, this research draws on methodologies that are suitable for theoretically driven empirical research. Weick (1989) suggests that theories should be developed using three systematic processes involving literature review, use of data, and use of intuition and assumptions. Lewis (1998) applies Weick's suggestions in building Operations Management theory and proposes the principle of iterative triangulation. The processes of theory development are not meant to be sequential (Lewis, 1998) and are to be used in conjunction and in balance (Eisenhardt, 1989).

Traditionally, Operations Management is dominated by deductive approaches (Swamidass, 1991) and mathematical modeling and simulation analysis are the common tools of analysis. In the 1990's, attention was drawn to the potential of empirical research involving cross-sectional and longitudinal data analysis. More recently case study is considered an indispensable complement to quantitative analysis

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(see McCutcheon and Meredith, 1993; Meredith, 1998). These empirical research methods highlight the use of natural vis-à-vis artificial data in understanding real-life Operations Management phenomenon.

In the following we describe how the methodologies of literature review, case studies and large-sample cross-sectional data analysis are used in conducting this research. These three methodologies are not conducted in strict sequence. Instead, they are used complementarily to develop, enhance, and empirically verify a Theory of Integrated Manufacturing Practices.

To address the research questions of this study a literature review of the relationships among TQM, JIT, and TPM and other relevant Operations Management studies is conducted. This study is theoretically grounded on management principles such as the concept of fit and the socio-technical systems theory. Using literature in Operations Management and general management principles, we explicitly articulate a single theoretical framework for a set of Integrated Manufacturing Practices that synthesizes and explains the combined impact of TQM, JIT, and TPM on manufacturing performance.

We conduct case studies of three manufacturing plants to provide a "reality check" of the relevance of the theoretically developed framework. Case studies can also serve as a source of analytic generalization to theory (Yin, 1994), hence information obtained from case studies is used to enhance the theoretical framework.

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Case analysis also helps answer the "why" and "how" questions in the natural setting of the phenomenon under observation and provides direction for subsequent research.

To systematically test the theoretical framework and its associated propositions, we conduct large-sample cross-sectional data analysis. We use data of 163 manufacturing plants collected as part of the ongoing World Class Manufacturing Project (Sakakibara et al., 1993; Flynn et al., 1994). We operationalize the constructs in the theoretical framework for empirical validation and use multiple regression analysis, discriminant analysis, and structural equation modeling to test the hypothesis of this study.

1.4. IMPORTANCE AND CONTRIBUTION OF THIS RESEARCH

There have been various comments about the inadequacies of theory in the field of Operations Management (Swamidass and Newell, 1987; Anderson et al., 1989; Flynn et al., 1990; Ahire et al., 1995; Swink and Way, 1995). Recently, Schmenner and Swink (1998) contend that many building blocks of theory are prevalent in existing Operations Management literature. They suggest that careful organization of our thinking can lead to the development of useful and productive theories. This study will contribute to theory development in Operations Management by building a single theoretical framework for examining a set of Integrated Manufacturing Practices using established management principles and Operations Management theories.

There is an abundance of literature that considers TQM and JIT but there is still confusion on why their implementation yields variable results. On the other hand,

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TPM has received less discussion in the academic literature. However, TPM is a highly influential technique that is in the core of Operations Management (Voss, 1995) and deserves academic attention. Many authors believe in the importance of simultaneous implementation of practices associated with TQM, JIT, and TPM. For instance, Roth and Miller (1992) contend that maintenance management may well be the biggest challenge facing companies that implement TQM, JIT, and computer-aided manufacturing. Similarly, Huang (1991) discusses the importance of considering the integration of JIT, TPM, total quality control, and factory automation with worker participation. Furthermore, Imai (1998) believes that TQM and TPM are the two pillars supporting the JIT production system. Miyake and Enkawa (1999) discuss how total quality control can be implemented with TPM. These highlight the renewed interest in the study of manufacturing programs with an emphasis in their simultaneous investigation, the main thrust of this research. However, these studies do not provide sufficient empirical evidence and details on how TQM, JIT, and TPM practices can be integrated.

There is some empirical study on the interrelationship between manufacturing programs. Vuppalapati et al. (1995) and Sriparavastu and Gupta (1997) empirically investigate the joint implementation of TQM and JIT. Flynn, Sakakibara and Schroeder (1995) study the relationship between TQM and JIT in terms of the relation between their associated practices and performance. The interrelationship of world-class manufacturing programs has also been supported in the work of McKone et al.

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(1999). They find that the level of implementation of TPM is better explained by the level of plant managerial factors such as TQM, JIT, and EI than by environmental and organizational contextual factors. All these studies support the need for a more systematic and comprehensive assessment of the status of managerial systems or programs being implemented in the plant and determine whether or not these programs fit together. This study extends this type of research by investigating TQM, JIT, and TPM together to understand their interrelationship and combined impact on manufacturing performance.

Many authors have acknowledged that difficulty exists in precisely defining or differentiating TQM, JIT, and TPM (Gunn, 1987; Dean and Snell, 1991; Groenevelt, 1993; Easton and Jarrell, 1994; Ahire et al., 1995). Some elements of one program are also included in another program. For instance, a recent study on JIT manufacturing included practices such as total quality control, quality circles, and total productive maintenance as three of ten JIT practices (White et al., 1999). While segregating the practices of the different programs may be arbitrary, relating the programs should be manageable. This study addresses this problem of confounding practices of TQM, JIT, and TPM by acknowledging the existence of overlapping practices and determining a set of common strategic- and human resource-oriented practices of these three programs.

Investigation of manufacturing programs is important for practitioners because these programs are what manufacturing managers consider when they think of

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strategic management of manufacturing operations (Hayes and Pisano, 1994). However, while programs such as TQM, JIT, and TPM have proliferated the manufacturing sector, management seems content with investing in these programs without a full sense of their implementation requirement and their impact on manufacturing performance. Hayes and Pisano (1994) believe that the crux of the problems that many companies have experienced with improvement programs is that most companies focus on the mechanics of the programs rather than on their substance, the skills and capabilities that enable an improvement program to achieve its desired results.

Some of the prominent problems in TQM, JIT, and TPM implementation include partial implementation, lack of a well-defined routine for attaining the objectives of implementation, cultural resistance to change, lack of training and education, and lack of organizational communication (Crawford et al., 1988; Becker, 1993; Patterson et al., 1995; Westphal et al., 1997). These problems reflect the lack of a clear understanding of what are the fundamental and complementary manufacturing practices. It can also be inferred that companies that encountered failure in their program implementation neglected the development of practices that support the implementation of TQM, JIT, and TPM techniques. This study will therefore inform management of the requirements of TQM, JIT, and TPM implementation by determining whether or not the development and integration of the common strategic-

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and human resource-oriented practices with the implementation of the programs' basic techniques help improve manufacturing performance.

In summary, this study provides the following contributions to the field of Operations Management.

1. This study contributes toward theory development in Operations Management that is grounded on the concept of fit and socio-technical systems theory, and Operations Management theories.
2. The development of a unified theoretical framework linking TQM, JIT, and TPM provides a mechanism for classifying the fundamental practices of three programs and understanding their interrelationships in one integrative system that is free of redundancies.
3. The empirical tests of the unified theoretical framework and its propositions provide evidence of the benefits of investigating complementary manufacturing programs together and highlight the importance of conducting comprehensive research that considers interrelated elements simultaneously.
4. The results of this study suggest that practitioners should not always think of different manufacturing programs as competitors of manufacturing's scarce resources. This study provides guidelines for practitioners who are interested in developing and implementing a coherent set of practices that emphasizes both human resource and strategic development and

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implementation of techniques that will improve manufacturing performance.

5. The study draws attention to the value of understanding the contextual factors of a manufacturing plant.
6. The empirical results provide different configurations of the implementation of practices that can positively affect performance depending on a manufacturing plant's performance priorities.

1.5. ORGANIZATION OF THE DISSERTATION

The rest of the dissertation is organized into seven chapters. Chapter 2 provides a literature review of management principles and Operations Management research that is relevant to this study. Chapter 3 develops a Theory of Integrated Manufacturing Practices. Chapter 4 discusses the case-based research used to enhance the theoretical framework. Chapter 5 states the hypotheses drawn from the theoretical framework that are empirically tested. Chapter 6 describes the data from the World Class Manufacturing Database and evaluates the psychometric properties of the measurements that are used for empirical investigation. Chapter 7 presents the methods and results of hypotheses testing. Finally, Chapter 8 concludes the dissertation by discussing the contributions and implications of this study for researchers and managers and directions for future research.

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CHAPTER 2
LITERATURE REVIEW

2.1. DEVELOPMENT OF TQM, JIT, AND TPM

History tells us that many of the changes in manufacturing practices are related to the loss of and then search for ways of regaining the competitive edge of U.S. companies after the Second World War and the increasing competition in the global marketplace since the 1980s. The reliance of U.S. manufacturers on huge work-in-process finished product inventories and the lack of emphasis on quality and customer satisfaction are considered some of the major reasons that led to the loss of their international dominance (Sriparavastu and Gupta, 1997). In an effort to correct these weaknesses in their operations, many companies have embarked on improvement programs. As a result there has been a proliferation of improvement programs including TQM, JIT, TPM, computer integrated manufacturing (CIM), materials resource planning (MRP), and business process engineering (BPR) to name a few.

This study considers three manufacturing programs, namely, TQM, JIT, and TPM, that have been critical to American companies' effort to restore their competitive edge and are recognized world-class manufacturing programs (Schonberger, 1986; Steinbacher and Steinbacher, 1993). In this section we briefly discuss how TQM, JIT, and TPM are developed and identify their similar emphases and practices.

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2.1.1. Total Quality Management

The notion of quality has been around for many years but the importance of a comprehensive approach to quality was only recognized in the 1960s when A. V. Feigenbaum (1961) coined the term *total quality control* (TQC). According to Feigenbaum (1983, p. 6), TQC is "an effective system for integrating the quality development, quality-maintenance, and quality-improvement efforts of the various groups in an organization so as to enable marketing, engineering, production, and service at the most economical levels which allow for full customer satisfaction." Japan has embraced the quality concept exhorted by quality gurus such as Deming, Juran, and Ishikawa since the end of the Second World War. While widespread recognition and implementation of the principles of quality as an organization-wide effort began only in the 1980s in the U.S. and came to be known as *total quality management* (TQM).

Powell (1995, p. 16) defines TQM as "an integrated management philosophy and set of practices that emphasizes, among other things, continuous improvement, meeting customers' requirements, reducing rework, long-range thinking, increased employee involvement and teamwork, process redesign, competitive benchmarking, team-based problem solving, constant measurement of results and closer-relationships with suppliers." From this definition, it can be inferred that TQM is a very broad concept, encompassing the entire organization and improving overall product quality. To understand TQM better some researchers have distinguished between the principles

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and practices of TQM. The principles are the values and beliefs of TQM while the practices are the activities and techniques through which the principles are concretized. For instance, Dean and Bowen (1994) identify the principles of TQM as customer focus, continuous improvement, and teamwork. This set of TQM principles is concurred by Evans and Lindsay (1999). For each of the three principles, Dean and Bowen (1994) identify a set of practices that can be implemented and these are:

1. For Customer Focus: direct customer contact, collection of information about customer needs, use of customer information in design and delivery of products and services
2. For Continuous Improvement: process analysis, reengineering, problem solving, plan/do/check/act
3. For Teamwork: search for cross-functional arrangements, formation of various types of teams, and training for group skills.

On the other hand, Hackman and Wageman (1995) review the work of Deming, Ishikawa, and Juran and identify four interlocked assumptions that form the basis of TQM. These assumptions are:

1. Quality: The cost of poor quality is far greater than the cost of developing processes that ensure good quality.
2. People: Employees care about quality and will contribute to its achievement so long as they are provided the means to do so.

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3. Organizations: Organizations are systems of interdependent functions that must be coordinated through cross-functional initiatives.
4. Senior Management: Top management must be committed to total quality and create the organizational system for its implementation.

Hackman and Wageman (1995) also specify four principles that should guide any organizational intervention or practice that is intended to improve quality. These principles are focus on work processes, analysis of variability, management by fact, and learning and continuous improvement. They identify five interventions or practices that can be implemented to realize the four principles and the interventions are explicit identification and measurement of customer requirements, creation of partnerships with suppliers, use of cross-functional teams to identify and solve quality problems, use of scientific methods to monitor performance, and use of process-management techniques to enhance the effectiveness of teams.

Numerous practices have been associated with TQM in both practitioner and academia oriented literature. To keep the review of TQM practices manageable, we consider studies that empirically validate factors of quality management or TQM implementation. A comparison and synthesis of the findings from such studies will be comprehensive since the factors considered in these studies are conceptualized on the basis of an extensive literature review on one or more of the following areas:

1. the works of quality gurus (see Saraph et al., 1989; Powell, 1995; Ahire et al., 1996)

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2. practitioner and empirical literature on TQM (see Flynn et al., 1994; Powell, 1995; Ahire et al., 1996)
3. literature related to the Malcolm Baldrige National Quality Award (see Powell, 1995; Ahire et al., 1996; Black and Porter, 1996; Samson and Terziovski, 1999)
4. literature related to other quality award criteria (see Samson and Terziovski, 1999)

A comparison of the factors of TQM from six studies (Saraph et al., 1989; Flynn et al., 1994; Powell, 1995; Ahire et al., 1996; Black and Porter, 1996; Samson and Terziovski, 1999) is provided in Table 2-1. Even though the sources from which the factors of TQM were formulated are different, the six studies provide very similar sets of practices (Table 2-1). Considering only the factors that are identified in three or more of the six studies, we classify the factors into nine practices, namely, cross-functional product design, process management, information and feedback, supplier quality management, customer involvement, committed leadership, strategic planning, cross-functional training, and employee involvement.

This set of nine practices is consistent with the conceptual definitions provided by Dean and Bowen (1994) and Hackman and Wageman (1995). The practices of committed leadership and strategic planning are manifestations of the importance of senior management's role in the implementation of TQM. Cross-functional product design and customer involvement highlight the importance of managing

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Table 2-1. A Comparison of Total Quality Management (TQM) Practices

This Study	Saraph et al. 1989 and Benson et al. 1991	Flynn et al. 1994	Powell 1995	Ahire et al. 1996	Black and Porter 1996	Samson and Terziovski 1999
Cross-functional Product Design	Product/service design	Product design	Flexible manufacturing	Design quality management	External interface management	
Process Management	Process management/ operating procedures	Process management	Zero defect mentality	SPC usage	Operational quality planning	Process management
			Process improvement			
Information and Feedback	Quality data and reporting	Quality information	Measurement	Internal quality information usage	Quality improvement measurement and info system	Information and analysis
Supplier Quality Management	Supplier quality management	Supplier involvement	Closer supplier relationships	Supplier quality management	Supplier partnerships	
Customer Involvement		Customer involvement	Closer customer relationships	Customer Focus	Customer satisfaction orientation	Customer focus

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Table 2-1 Continued. A Comparison of Total Quality Management (TQM) Practices

This Study	Saraph et al. 1989 and Benson et al. 1991	Flynn et al. 1994	Powell 1995	Ahire et al. 1996	Black and Porter 1996	Samson and Terziovski 1999
Committed Leadership	Role of divisional top management and quality policy	Top management support	Committed leadership	Top management commitment	Strategic quality management	Leadership
Strategic Planning	Role of quality department		Adoption and communication of TQM		Corporate quality culture	Strategic planning
Cross-functional Training	Training		Increased training	Employee training		
Employee Involvement	Employee relations	Work force management	Open organization	Employee involvement	People and customer management	People Management
			Employee empowerment	Employee empowerment	Teamwork structures	
General Management Practice			Benchmarking	Benchmarking		

interdependencies and provide the mechanisms for designing products that will satisfy the specification of the customer. The use of process management and information and feedback not only emphasizes the reduction and elimination of variability and defects at its source but also accents the role of workers in the production process. The use of cross-functional training, employee involvement, and supplier quality management are manifestations of the importance given to both internal and external teamwork and continuous improvement and learning.

The popularity of TQM has come to a point where some organizations adopt TQM to simply acquire institutional status and conform to institutional pressures (Campbell, 1994; Westphal et al., 1997). Some researchers believe that this may be a cause for failure of some TQM implementation because of the lack of full understanding of the requirements and routines for attaining quality (Westphal et al., 1997).

Another critical factor believed to have caused problems in the implementation of TQM is the lack of a support system to facilitate learning and transform learning into effective diffusion of the practices of TQM (Cole, 1998). While TQM encompasses a variety of tools and techniques the use of these tools should be supported by an empowered workforce that can use the data gathered to identify and solve problems (Becker, 1993). It is therefore necessary to develop TQM support practices such as committed leadership, strategic planning, cross-functional training, and employee involvement that enhance the human resource, structure and

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relationships of an organization. These strategic- and human resource-oriented practices enable the successful implementation and diffusion of TQM basic techniques such as cross-functional product design, process management, information and feedback, supplier quality management, and customer involvement that ensure process variability reduction and product quality improvement.

2.1.2. Just-in-Time

Another important world-class manufacturing program that has gained popularity is Just-in-Time (JIT). JIT evolved from the Toyota Production System that is based on two pillars, namely, the achievement of a pull production process and automation with a human touch (Ohno, 1988). The objective of JIT is the elimination of all forms of waste (Sugimori et al., 1977; Ohno, 1988; Brown and Mitchell, 1991) by capitalizing on the power of individual skill and teamwork (Ohno, 1988).

Toyota's track record of JIT success over the more traditional production systems of the 1970's led to the broad adoption of JIT by other companies in Japan (Suzaki, 1985; Groenevelt, 1993; Vuppalapati et al., 1995). Since then, the popularity of the JIT system has spread to other parts of the world (Groenevelt, 1993) and other industries (Inman and Mehra, 1990).

Monden is credited with being the first to provide a thorough overview of JIT. Monden agrees with Ohno on the central tenet of JIT and emphasizes the use of Kanban system, production smoothing methods, and setup time reduction (Monden, 1981a, 1981b, 1981c, 1981d). Schonberger (1982), another pioneer in JIT studies,

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consider simplicity the guiding theme for JIT. He also emphasizes the importance of quality management for JIT and discusses the effect of motivational and human resource management.

While the pioneers of JIT implementation and research generally agree that JIT production is characterized by the production and delivery of the right part at precisely the right time and in the right quantity (Monden, 1981a; Schonberger, 1982; Ohno, 1988), the literature reveals that a certain amount of confusion exists over what exactly constitutes a JIT system (Groenevelt, 1993).

To account for the possible evolution of JIT since its first implementation in the Toyota Motor Company, we identify the practices of a JIT program by comparing six academic studies within the last seven years that empirically validate the factors of JIT implementation identified from a systematic review of the literature. The six studies that we consider review JIT related literature covering various aspects of its development from the work of the pioneers, academic and practitioner oriented studies and/or surveys of industry practices (see Davy et al., 1992; Mehra and Inman, 1992; Sakakibara et al., 1993; McLachlin, 1997; Sakakibara et al., 1997; Ahmad, 1998).

The study of Mehra and Inman (1992) considers four key factors of JIT implementation, namely JIT production strategy, JIT vendor strategy, JIT education strategy and management commitment. They find JIT production strategy and vendor strategy to be significantly related to JIT implementation success as measured in terms of downtime, inventory and workspace reduction, increased quality, labor and

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equipment utilization, and increased inventory turns. Davy et al. (1992) empirically derive three factors underlying JIT implementation--operating structure and control, product scheduling, and quality implementation. Sakakibara et al. (1993) develop a measurement instrument for JIT and identify three factors representing core JIT components and these are management of people and schedules in a JIT system, simplified physical flow, and supplier management. They conceptually identify JIT supporting practices but did not empirically validate them.

The three other studies specifically differentiate between the management initiatives or infrastructure practices of JIT implementation and the JIT specific practices (McLachlin, 1997; Sakakibara et al., 1997; Ahmad, 1998). McLachlin (1997) concludes that four management initiatives--promotion of employee responsibility, provision of training, promotion of teamwork, and demonstration of visible commitment--are necessary conditions for the implementation of JIT flow, JIT quality and employee involvement in JIT manufacturing. The provision of workforce security and use of group performance measures are rejected as necessary conditions for JIT implementation.

In their study of the impact of JIT manufacturing and its infrastructure on manufacturing performance, Sakakibara et al. (1997) find the infrastructure practices to be strongly related to performance. While the set of JIT practices alone does not have significant relation with performance, the combination of JIT practices and infrastructure is related to manufacturing performance. This result contradicts Mehra

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and Inman's study (1992) which does not find management commitment and JIT education strategy to be critical elements of JIT implementation. On the other hand, Ahmad's study (1998) supports the importance of JIT infrastructure in providing a moderating relationship between JIT managerial practices and performance.

Taken together, the work of the pioneers and the six empirical studies reviewed provide a strong support for considering JIT as composed of both support practices and core JIT production practices. Nine practices that are most commonly identified in the studies can be classified into strategic- and human resource-oriented practices--committed leadership, strategic planning, cross-functional training, and employee involvement, and JIT basic techniques--setup time reduction, pull system production (involving the use of small lot size and kanban control), JIT delivery by suppliers, equipment layout, and daily schedule adherence (see Table 2-2). The remaining practices identified in the studies are better classified as TQM or TPM techniques because of theirprocess quality improvement or equipment maintenance orientation.

The nine JIT practices identified above are consistent with the philosophy of pull system production and emphasis on individual skill and employee involvement (Ohno, 1988). They also reflect a focus on process simplification (Schonberger, 1982) and gradual process improvement and learning (Groenevelt, 1993). Therefore, these nine practices identified represent a relatively comprehensive set of practices that captures the essence of JIT.

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Table 2-2. A Comparison of Just-in-Time (JIT) Practices

This Study	Mehra and Inman 1992	Davy et al. 1992	Sakakibara et al. 1993	McLachlin 1997	Sakakibara et al. 1997	Ahmad 1998
Setup Time Reduction	Setup time reduction	Time reduction	Set-up time reduction	Setup reduction	Set-up time reduction	Setup time reduction
Pull System Production	In-house lot sizes		Small- lot sizes	Small lot size		
			Kanban		Kanban	Kanban system
			Pull system support	Pull system		
JIT Delivery By Suppliers	Vendor lead time		JIT delivery from suppliers	JIT delivery from suppliers	JIT supplier relationship	JIT delivery by suppliers
	Vendor lot sizes					
	Sole sourcing					
Equipment Layout	Group technology		Equipment layout	Equipment layout	Equipment layout	Equipment layout
Daily Schedule Adherence			Daily schedule adherence	Daily schedule adherence	Schedule flexibility	Daily schedule adherence
				Uniform plant load		
Result of JIT						JIT links with customers

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Table 2-2 Continued. A Comparison of Just-in-Time (JIT) Practices

This Study	Mehra and Inman 1992	Davy et al. 1992	Sakakibara et al. 1993	McLachlin 1997	Sakakibara et al. 1997	Ahmad 1998
Committed Leadership	Formal means for listening	Organizational commitment		Demonstrate visible commitment		
	JIT champion					
	Management education					
Strategic Planning	Vision of the future	Policy support			Manufacturing strategy	Manufacturing strategy
Cross-functional Training	Cross-training		Training	Provide training		
Employee Involvement	Quality circles	Problem solving	Small group problem solving	Promote employee responsibility	Work force management	Work integration system
	JIT team	Employee involvement		Promote teamwork		
	Investigate suggestions	Decentralized control		Use group performance measures		
	Authority to stop line			Employee involvement		

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Table 2-2 Continued. A Comparison of Just-in-Time (JIT) Practices

This Study	Mehra and Inman 1992	Davy et al. 1992	Sakakibara et al. 1993	McLachlin 1997	Sakakibara et al. 1997	Ahmad 1998
TPM: Planned Maintenance	Preventive maintenance	Preventive maintenance	Preventive maintenance		Maintenance	
TQM: Supplier Quality Management	Quality certification of suppliers		Supplier quality level	Supplier quality level		
TQM: Process Management		Process simplification		Zero defects quality control	Quality management	Quality management
				Statistical Process control		
				Use of charts and feedback		
TQM: Cross-functional Product Design			Production design simplicity		Product design	Product technology
General Management Practices	Pilot project, Outside consultant	Efficient resource use		Provide workforce security	Organizational characteristics	HRM policies

However, the literature is proliferated with a diversity of specific practices that reflects an even wider variance in actual JIT implementation. Thus, while there are successful implementations of JIT (Schonberger, 1986; Voss and Clutterbuck, 1989), the number is limited (Dertouzos et al., 1989). Some researchers have asserted that a piecemeal approach to JIT can create "islands of JIT" that fall short of achieving company-wide improvements (Crawford et al., 1988; Safayeni et al., 1991).

Vuppalapati et al. (1995) state that companies that have properly incorporated JIT elements into a broader TQM implementation have benefited significantly and cite the Ford Motor Company as an example. However, neither does the implementation of TQM guarantee success (Choi and Behling, 1997) so a combination of TQM and JIT implementation is not necessarily the panacea to failed JIT implementation.

It is important to identify the root causes of failed JIT implementation. Some of the fundamental problems discussed are cultural resistance to change, lack of training and education, poor quality (Crawford et al., 1988), lack of coordination of the different departments, and confusion on the relationship between JIT and other manufacturing subsystems (Safayeni et al., 1991). These problems indicate that companies that failed in JIT implementation may not have developed the requisite strategic- and human resource-oriented practices to support JIT implementation.

2.1.3. Total Productive Maintenance

Total Productive Maintenance (TPM) is another important world-class manufacturing program introduced during the quality revolution. According to

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Nakajima (1988), vice-chairman of Japan Institute of Plant Maintenance, TPM is a combination of American preventive maintenance and the Japanese concepts of total quality management and total employee involvement.

A TPM program typically enlarges the responsibility of production employees from operating machines to such areas as detecting machine failures, performing basic maintenance, and keeping work areas clean and organized. The practices of TPM help eliminate waste arising from an unorganized work area, unplanned downtime, and machine performance variability. The goal of TPM is to continually maintain, improve and maximize the condition and effectiveness of equipment through complete involvement of every employee, from top management to shop floor workers.

Existing literature on TPM is found mostly in trade journals and practitioner oriented books. Many of the writings on TPM are influenced by the work of Nakajima (1988). The basic practices of TPM are often called the pillars or elements of TPM. A comparison of the basic practices of TPM discussed in four books (Nakajima, 1988; Takahashi and Osada, 1990; Tsuchiya, 1992; Steinbacher and Steinbacher, 1993) is given in Table 2-3. The practices that are consistently emphasized in these books can be classified into autonomous maintenance, planned maintenance--which includes breakdown, preventive, and predictive maintenance (Suzuki, 1994), equipment design and improvement, and cross-functional training of workers.

Autonomous maintenance involves daily maintenance activities of the operators. In order for the daily maintenance activities to be productive, operators

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Table 2-3. A Comparison of Total Productive Maintenance (TPM) Practices

This Study	Nakajima, 1988	Takahashi and Osada 1990	Tsuchiya, 1992	Steinbacher and Steinbacher 1993	McKone and Weiss 1999	McKone et al. 1999	Maier et al. 1998
Autonomous Maintenance	Autonomous maintenance	5s's self-initiated maintenance	Five S's and autonomous maintenance	Autonomous maintenance	Autonomous maintenance	Housekeeping, operator involvement	Operator involvement
Planned Maintenance	Scheduled maintenance	Specialized maintenance (planning and management of maintenance)	Planned maintenance	Preventive maintenance and predictive maintenance	Planned maintenance	Disciplined planning of maintenance task, schedule compliance	Preventive maintenance
Equipment Design and Improvement	Eliminate six big losses to improve equipment effectiveness	Improvements in production efficiency and individual improvements	Equipment improvement	Corrective maintenance	Early equipment design		
	Initial equipment management	Equipment technologies	Maintenance prevention design	Maintenance prevention			
Planned Maintenance, Equipment Design and Improvement		Quality maintenance	Quality maintenance				

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Table 2-3 Continued. A Comparison of Total Productive Maintenance (TPM) Practices

This Study	Nakajima, 1988	Takahashi and Osada 1990	Tsuchiya 1992	Steinbacher and Steinbacher 1993	McKone and Weiss 1999	McKone et al. 1999	Maier et al. 1998
Cross-functional Training	Increased skills of operations & maintenance personnel	Human resources development (skills training)	Education for multi-skilling		Training	Cross-training	
Employee Involvement			Management-by-objectives (action plans, small groups)		Support group activities, Focused improvement teams	Teams	Teamwork
TQM: Cross-functional Product Design					Early product design		
TQM: Information and Feedback						Information tracking	Measurement & information availability, Work documentation
General Management Practice							Work environment

have to be cross-trained to do their maintenance tasks. Planned maintenance deals with both short- and long-term maintenance efforts mostly accomplished by the maintenance crew. Equipment maintenance can be facilitated or minimized through incremental equipment improvement or major equipment redesign. However, fundamental to equipment design is that the equipment should meet operational requirements (Blanchard, 1981) and be easy to maintain.

Emphasis on equipment design and development is consistent with Hayes and Wheelwright's (1984) observation that the development of unique capabilities of equipment helps rebuild manufacturing engineering and provide the company with an equipment advantage that cannot be easily copied. Being an expert in the design and manufacture of production equipment has been considered a subtle indicator of a world-class (Stage IV) company (Hayes et al., 1988).

Another practice that is mentioned as part of TPM is quality maintenance (Takahashi and Osada, 1990; Tsuchiya, 1992). Quality maintenance deals with the establishment and control of equipment conditions to ensure zero defect production. This practice emphasizes the role of equipment in the achievement of quality. It is closely related to process management in TQM in terms of its objectives and is achieved through planned maintenance and equipment improvement. Thus, quality maintenance is not considered a separate practice of a TPM program.

Some academia-oriented articles that investigate issues related to TPM also discuss practices of the TPM program (see Maier et al., 1998; McKone et al., 1999;

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McKone and Weiss, 1999). A comparison of these articles is found in Table 2-3. McKone and Weiss (1999) identify training, early equipment design, early product design, focused improvement teams, support group activities, and autonomous and planned maintenance as the six major activities in TPM implementation. McKone et al. (1999) consider only short-term TPM activities that are typically implemented in a plant. They consider autonomous maintenance related activities such as the use of teams, housekeeping, cross-training, and operator involvement; and planned maintenance related activities such as disciplined planning of maintenance tasks, information tracking, and schedule compliance.

In measuring TPM implementation, Maier et al. (1998) consider preventive maintenance, teamwork, shop floor employee qualification, measurement and information availability, work environment, work documentation, and extent of operator involvement in maintenance activities as factors reflecting TPM implementation.

Some of the implementation factors considered by McKone et al. (1999) and Maier et al. (1998) are more related to the development of an environment or mechanism for employees to better implement the TPM techniques of autonomous and planned maintenance. An examination of the practices discussed in the three articles reviewed above reflects the importance given to training and employee involvement. Employee involvement is also emphasized as a component of TPM philosophy in the works of Nakajima (1988) and Suzuki (1992).

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Some authors also consider the steps in a TPM development program (Nakajima, 1988; Suzuki, 1994). A TPM development program typically emphasizes among other things the leadership role of top management in launching and implementing TPM, establishment of TPM policies, goals, and master plan and communicating these to everyone in the company, and building a system for training and employee involvement. The commitment of top management in preparing a suitable environment for TPM's introduction and in planning and coordinating for its implementation is considered crucial to TPM's success (Fredendall et al., 1997).

In order to capture the TPM program completely, we have to combine the TPM practices identified as pillars or elements of TPM with the TPM development activities. From the books and articles reviewed, we identify the TPM basic techniques as autonomous maintenance, planned maintenance, and equipment design and improvement. We also determine the developmental activities that support the implementation of TPM basic techniques that include committed leadership, strategic planning, cross-functional training, and employee involvement. These developmental activities form a set of strategic- and human resource-oriented practices.

Implementation of TPM is believed to result in superior tangible benefits such as reducing equipment breakdown, shortening setup times, increasing overall effectiveness, cutting costs, improving quality, assuring safety, and eliminating accidents (Steinbacher and Steinbacher, 1993; Suzuki, 1994). Moreover, successful TPM implementers claim intangible benefits such as continuous improvement of work

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force skills and knowledge and more open communication within and among workplaces (Suzuki, 1994).

The outstanding results of TPM implementation have led many firms facing competitive pressures to adopt TPM (McKone and Weiss, 1999). TPM is also implemented by many companies including Toyota, Procter and Gamble, Dupont, Ford and Tennessee Eastman to augment their TQM and JIT programs since the benefits from these programs have often been limited by unreliable and inflexible equipment (Garwood, 1990; Maggard and Rhyne, 1992; Tajiri and Gotoh, 1992; Fredendall et al., 1997).

However, only five percent of companies surveyed by Giffi et al. (1990), that have some type of maintenance management programs, believed their programs were effective. It is possible that some of these companies do not implement a comprehensive TPM program. A potential barrier that will possibly inhibit TPM's success is the inability of a company to coordinate its human resource practices, management policies, and technology (Fredendall et al., 1997). Thus, the strategic- and human resource-oriented practices identified above are crucial in the implementation of a comprehensive TPM program.

2.1.4. Why Relate TQM, JIT, and TPM?

While there are numerous practices in manufacturing management (Skinner, 1996), this study has chosen to investigate and relate TQM, JIT, and TPM because of the following reasons that can be identified from the preceding discussion.

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1. They consist of a comprehensive set of practices involving both the social and technical or process-oriented aspects of manufacturing and emphasize continuous improvement (Schonberger, 1986; Nakajima, 1988; Ohno, 1988; Evans and Lindsay, 1999). In the preceding sections, we have identified that TQM, JIT, and TPM include unique basic techniques and strategic- and human resource-oriented practices that are common to the three programs.
2. They have similar goals of elimination of waste in the production process (Crosby, 1979; Nakajima, 1988; Ohno, 1988) to increase production efficiency and effectiveness; (Schonberger, 1986; Tsuchiya, 1992; Steinbacher and Steinbacher, 1993).
3. They are recognized world-class manufacturing programs (Schonberger, 1986; Steinbacher and Steinbacher, 1993; Schonberger, 1996). Successful implementation of TQM, JIT, and TPM is found to improve manufacturing performance and help companies gain a competitive edge (Inman and Mehra, 1993; Hendricks and Singhal, 1997; McKone and Weiss, 1999).

Furthermore, the implementations of TQM, JIT, and TPM are interrelated. After an examination of the connections between JIT and TQM from conceptual, philosophical and implementation perspectives, Vuppalapati et al. (1995) argue that companies which implement JIT and TQM jointly will outperform those that have

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implemented only one of these, or none. This thesis is supported by an empirical study of manufacturing units by Sriparavastu and Gupta (1997). They conclude that manufacturing units implementing JIT and TQM jointly observe increased productivity level when compared to manufacturing units implementing only TQM.

Flynn, Sakakibara, and Schroeder (1995) find that a set of common infrastructure practices formed a strong foundation for the achievement of both JIT and TQM performance goals. They also demonstrate that TQM and JIT practices interacted. In a study of the contextual factors that are related to TPM implementation, McKone et al. (1999) find that managerial contextual factors such as the implementation level of TQM, JIT and EI better explain the implementation level of TPM than environmental and organizational contextual factors. In a separate study, McKone et al. (forthcoming) also find that TPM is indirectly related to manufacturing performance through the implementation of JIT practices.

Roth and Miller (1992) suggest that maintenance management may be the greatest challenge facing companies attempting to implement TQM and JIT. Furthermore, Imai (1998) believes that TQM and TPM are the two pillars supporting the JIT production system. Huang (1991) discusses the importance of considering the integration of JIT, TPM, total quality control, and factory automation with worker participation. Thus, the development and implementation relationships of TQM, JIT, and TPM provide support for the simultaneous investigation of their practices and impact on manufacturing performance.

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2.2. *THEORETICAL FOUNDATION*

The mixed success and failure of the TQM, JIT, and TPM programs call for a study to identify the specific practices constituting these programs that can lead to implementation success. While there is evidence that suggests that their joint implementation provides a better chance for success (Garwood, 1990; Tajiri and Gotoh, 1992; Vuppalapati et al., 1995), there is no study that provides a theoretical and systematic investigation of this. However, it is clear that there are similarities in the goals, practices and implementation scenarios of TQM, JIT, and TPM. Therefore, this study aims to develop a theory that can explain what provides for a successful joint implementation of TQM, JIT, and TPM.

While the field of Operations Management may be inadequate in theory development (Swamidass and Newell, 1987; Anderson et al., 1989; Flynn et al., 1990; Ahire et al., 1995; Swink and Way, 1995) there are building blocks of theory in the existing literature (Schmenner and Swink, 1998). To complement the theories and laws in Operations Management, this study will rely on generally accepted management principles to build a theoretical framework for understanding the interrelationship of TQM, JIT, and TPM and their impact on manufacturing performance. This section will review the concept of fit, socio-technical systems theory, and Operations Management theories such as the Theory of Swift, Even Flow, a Theory of Internal Variability of Production Systems, and the Theory of Performance Frontiers.

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2.2.1. The Concept of Fit

The concept of fit has received considerable attention in organizational research (Chandler, 1962; Lawrence and Lorsch, 1967; Thompson, 1967). Research involving this concept investigates the fit among the organization structure, strategy, and context (external fit), and/or fit among the groups or subsystems within an organization (internal fit). In general, fit means consistency of two or more factors and it is believed that a good fit among relevant factors will lead to better performance. For example, White and Hamermesh (1981) provide a model which argues that internal consistency of a business unit's structural elements and the fit between its strategy and structure affect performance. There also exists empirical evidence that a better match between manufacturing structural policy and organizational variables is strongly related to better performance (Khandwalla, 1974).

Fit is referred to by many terms. For example, in the general strategy literature fit is also known as coalignment, consistency, contingency, and congruency (Venkatraman, 1990). In organizational innovation literature fit has been labeled synchronous innovation (Ettlie, 1988), while in economic research it is termed complementarity (Milgrom and Roberts, 1995). In ecology, fit can be inferred as selection of an organization by the environment (Hannan and Freeman, 1984). However, fit is more commonly known in terms of contingency theory, a term coined by Lawrence and Lorsch (1967). Contingency theory asserts that the effect of a factor

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cannot be universally superior in all contexts but rather depends on its match with the context.

Traditionally there are two perspectives in organizational innovation research--the technological perspective and the administrative perspective. More recently researchers are beginning to realize that consistency among different innovations such as technological and administrative innovations is needed to improve an organization's performance (Cohen and Zysman, 1988; Gerwin, 1988; Georgantzas and Shapiro, 1993). Ettlie (1988) labels this phenomenon of simultaneous adoption of compatible technological and administrative innovations as synchronous innovation.

In economic research Milgrom and Roberts (1995) use the notion of complementarity and mathematical theories of games and optimization of supermodular functions to provide a framework for the analysis of systems. By complementarity, they mean, "doing more of one thing increases the returns to doing more of another" (Milgrom and Roberts, 1995). Through a case study of Lincoln Electric Company, Milgrom and Roberts (1995) illustrate how the complementarity of piece-rate and bonus systems enables the company to attain high productivity without sacrificing product quality.

In the field of Operations Management, Skinner's (1974) work on "the focused factory" is an example of internal fit wherein manufacturing policies are structured so that they are focused on and consistent with the single chosen manufacturing task essential for a firm to successfully compete in its industry. More recently, Sakakibara

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et al. (1997) and Ahmad (1998) examine the fit between firm's manufacturing infrastructure practices and just-in-time manufacturing.

There are two general perspectives of fit in strategic management, namely, the reductionistic and holistic perspectives. The reductionistic perspective is based on the assumption that the fit between a few factors can be modeled in terms of pairwise coalignment among the factors' distinct components that are treated as independent of one another (Venkatraman and Prescott, 1990). This perspective generally approaches fit in terms of moderation or matching. These approaches enable the investigation of precisely specified theoretical relations among the distinct components of the factors investigated by invoking ceteris paribus conditions (Venkatraman and Prescott, 1990). However, they cannot determine whether or not multivariate relationships exist and the relations being examined apply in different contexts.

On the other hand, the holistic perspective provides a broader conceptualization of fit among the components of the factors being investigated. This perspective models fit as gestalts, profile deviation or covariation. These three approaches provide a systemic view of the factors and their components, however, the complexity of coalignment makes it difficult to hypothesize the nature of the specific linkages between the factors (Venkatraman and Prescott, 1990).

The holistic perspective of fit is consistent with the systems framework that supports the use of an integrated approach in examining the interrelated building blocks of an organization (Gerwin, 1976; Galbraith, 1977; Van de Ven and Ferry,

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1980). According to Russel Ackoff, a system's essential properties and functions are derived from the interaction of its parts and not from the actions of its parts taken separately (Finnie, 1997).

The concept of fit and the systems framework suggest that manufacturing programs such as TQM, JIT, and TPM should be modeled within a single theoretical framework. The three programs are tightly interrelated in terms of their goals, practices, and implementation and it is also very likely that manufacturing plants will implement them simultaneously. It is necessary to investigate the interrelationship among the three programs' practices and determine whether or not appropriate implementation of a coherent set of practices will lead to better manufacturing performance. In order to maintain a systemic view of TQM, JIT, and TPM this study will investigate the effect of their joint implementation by adopting a holistic perspective of fit.

2.2.2. Socio-technical Systems Theory

Socio-technical systems theory (STS) views organizations as consisting of two independent, but linked, systems: a social system and a technical system. The social system consists of people and relationships, while the technical system is composed of equipment and processes (Ketchum and Trist, 1992). It is considered impossible to optimize for overall performance without seeking to optimize jointly the correlative independent social and technical systems (Emery, 1990). This concept of joint

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optimization deviates from the more widely held view wherein the social system is thought to be dependent upon the technical system (Davis, 1990).

The importance of joint optimization of the social and technical systems is reflected in Rehder's (1989) study of successful Japanese transplants. Rehder argues for the importance of building manufacturing competitiveness upon the integration and coordination of strategy, structure, culture, and human resource subsystems within a complex, changing environment. He shows that the concept of a balanced socio-technical system is reflected in all subsystems of the successful transplant's organization.

On the basis of the STS literature, Cherns (1990) states nine principles of socio-technical design. The nine principles are briefly described below.

1. Compatibility. The process of designing the organization must be compatible with the objectives of the design.
2. Minimal Critical Specification. In designing a job specify no more than what is absolutely essential.
3. The Socio-Technical Criterion. Variances (unprogrammed events) should be controlled as close to their source as possible when they cannot be eliminated.
4. The Multifunctionality Principle - Organism vs. Mechanism. Job design should be based on the redundancy of functions rather than the

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redundancy of parts. Highly specialized, fractionated tasks should be avoided and individuals should be trained to develop multiple skills.

5. Boundary Location. Departmental boundaries should be drawn such that sharing of knowledge and experience is facilitated and the taking of responsibility is encouraged. A possibly better departmental division may be by sequential relation rather than technological similarity of tasks.
6. Information Flow. Information should be made available to where it is needed in a timely fashion.
7. Support Congruence. The social support system should enable the reinforcement of an organization's philosophy.
8. Design and Human Values. The design of an organization should enable the human resource to experience quality of work life without pressure from peer control.
9. Incompletion. The process of organization design process is never ending.

The above principles are consistent with Douglas McGregor's (1960) Theory Y, one of his two models of the "industrial man" and assumptions about human motivation. Theory Y emphasizes the integration of goals and assumes that the average person has intrinsic interest in his work, desires to be self-directing, seeks responsibility, and has the capacity to be creative. Basically, individuals are considered to be capable of self-supervising. McGregor (1960) believes that Theory Y

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reflects a better approach to organization than Theory X, which assumes that people dislike work, and must be coerced, controlled, and directed toward organizational goals.

STS recognizes the importance of developing the social forces in an organization and that people are more than extensions of machines and are a significant resource for increasing organizational performance (Trist, 1981). Empirical research also supports the importance of developing the human subsystem of an organization. It has been shown that the effects of manufacturing practices can be magnified or diminished by the social system reflected in the manufacturing strategy and competitive environment (Dean and Snell, 1996). In a study of flexible production systems, Macduffie (1995) argues that manufacturing practices can be integrated with complementary bundles of human resource practices to enhance organizational performance. While in a study on strategic fit between skills training and levels of quality management, Gee and Nystrom (1999) show that the success of TQM has been largely dependent on investments made on manpower training and skills enhancement programs.

Following STS, we believe that the institution of the common strategic- and human resource-oriented practices is important for the effective implementation of the basic techniques of TQM, JIT, and TPM. The institution of the common practices can enhance the human capital of a manufacturing plant and help resolve some problems

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associated with manufacturing program implementation such as cultural resistance to change, lack of education, and lack of organizational communication.

2.2.3. Operations Management Theories

This section reviews theories in Operations Management that can be used to provide insights into the effects of TQM, JIT, and TPM implementation. These theories are The Theory of Swift and Even Flow, a Theory of Internal Variability of Production Systems, and The Theory of Performance Frontiers. The Theory of Swift and Even Flow addresses the issues related to differences in cross-factory production (Schmenner and Swink, 1998). The theory holds that the production process is more productive when the flow of materials is faster and more uniform. Materials can move swiftly when non-value added steps or waste of production are either eliminated or reduced and when there are no bottlenecks or impediments in the production process. The flow of material can be made more uniform when variability associated with demand or production operations is reduced.

This theory supports the importance of good quality of products and reliable and consistent processes. Product and process quality problems such as rework, scrap, machine downtime, and machine variability interrupt the flow of operations, create variation, and introduce bottlenecks. Therefore, quality problems will lower the output of the production process. The theory also favors reduction of work-in-process inventories as they deter the flow of materials and increase throughput times. A pull

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system better assures a smooth flow than a push system since upstream operations cannot flood their subsequent operations with work-in-process inventory.

In general, the Theory of Swift and Even Flow favors practices that either speed flows or reduce variation. Some of these practices include quicker changeovers of equipment, smaller production batches, regular preventive maintenance, and cross-training of workers. Schmenner and Swink (1998) contend that this theory is very much in tune with the philosophy of JIT. A lot of the practices associated with TQM and TPM also address the issues of variability reduction and smoother workflow and are therefore consistent with this theory as well.

A Theory of Internal Variability of Production Systems is proposed by Wacker (1987) to understand the complementary nature of manufacturing goals by their relationship to throughput time. He argues that the major manufacturing goals of demand responsiveness, production efficiency, and high quality are all closely related to internal throughput time. Using mathematical analysis, Wacker shows that effective preventive maintenance programs improve quality that in turn can lead to improvement in internal throughput time. On-time delivery and unit cost improve as throughput time is shortened. Thus, improvement in quality and throughput time lead to better goal performance.

Furthermore, it is shown that internal variability of throughput time is caused by variability in move times and processing times. On the basis of the literature, Wacker (1987) suggests that move times can be shortened by requiring short move

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distance, high-speed automated moving, and more frequent move policies, all of which are associated with a just-in-time production system. On the other hand, processing time variability can be reduced by lower rework time and lower down time, both of which can be achieved through systematic preventive maintenance programs.

A later study by Wacker (1996) supports the above results and suggestions. Using a theoretical model of manufacturing lead times, Wacker mathematically illustrates that setup time reduction, defect reduction, and preventive maintenance programs most affect lead-time variance reduction. He also mathematically illustrates that the control of lead-time variances can enable the cumulative achievement of the manufacturing goals of quality, delivery reliability, productivity, short delivery time, current product flexibility and new product design flexibility.

The two theories discussed above are supportive of one another since practices that enable reduction of variability in lead time also allow for faster and smoother production flows and leads to higher productivity. The different manufacturing practices favored by the two theories are also consistent with intuitive arguments or generally recognized low-level abstraction theories and laws such as: (1) shorter set-up times facilitate smaller lot sizes, (2) smaller lot sizes reduces work-in-process, (3) lower work-in-process enhances quality (Wacker, 1998), (4) smaller lot sizes reduces lead time (Hopp and Spearman, 1996), (5) productivity can be improved as quality is enhanced and waste is reduced (Schmenner and Swink, 1998), and (6) throughput can

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be increased when the most important constraint or bottleneck is relieved (Goldratt, 1989).

Furthermore, Wacker's (1996) mathematical contention that manufacturing goals are complementary and can be cumulatively achieved through control of lead time variability reduction is consistent with The Theory of Performance Frontiers (Schmenner and Swink, 1998). This theory asserts that if all plants are far from their asset frontier, a plant can be simultaneously superior in the achievement of the different manufacturing goals. This situation is possible when plant management creates an operating frontier that is superior to its competitors through "betterment" (the successful alteration of manufacturing operating policies within the given set of assets that management is 'dealt'). Some ways by which betterment may occur include the adoption of JIT and quality related improvements that are aimed at enhancing operating efficiencies (Schmenner and Swink, 1998).

Together, the three Operations Management theories reviewed in this section can be used to explain why the development of human and strategic practices and the implementation of TQM, JIT, and TPM's basic techniques can positively affect multiple dimensions of manufacturing performance. In the next chapter we synthesize the literature reviewed in this chapter to formulate a Theory of Integrated Manufacturing Practices that relates the manufacturing practices of TQM, JIT, and TPM to manufacturing performance.

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CHAPTER 3

DEVELOPMENT OF A THEORY OF INTEGRATED MANUFACTURING PRACTICES

In this chapter we develop a Theory of Integrated Manufacturing Practices that relates TQM, JIT, and TPM. The theoretical development is based on the concept of fit, socio-technical systems theory, and Operations Management theories discussed in the previous chapter. Following Sutherland (1975), this study considers a theory "an ordered set of assertions about a generic behavior or structure assumed to hold throughout a significantly broad range of specific instances." That is, we seek to identify and explain relationships that exist among constructs that can be approximated in the empirical world within a set of limitations.

We develop theory through a logical synthesis of the relationships provided by the literature, data or empirical evidence, and intuition or assumption. This manner of theory development is consistent with that suggested by Weick (1989) and applied by Lewis (1998). We provide conceptual definitions of key terms used in the theoretical development, and state the limitations of this study. Then we discuss the relationships observed and hypothesized.

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3.1. CONCEPTUAL DEFINITIONS AND LIMITATIONS

In this section we provide definitions for the key constructs used in this study. The constructs are defined within the framework of a manufacturing system even though the constructs may also be used in other contexts.

3.1.1. TQM, JIT, and TPM

The manufacturing programs being investigated in this study are TQM, JIT, and TPM. As evidenced by the literature review, these programs represent broad concepts and there is no consensus on a single definition for each of these programs. We therefore define the three programs by considering their main objective and emphasis within the context of a manufacturing plant as discussed in the literature review. Following are the definitions of the three programs.

TQM is a manufacturing program aimed at continuously improving and sustaining quality products and processes by capitalizing on the involvement of management, workforce, suppliers, and customers, in order to meet or exceed customer expectations. To improve both product and process quality, interfunctional product design and systematic process management are necessary. Information obtained from process management should be made available to the employees for better decision-making. Customers should be involved to better determine their expectations and long-term developmental relationship should be established with the suppliers to ensure quality of the input materials. The implementation of these practices will not be possible without the commitment of management and a well-

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established strategy that is communicated to all the people involved. For process management to be effective and for information to be useful employees need to have the motivation and comprehensive training to be involved in problem solving.

JIT is a manufacturing program with the primary motivation of continuously reducing and ultimately eliminating all forms of waste through just-in-time production and involvement of the work force. In particular, two major forms of waste--work-in-process inventory and unnecessary delays in flow time (Brown and Mitchell, 1991) can be addressed through the implementation of pull system production, setup time reduction, JIT delivery by suppliers, equipment layout, and daily schedule adherence. Such practices cannot be implemented without the supporting mechanism of a well-planned and coordinated manufacturing plan championed by committed leadership. Employees that are involved and multi-skilled help alleviate disruptions (e.g. work force absenteeism, unplanned production stoppages) that may be fatal in a just-in-time production environment.

TPM is a manufacturing program designed primarily to maximize equipment effectiveness throughout its entire life through the participation and motivation of the entire work force. To maintain equipment effectiveness, daily maintenance by operators is crucial. Unexpected breakdowns can be prevented through carefully planned maintenance and the improvement or development of equipment. Since maintenance is usually considered an expense, it is important that all employees from management to shop floor are committed and involved in the maintenance process and

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understand the role of maintenance in manufacturing. Cross-functional training of operators is necessary to enable them to do the daily maintenance tasks.

3.1.2. Integrated Manufacturing Practices

We seek to examine the relationships of TQM, JIT, and TPM within a single theoretical framework and believe that the consistent implementation of practices from these three programs enhances the performance of a manufacturing plant. Thus, we consider a set of Integrated Manufacturing Practices that is a synthesis of the core practices of TQM, JIT, and TPM identified from literature review. While it may be possible to include practices from other manufacturing programs within the Integrated Manufacturing Practices set, we have chosen to limit our investigation to TQM, JIT, and TPM practices for reasons already stated in section 2.1.4.

We consider the Integrated Manufacturing Practices a group of interrelated practices from TQM, JIT, and TPM that seeks to satisfy the customer through the efficient production of quality goods by emphasizing elimination of waste and continuous improvement of the work force and production process. These practices can be classified into two main components, namely the basic techniques and the common strategic- and human resource-oriented practices (Figure 3-1).

Each of TQM, JIT, and TPM consists of fundamental practices that are unique to its program. These practices are generally process or technically oriented and are considered the basic techniques of TQM, JIT, and TPM. The three programs also have strategic- and human resource-oriented practices that support the implementation

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Figure 3-1. Framework of Integrated Manufacturing Practices

<table>
<tr><th>TQM Basic Techniques</th><th>JIT Basic Techniques</th><th>TPM Basic Techniques</th></tr>
<tr><td>Cross-functional Product Design
Process Management
Information and Feedback
Supplier Quality Management
Customer Involvement</td><td>Setup Time Reduction
Pull System Production
JIT Delivery by Suppliers
Equipment Layout
Daily Schedule Adherence</td><td>Autonomous Maintenance
Planned Maintenance
Equipment Design and Improvement</td></tr>
<tr><th colspan="3">Common Strategic- and Human Resource-Oriented Practices</th></tr>
<tr><td colspan="3">Committed Leadership
Strategic Planning
Cross-functional Training
Employee Involvement</td></tr>
</table>

of their basic techniques. From the literature review discussed in section 2.1, it is clear that these practices are common to the three programs. We therefore consider these practices that reflect plant management strategic culture and human resource related initiatives common to TQM, JIT, and TPM as the common strategic- and human resource-oriented practices and, for brevity, we also refer to these as common practices.

Following are the definitions of the basic techniques and common practices identified in section 2.1 and that are also mentioned in the definition of TQM, JIT, and TPM provided in the previous section.

TQM Basic Techniques

1. Cross-functional Product Design: involvement of different entities concerned in the design of products for producibility and customer satisfaction
2. Process Management: use of statistical or other systematic techniques for monitoring and controlling process variance
3. Information and Feedback: availability of timely information and feedback about quality performance
4. Supplier Quality Management: cooperative interaction with suppliers regarding quality concerns
5. Customer Involvement: focus on knowing and meeting customer requirements through customer involvement and feedback

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JIT Basic Techniques

1. Setup Time Reduction: efforts for continually lowering production setup time
2. Pull System Production: production of needed parts at the needed time through kanban controls and the use of small lot sizes
3. JIT Delivery by Suppliers: suppliers are integrated into the production system and make frequent, reliable deliveries
4. Equipment Layout: use of machine and process layout that facilitates production, movement and layout changes
5. Daily Schedule Adherence: ability to meet daily production expectation as scheduled

TPM Basic Techniques

1. Autonomous Maintenance: involvement of operators in daily equipment maintenance
2. Planned Maintenance: scheduled maintenance to ensure continuous and smooth operation of equipment
3. Equipment Design and Improvement: design or selection of new equipment and improvement of existing equipment to allow minimal or easier maintenance and meet production needs

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Common Strategic- and Human Resource-Oriented Practices or Common Practices

1. Committed Leadership: an unwavering, long-term commitment by top management to continuous improvement through communication and support of the implementation of program practices
2. Strategic Planning: formalization of manufacturing plans and policies and communication of these plans and policies to the employees
3. Cross-functional Training: training and education of employees to increase the breadth of employees' skills
4. Employee Involvement: inclusion of employees in the problem-solving process through teamwork and decentralization of decision making responsibility

When the three sets of basic techniques are each added to the common practices we have three relatively comprehensive sets of practices constituting the TQM, JIT, and TPM programs. Therefore, our set of Integrated Manufacturing Practices represents a relatively exhaustive group of improvement initiatives.

3.1.3. Manufacturing Performance

We seek to relate the implementation of the integrated manufacturing practices to the performance of a manufacturing plant. While there are many performance measures, it is important to recognize that some "order-winning criteria" are not within the responsibility of manufacturing (Hill, 1985). We therefore use manufacturing

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performance to refer to performance outcomes that are relevant at the plant level of an organization and that are within manufacturing's jurisdiction.

The most predominant approach in the literature is to use cost, quality, delivery, and flexibility as the four basic dimensions of manufacturing performance which can be traced back to the work of Skinner (1969). In some studies, these dimensions have been expanded to include several additional measures (e.g., Hayes et al., 1988; Vickery et al., 1993; Miller and Roth, 1994). We consider the more common performance outcomes within the dimensions of cost, quality, delivery, and flexibility that are the primary responsibility of manufacturing and these include cost efficiency--low unit costs and inventory, quality--conformance quality and product reliability and capability, delivery--on-time delivery and cycle time, and flexibility--flexibility of product mix and volume.

Cost can be directly considered in terms of unit cost of production but also the economic cost of holding inventory. Reduction in inventory will eventually be reflected in reduced working capital, reduced factory storage, and reduced material handling that will lower manufacturing overhead costs (Kaplan, 1984). Inventory cost can be measured in terms of inventory turnover ratio and a high turnover ratio indicates a low cost position.

It is clear from the literature that quality as conformance refers to the consistency of product quality as determined by conformance with meeting production specifications (Garvin, 1988; New, 1992). Quality from the standpoint of the

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manufacturing function can also be considered in terms of product durability and reliability (Vickery, 1991). At the minimum, a product should be capable of performing its intended function.

Delivery may be considered in terms of delivery time, delivery dependability and cycle time (Vickery et al., 1993). At the minimum, deliveries are expected to be made on time. Dependable delivery may be considered as consistent delivery on or before the due date, hence, how fast a delivery can be made is a performance outcome that is also worth tracking. Manufacturing cycle time can be defined in terms of the "time required for a product to move through the entire manufacturing process, beginning as raw material and ending as finished output" (Lieberman, 1990). In short, it is the time spent from receipt of raw material for production to shipment of product.

Suárez et al. (1996) consider mix, volume, new product, and delivery time as the four basic types of flexibility. We consider delivery performance separately while the achievement of new product flexibility is highly dependent upon the involvement of other functional area such as marketing. Therefore, we only consider mix and volume flexibility. Mix flexibility includes the ability to change product models, colors and configurations (Maskell, 1989) and the ability to change the relative production quantities among the products in a product mix (Olhager, 1993). Volume flexibility is the ability to change the production volume.

We do not intend to relate the implementation of the manufacturing programs to performance measures such as performance quality, speed of new production

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introduction, and number of new products introduced since the achievement of good performance in these areas is dependent on several functional departments, many of which are outside the control of the plant.

3.2. RELATIONSHIP BUILDING

The manufacturing programs TQM, JIT, and TPM have similar practices and are closely interrelated. For instance, Dean and Snell state, "like just-in-time, total quality involves a few relatively simple central concepts and an amorphous array of peripheral associated practices" (1991, p.778). The three programs have the common objective of making a production system more efficient and effective through continuous improvement and elimination of waste. TQM is focused on the elimination of defects and rework. JIT primarily emphasizes reduction of waste in inventory and flow time (Brown and Mitchell, 1991). TPM targets waste caused by equipment problems such as failure, unnecessary setup and adjustment time, idling and minor stoppages, reduced speed, process defects, and reduced yield (Nakajima, 1988). These different emphases on waste reduction and elimination are complementary. We therefore consider why the combination of TQM, JIT, and TPM practices can affect manufacturing performance.

3.2.1. Effect of Implementation of Basic Techniques

We first examine the effects of the implementation of basic techniques on manufacturing performance. Quality is a very important attribute since ultimately the products manufactured should satisfy the customers. Rejection of material not

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meeting specifications is perhaps the worst form of production waste. Defects when found on the shop floor can be either reworked or discarded but the handling of defects will add cost and not value to the product.

The basic TQM techniques seek to eliminate waste of defects and rework. Process management and availability of information and feedback provide workers with timely resources for controlling process variability that can reduce production of parts that do not meet product specifications. Designing products by incorporating the suggestions of the different functional areas such as engineering, manufacturing, and marketing helps ensure the design of products that can be easily manufactured, in good condition and that meet customer specification. This practice is important since the greatest source of failure often lies in design weaknesses, with failure costs multiplying when discovered by the customer (Cole, 1981). The involvement of customers provides continuous feedback on the changes in customer expectation and supports product design. Since a product cannot be any better than the materials used to produce it, quality of the materials used in production is very important. Suppliers should be made aware of the quality expectations and should be involved in the production process.

A production system that is organized and simple to monitor will facilitate the identification and correction of process defects. The basic techniques of JIT production can complement the basic techniques of TQM in ensuring the production of quality products. The use of a pull production system where production lot sizes are

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significantly reduced and production and delivery are controlled by kanban reduces work-in-process inventory. Detection of defects is easier when there is a low level of inventory since each step of production is tightly coupled with its adjacent steps. This relationship between small lot size, work-in-process and quality is consistent with the low-level abstraction theories identified by Wacker (1998) and reviewed in section 2.2.3.

The reduction of setup time and use of efficient equipment layout also facilitate immediate response to quality problems when defects need to be reworked. Low setup time enables rework to be processed more quickly and efficient equipment layout simplifies the identification of the process step and equipment involved in the occurrence of defect. Just-in-time delivery by suppliers also enables suppliers to quickly respond to quality problems when they occur.

Aside from creating a better environment for the production of quality products, JIT basic techniques enable on-time and fast delivery of products. Setup time reduction and use of small lot sizes reduce cycle time and allow the production system to respond to demand with flexibility and more quickly. The use of efficient equipment layout also reduces cycle time by eliminating unnecessary time spent in moving work-in-process. Adherence to daily production schedule is an important practice because time and inventory buffers are minimal or do not exist in a just-in-time production environment.

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The basic techniques of TPM can also facilitate the production of quality products. When machines are well maintained and work areas are well kept, many sources of quality problems can be easily detected. Monitoring and maintaining the condition of equipment reduces variance in equipment performance. Efforts at improving the design of the equipment can be implemented in conjunction with cross-functional product design to facilitate product manufacturability or to enable the manufacture of products with unique features.

Implementation of TQM and JIT basic techniques also increases the attention given to maintenance of equipment since quality and just-in-time production requires reliable machines. The use of pull system of production with lot size reduction greatly multiplies the number of changeovers. To reduce the time required for each changeover, setup time has to be reduced and equipment efficiency has to be increased, thus equipment improvement is important in a JIT environment. Adherence to planned maintenance is also important in JIT production. When the production processes are tightly linked, unplanned stoppage of one machine can tie-up the whole production system and build up unnecessary work-in-process inventory. Furthermore, equipment failure causes quality problems and lengthens cycle time.

The above examination of the interrelationships of the basic techniques of TQM, JIT, and TPM provides arguments that the joint implementation of these techniques will help reduce non-value added activities, waste in production, and process variability. By the Theory of Swift and Even Flow (Schmenner and Swink,

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1998), it can be expected that when the joint implementation of the basic techniques is successful, production flow will be more uniform and faster and the manufacturing process will be more productive.

Furthermore, it is evident that the successful implementation of the basic techniques help reduce rework, downtime of machine, variability in move and processing times, and in general variability in throughput time. Following Wacker's (1987) Theory of Internal Variability of Production Systems, it can be expected that manufacturing plants implementing the basic techniques of TQM, JIT, and TPM will be more responsive to demand, have more efficient production and higher quality because of reduction in internal throughput time.

3.2.2. Effect of Institution of Common Practices

While the basic TQM, JIT, and TPM techniques are developed with the intention of improving manufacturing processes and are shown to be theoretically related to throughput time and variability reduction, the successful implementation of these basic techniques is dependent on the manufacturing environment and the employees. Piecemeal approach to the implementation of TQM, JIT, and TPM practices has been observed to lead to failure.

The commonly cited problems in the implementation of manufacturing programs are those related to cultural resistance to change, lack of training and education, poor quality (Crawford et al., 1988), lack of coordination of the different departments, and confusion on the relationship between manufacturing subsystems

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(Safayeni et al., 1991). Hayes and Wheelwright (1984) also identify the root cause of "manufacturing crisis" to be the incompatibility of manufacturing policies and people with its facilities and technology choices. These provide evidence of the importance of the institution of practices that will facilitate the successful implementation of the basic techniques.

The common strategic- and human resource-oriented practices identified from TQM, JIT, and TPM programs are committed leadership, strategic planning, cross-functional training, and employee involvement. Top management must be personally involved in the implementation of manufacturing practices and must serve as role model for middle management. Senge (1990) exhorts the importance of leaders who can act, simultaneously, as a designer, teacher, and steward to lead the other members of the organization toward a learning organization. A formal strategy allows everyone in the manufacturing plant to have a common vision and to work towards a common goal. A good strategic plan also ensures the implementation of practices that are consistent with the existing structure and practices.

Moreover, it is essential to provide employees with the tools to become involved and to help fulfill the strategic plan. Cross-functional training provides the employees with opportunities to acquire new skills, take on more responsibilities, and grow professionally. Institution of teamwork can support the development of multifunctional employees. The contributions that teamwork can make to enhance involvement have long been recognized (Trist and Bamforth, 1952). Employee

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involvement through teamwork also allows for the collaboration of the people who are most knowledgeable and concerned about a problem to solve the problem together. Investments in the work force such as cross-functional training and development of problem solving teams are believed to increase the human capital of an organization (Snell and Dean, 1992) and ensure smooth production flow (Luthans and Fox, 1989).

Consistent with Cole's (1994) discussion on the prerequisites of organizational learning, the institution of the common practices can be expected to provide the requisite environment and motivation needed for organizational learning. However, it is also important to note that there are two kinds of learning—exploration (the pursuit of new things) and exploitation (the use and development things already known) (March, 1991). An organization should be wary of becoming locked into a "competency trap" of exploiting the existing procedures at the expense of exploring new and innovative ways of managing its operations (Levitt and March, 1988). While the common strategic- and human resource-oriented practices can facilitate learning and continuous improvement, these practices should be implemented in such manner that both exploration and exploitation of knowledge can be supported.

Moreover, Snell and Dean (1992) identify the human resource as a key component in the value creation process. Since the common practices will help in establishing a structure whereby the human resources of a plant can acquire information and learn, be empowered, and be involved in operations; these practices will contribute towards manufacturing's success. It is believed that the greater a

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firm's absorptive capacity for learning, the easier it is for the firm to gain more knowledge that will contribute to success (Roth et al., 1994). Flynn, Sakakibara, and Schroeder (1995) also show that implementation of infrastructure practices that support both JIT and TQM programs is significantly related to manufacturing performance.

In a recent study of long-lived companies, de Geus (1997) identifies awareness of identity, tolerance of new ideas, valuing people not assets, loosening steering and control, and organizing for learning as some of the most important characteristics of long-lived companies. The common strategic- and human resource-oriented practices can help in the development of these characteristics of long-lived companies since together they facilitate learning and continuous improvement by providing a clear collective goal coupled with management support and employee development and involvement.

Based on the literature review, the common strategic- and human resource-oriented practices lay an important foundation for the implementation of manufacturing programs. Therefore, we expect these practices to have a positive effect on manufacturing performance.

3.2.3. Effect of Implementation of Integrated Manufacturing Practices

TQM, JIT, and TPM have similar philosophies emphasizing waste reduction and elimination, continuous improvement, and employee involvement. Empirical studies have indirectly provided evidence that these programs are interrelated (see

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Flynn et al., 1995; Sriparavastu and Gupta, 1997; McKone et al., 1999, forthcoming). We also believe that the concept of fit, socio-technical systems theory and the Operations Management theories support the complementarity of these programs.

In accordance with the systems framework, TQM, JIT, and TPM should be examined within a single theoretical framework so that the effects of their joint implementation can be examined through a holistic perspective. The concept of internal fit holds that a good fit among the groups or subsystems within an organization will lead to better performance. Similarly, we can hypothesize that a higher level of manufacturing performance can be expected when the different practices of TQM, JIT, and TPM are integrated into a consistent set of practices appropriate for the intended purpose of implementation.

Moreover, according to the socio-technical systems theory the joint optimization of practices that are socially and technically oriented should lead to good performance. We have already identified the practices of TQM, JIT, and TPM as forming two components of the set of Integrated Manufacturing Practices--the basic techniques (TQM: cross-functional product design, process management, use of information and feedback, supplier quality management, and customer involvement; JIT: setup time reduction, pull system production, JIT delivery by suppliers, equipment layout, and daily schedule adherence; and TPM: autonomous maintenance, planned maintenance, and equipment design and improvement) that are process and technically oriented and the set of common strategic- and human resource-oriented practices

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(committed leadership, strategic planning, cross-functional training, and employee involvement) that is akin to development initiative for the social aspect of an organization.

We discuss how the nine principles of STS (Cherns, 1990) are embodied in the Integrated Manufacturing Practices.

1. Compatibility. The objective of TQM, JIT, and TPM is the attainment of an efficient and effective production system through continuous improvement and learning and elimination of waste by capitalizing on the involvement of all employees. The different practices of TQM, JIT, and TPM are compatible since they complement each other in eliminating waste of production. For the implementation of Integrated Manufacturing Practices to be successful, the organization should be built upon a philosophy of continuous improvement and employee involvement.
2. Minimal Critical Specification. There has to be flexibility in the design of a job. The practice of employee involvement through problem solving provides the employees with flexibility and the opportunity to use their creativity in improving the production process. The skills of the employees cannot be exploited when the job design is very restrictive and routine.
3. The Socio-Technical Criterion. The practices of employee involvement, process management, information and feedback, and autonomous

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maintenance empower workers with the information and responsibility to keep the equipment in good condition and the production process under control. These practices enable workers to identify and control variability in machine performance and production at its source. The need to meet daily production schedule and the use of setup time reduction and pull system production further highlight the criticality of immediate response to variability since there is little or no buffer time and inventory in the production system. Furthermore, the involvement of employees (e.g., operators, maintenance crew and engineering) facilitates the determination of necessary maintenance and better equipment design.

4. The Multifunctionality Principle - Organism vs. Mechanism. When tasks are too specialized or fractionated work can become too mechanistic. Cross-functional training of workers ensures the acquisition of multiple skills and enlarges the responsibility of the workers.
5. Boundary Location. Cross-functional training and cross-functional product design facilitate communication within and between departments. Efficient layout of equipment enables the organization of machines and tasks around the flow of production rather than by task similarity alone. These practices facilitate work-in-process movement, information exchange, and experience sharing.

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6. Information Flow. The practice of providing information and feedback helps make relevant production data readily available and usable to the workers. External communication and involvement with suppliers and customers provide timely information for obtaining quality supplies in a just-in-time basis and for the production of goods that meet the changing needs of the customers.
7. Support Congruence. The commitment of management and communication of a well-established strategic plan reinforce the philosophy of employee involvement. Employees cannot take an active role when they do not know how their responsibility helps in the attainment of the goals of the organization.
8. Design and Human Values. Emphasis on cross-functional training and employee involvement enables employees to recognize the value of their job and provide them an avenue to utilize their skills and creativity.
9. Incompletion. The implementation of an integrated manufacturing program is a dynamic process with the aim of continuous improvement and learning of the production system including the workers. For instance, the implementation of planned maintenance requires continuous adherence to the maintenance schedule while practices that are intended to improve the equipment requires continuous examination and learning

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to determine the current and future needs of production in terms of equipment design.

The discussion above provides evidence that the Integrated Manufacturing Practices are compatible and address both the social and technical aspects of a manufacturing system. In line with STS, we can expect better manufacturing performance when the different practices are jointly and optimally implemented. We can conceptualize joint optimization of the practices as fit between the common strategic- and human resource-oriented practices and basic techniques of TQM, JIT, and TPM. The enhanced performance of the manufacturing system can then be attributed to the fit between the common practices and basic techniques. These relationships between manufacturing practices and performance are depicted in Figure 3-2.

More specifically, Figure 3-2 shows the practices that are common to TQM, JIT, and TPM that are strategic- and human resource-oriented and the basic techniques of each of these three programs that are process oriented. The compatibility of these practices in enabling a production system to operate more efficiently and effectively have been discussed, thus, we expect these practices to fit together. By fit, we mean that coalignment or internal consistency exists among the practices. In line with Milgrom and Roberts' (1995) notion of fit, we expect the institution of the common practices will increase the returns of the implementation of basic techniques and conversely the implementation of basic techniques will increase the returns of the

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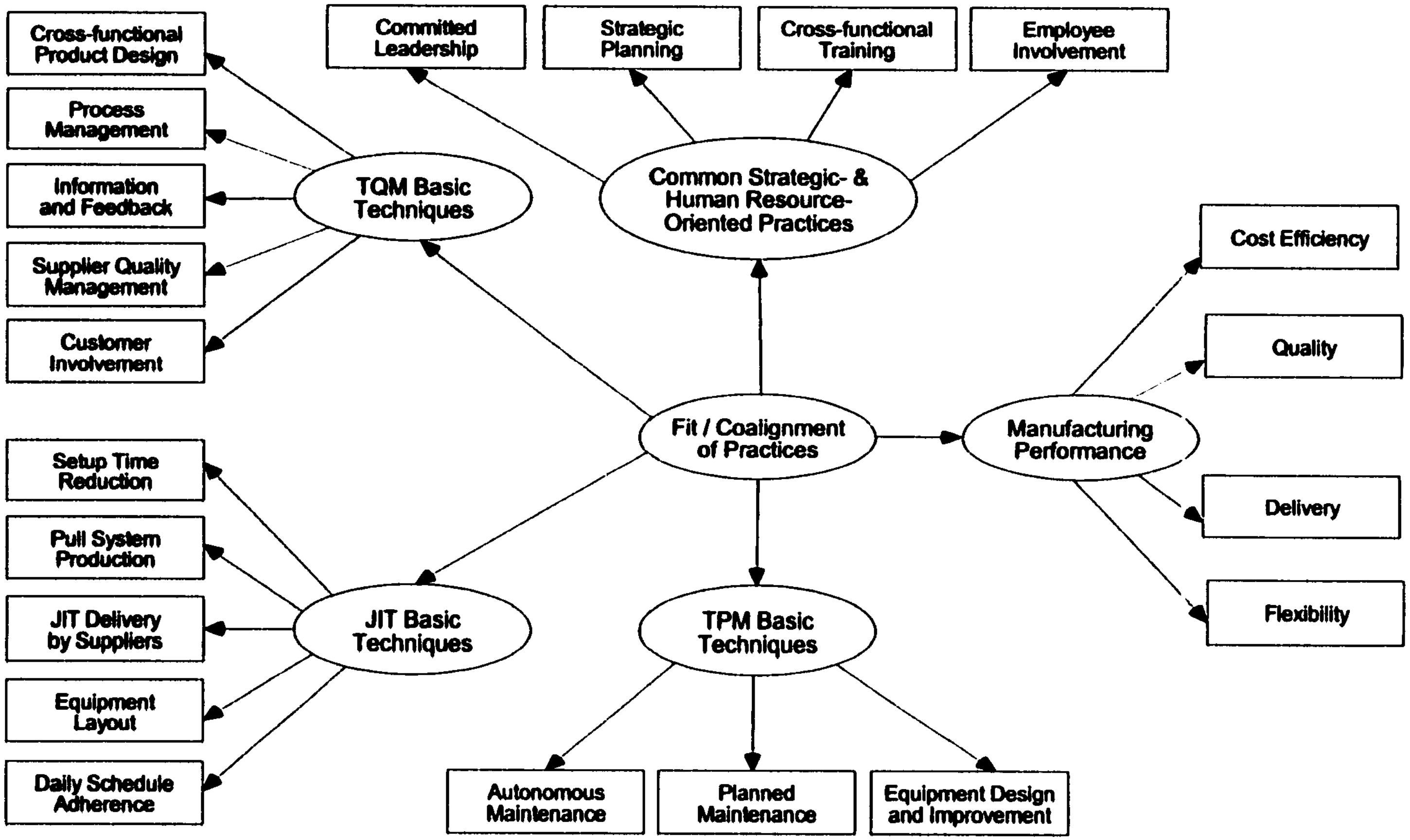
Figure 3-2. Framework of the Effect of Integrated Manufacturing Practices Implementation



institution of the common practices. Thus, in a manufacturing system we expect the returns of coalignment of practices to be manifested through its positive relationship with manufacturing performance as customarily measured in terms of cost efficiency, good product quality, reliable and fast delivery, and flexibility.

Empirical evidence supports the above contention. MacDuffie and Krafcik (1992) show that complementarities between aspects of human resource and manufacturing organization policies affect productivity and quality in automobile assembly. Ichniowski et al. (1997) also confirm that a large number of human resource related practices are complementary in affecting productivity of U.S. steel industry. It can therefore be inferred that the effect of implementation of the basic techniques on manufacturing performance is related to the institution of the common strategic- and human resource-oriented.

For instance the provision of information and feedback will be useless when the employees cannot use the available information to solve problems identified from process management techniques. Cross-functional training of workers is a requisite for autonomous maintenance; otherwise operators will not be able to perform daily housekeeping and maintenance tasks that complement the scheduled maintenance activities to be performed by the maintenance crew. More generally, the common practices provide the mechanism for supporting cumulative learning that can lead to actual or potential collective behavioral change towards skill development and commitment to the implementation and diffusion of the basic techniques.

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When the basic techniques are successfully implemented, production waste will be reduced, lead time will be shortened, and product quality can be improved. These provide value to a manufacturing plant since manufacturing costs can be reduced and the customer will be satisfied with product quality and delivery efficiency. Porter states that "*Competitive advantage grows fundamentally out of improvement, innovation, and change. ... Competitive advantage is sustained only through relentless improvement.*" (Porter, 1990, pp. 578-590). Since the implementation of common practices and basic techniques encourages continuous improvement and learning, the adoption of Integrated Manufacturing Practices represents a valuable strategic asset for competing in a dynamic environment.

The complete implementation of Integrated Manufacturing Practices can be considered rare. Many firms implement some form or combination of TQM, JIT, and TPM, however, comprehensive and coherent implementation of mutually supporting practices is not as common. There are documented cases of partial implementation of manufacturing programs. Many manufacturing plants do not have the appropriate environment for the implementation of practices that require management commitment and total employee involvement.

The practices we have identified as part of the Integrated Manufacturing Practices are also consistent with the practices that other researchers have associated with world-class manufacturing. Clearly, we follow Schonberger (1986; 1996) in considering practices associated with TQM, JIT, TPM, and EI. However, we give

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more emphasis on the development of equipment for both maintainability and production needs. We also delineate the common and unique practices of TQM, JIT, and TPM and consider their relationships at the practice level.

Many of the practices we identify also map closely with five of the six world-class manufacturing practices identified by Hayes and Wheelwright (1984) which are development of workforce skills and capabilities, competing through quality, development of management technical competence, workforce participation, rebuilding manufacturing engineering through development of unique capabilities of equipment, and incremental improvement approaches. The practice of development of management technical competence is not explicitly covered in our Integrated Manufacturing Practices, however, it can be considered a reflection of committed leadership. If top management is to lead the improvement process, it may require top management should not only communicate and support the implementation of practices but should also develop themselves technically to provide necessary guidance to the work force. Flynn et al. (1999) have shown that Hayes and Wheelwright's practices are still relevant in today's manufacturing environment and can serve as foundation for the use of practices associated with quality management and just-in-time.

Giffi et al. (1990) also identify eight categories of best practices that differentiate world-class companies and these are quality management practices, innovative human asset management, streamlined organizations (which may include

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practices such as cross-functional teams and partnerships with other companies), restructure engineering processes, JIT techniques, production planning and control, product and process simplification, and progressive approaches to equipment and facilities maintenance. Of these eight practices, production planning and control is not explicitly considered in our Integrated Manufacturing Practices. However, planning and scheduling for material requirements and production will be substantially determined by the production system being implemented. Manufacturing plants that implement just-in-time production practices will have to choose a compatible production planning and control system.

We have not only identified a set of manufacturing practices that are consistent with the practices that other researchers have observed as being implemented by world-class manufacturers but have also shown that these practices can be considered a set of Integrated Manufacturing Practices that is internally consistent in accordance with the socio-technical systems theory. Furthermore, given the strong conceptual and empirical evidence of the value of integrating the practices of TQM, JIT, and TPM, we propose a Theory of Integrated Manufacturing Practices which holds that simultaneous and higher level of implementation of the common practices and basic techniques of TQM, JIT, and TPM will lead to a higher level of manufacturing performance.

While the formulation of our theoretical framework may be associated with the "best practice" approach to manufacturing strategy (Voss, 1995), we differ from researchers who believe in only one best way for achieving success. We recognize and

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accept the concept of equifinality, that goals can be achieved in different ways. Hence, we are not proposing that the integration of TQM, JIT, and TPM is the only way to achieve better manufacturing performance. A competing theory may hold that a stable plant environment that does not implement integrated manufacturing practices can improve manufacturing performance. It is possible for manufacturing plants to carry high inventory levels and have long cycle times in order to maximize labor efficiency and support division of labor. This competing theory will likely hold in a plant environment that is very different from one where TQM, JIT, and TPM can be successfully implemented. The inherent assumption on the role of employees is one where employees are expected to contribute only through judicious execution of a well-defined set of tasks rather than participation in the problem solving process.

However, when a manufacturing plant seeks to capitalize on the involvement of its employees and is implementing one of the three programs of TQM, JIT, and TPM we believe that the benefits that can be achieved will be maximized when the plant also implements the basic techniques of the other two programs. Furthermore, it is our contention that the implementation of basic techniques alone will not provide as strong an impact on manufacturing performance as the combined institution of the common practices and implementation of basic techniques since both the social and technical subsystems should be jointly optimized to achieve the best possible performance.

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CHAPTER 4

CASE-BASED RESEARCH

In Chapter 3 we proposed a theoretical framework of Integrated Manufacturing Practices that identify the practices of TQM, JIT, and TPM and classify them into common strategic- and human resource-oriented practices and basic techniques. We also related the implementation of the Integrated Manufacturing Practices to manufacturing performance. This framework is developed from an extensive review of relevant literature and theoretically grounded on the concept of fit, socio-technical systems theory and Operations Management theories. In this chapter we discuss the findings from our case-based research to substantiate and enrich the theoretical framework.

4.1. PURPOSE OF CASE-BASED RESEARCH

Case-based research is a formal research strategy that can be used to accomplish various aims such as: provide description, illustrate phenomenon, explore situations, serve as a "meta-evaluation" (study of an evaluation study), explain causal linkages, test theory, and generate theory (see Eisenhardt, 1989; Yin, 1994). Traditionally, many researchers have prejudices against case study and view it as a less desirable form of inquiry than either experiments or surveys (Yin, 1994). However, researchers are beginning to recognize the importance of case-based research in

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building theories (see Eisenhardt, 1989; Meredith et al., 1989; McCutcheon and Meredith, 1993).

A theory that is developed through case-based research is believed to have a high likelihood of being a valid theory because the theory-building process is intimately tied with empirical evidence (Eisenhardt, 1989). At the minimum, case-based research allows a phenomenon to be studied in its natural setting and thus provide a "reality check" of the relevance of a theory that is being tested using case-based research.

Case study is the preferred strategy of inquiry when investigators are seeking answers to the questions of "why" and "how". Moreover, case study allows more meaningful examination of the phenomenon of interest when the investigators cannot control or manipulate the events and when the boundaries between phenomenon and context are not clearly evident (Yin, 1994).

Thus, we use case-based research to complement our theoretical development and subsequent empirical quantitative analysis for three reasons: (1) to determine whether or not the theoretical framework that we have formulated on the basis of existing theoretical and empirical literature is relevant to practice, (2) to enrich and modify the theoretical framework using evidence from the natural environment where manufacturing practices are being implemented, and (3) to understand the contextual factors that may affect the implementation and impact of manufacturing practices, the phenomenon of interest in this study.

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4.2. RESEARCH DESIGN

The unit of analysis (i.e. a case) for our case-based research is a manufacturing plant. We investigate three manufacturing plants. These three plants can be generally classified as belonging to the electronics (disk drive component), machinery (landscape equipment), and automobile parts supplier (filter products) industries respectively. Two of these plants have obtained a quality award or certification. Attainment of an award or certification provides some evidence of the greater emphasis that a plant gives to the implementation of manufacturing practices for improvement purposes vis-à-vis a more traditional plant. This sample of three plants shares similar sampling frame characteristics (with respect to industry membership and general orientation towards implementation of manufacturing practices) as the sample of plants included in the database used for quantitative analysis.

In order to ensure free access to information and to get reliable comments we agreed to keep the identity of the plants confidential. Prior to visiting the plants, we gathered background information on the parent companies from their websites. This enabled us to understand the basic operations and products of the companies. The primary sources of information during the plant visits included an informative plant tour, semi-structured interviews, discussion session, and some archival data. We used multiple sources of data collection to increase the reliability and validity of the data.

The plant manager or director of operations provided us with an informative plant tour describing the operation, production process, and general management

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practices at the plant. One of the plant managers also provided us with archival information about the development and plans of the plant. We conducted semi-structured interviews with six to nine managers in each of the three plants. The interviewees were chosen on the basis of the relevance of their areas of expertise to our issues of interest. Half of the interviews were focused on determining the manufacturing practices and issues related to the implementation of TQM, JIT, and TPM at the plant and are used in this study (see Appendix A for the list of interview guide questions). The other half of the interviews were focused on strategy and sources of competitive advantage and are used in another study. During the interview, notes were taken to provide reminders for follow-up questions. All interviews were tape-recorded and relevant information was subsequently transcribed.

We also provided the interviewees with questionnaires to answer and return by mail. The questionnaires include items that ask for information on the extent to which a plant is implementing specific manufacturing practices related to TQM, JIT, and TPM. Of the eleven questionnaires that we handed out, nine were returned and usable.

After all the interviews at a plant, a discussion session with some of the managers followed. In the discussion session we provided a summary of the information we obtained that is important to our study. This allowed us to clarify our understanding of the information that we have gathered and verify if we have made a fair assessment of the plant's condition. We also presented our theoretical framework

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to the plant representatives to determine the relevance of the framework to their plant and to obtain feedback on how the framework can be enhanced.

Immediately after each of the plant visits, the three researchers discussed the information obtained from the visit. We provided the plants with a written summary report less than a week after each plant visit. In the summary report, this researcher discussed the state of emphasis, implementation and impact of manufacturing practices at the plant. The other researcher discussed issues related to his interviews. We also encouraged the plant managers to provide us with feedback and correction on our assessments.

The use of multiple sources of data collection enabled us to check the consistency of information gathered. Through the discussion session and summary report we were able to verify the correctness of our interpretation of the data. Overall, the approach we have taken in data gathering and verification helps ensure the validity and reliability of the information obtained.

4.3. CASE ANALYSIS

In this section we report the findings of the case studies that are relevant to this research. To facilitate the discussion we refer to the plants by their fictitious names. We discuss some background information of each plant, the relevant manufacturing practices that are being implemented, the contextual factors affecting the implementation of the practices, and the achieved or perceived impact of these practices on manufacturing performance.

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We use relational inference as opposed to representational inference (Meredith, 1998) in our case analysis. Each case is not intended to represent a sample from a population. We use logic to deduce or infer relationships since we are interested in determining if one factor (e.g., practices, context, performance) is related to another.

4.3.1. Plant 1: Disk

The Disk plant is a large-volume manufacturer of disk drive components and component assemblies. This plant, hereafter called Disk, belongs to a company that has the majority of the world's market share for the products that it manufactures. It is a recipient of a State Quality Award and is also ISO 9001 certified. Disk produces several million parts per week and has approximately 4,000 employees.

The production process is highly capital and technology intensive. Disk develops sophisticated proprietary manufacturing processes, controls, tools and equipment that they protect through patent or secrecy. These proprietary assets are essential to the precision and reliability of its products. Disk designs and builds its prototype machines and subsequently out sources their production. Technology is believed to offer them a high leverage in the industry.

Disk purchases its primary raw material from a single supplier and maintains close relations with this supplier to ensure the highest quality. The plant implements statistical process control and monitors both in-process and final product quality. Nevertheless, due to the expected high standard of quality and the nature of the

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product, it is not possible to eliminate final product inspection. Disk also keeps good records of the component defect rates and causes of failure.

The product design team consists of representatives from different departments. Disk also maintains close contact with its customers and often co-designs its products with the customers to meet the customers' requirements. Such co-design efforts are made possible by the presence of a highly skilled engineering corps that understands not only Disk's own products but also its raw materials and the products of its customers.

The production process is a mixture of batch, repetitive and continuous processes. The pull system of production is generally used. However, work-in-process (WIP) limits are used instead of kanban for determining the production rate at each workstation when a production line has bottleneck operations occurring towards the end of the line. The use of WIP limits ensures that the bottleneck will not be starved while controlling the lead time of the production line. Line balancing is also used to keep work-in-process flowing smoothly from station to station. Disk emphasizes the use of a facility layout that follows the process flow to minimize move distance.

Disks' managers believe that the different practices that allow work-in-process to move successively from workstation to workstation are synergistic with the quality-oriented practices. The immediate use of work-in-process allows quality-related concerns to be addressed earlier. The managers also recognize the value of preventive

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maintenance in supporting quality. However there is concern that production people give more emphasis to meeting production targets than adhering to the maintenance schedules because of the importance of fast and reliable deliveries.

Disk recognizes the value of daily equipment maintenance and seeks to improve the involvement and training of operators in the maintenance process. The goal is to develop operators who know exactly what to look for when assessing their equipment. However, the plant recently instituted job rotation and this poses a challenge to daily equipment maintenance, since operators are not yet familiar with every piece of equipment that they operate. More generally, Disk's managers believe that cross-functional training is a universal prescription in the industry. Cross-functional training keeps the workforce vibrant and motivated. Flexibility of the human resource is also essential in responding to a fast-changing environment.

While proprietary equipment is an important asset for Disk, the plant managers acknowledge that people and not technology is their strength. It is the ability of the employees to understand the foundations and characteristics of the high technology environment that enable Disk to exploit its resources. Moreover, the strength of the employees lies in not only knowing what to do but also knowing why things are done. The managers point out that employees should be provided with the necessary information and feedback to enable them to understand the condition of the plant. The need for availability of information is not only confined to data pertaining to product

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quality audits but also data related to production, equipment condition and other information that helps employees better understand their role and make decisions.

Generally, Disk values training and broad education of its employees. It built an education complex on its premises four years ago where employees can further their education in areas not directly related to the day-to-day operations. Also, consistent with Disk's emphasis on increasing employee understanding, the purpose of its strategic planning is not only to decide on a plan but also for management to communicate with and involve employees in the pursuit of a common goal. It is important to note that some of the managers pointed out that strategic decisions regarding plant size include not only capacity considerations but also the extent to which plant size may affect communication and coordination of the employees.

Even though the industry is unpredictable and fast changing, the managers believe that the nature of their core competencies and the fundamental manufacturing practices has remained the same over the years. The plant seeks to further develop its human resource and inculcate a system viewpoint. Disk considers practices related to TQM, JIT, and TPM as important foundational practices that affect manufacturing performance and enable it to adopt new complementary practices.

This site visit highlights the importance of the development of the human resource in supporting the implementation of manufacturing practices. We learn that the provision of information and feedback is considered a common practice that is essential in the successful implementation of TQM, JIT, and TPM techniques. When

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employees are expected to take an active role in the problem solving process they have to be provided with the tools for making informed decisions. There are also contextual factors such as plant size and nature of the production process that can affect the implementation of manufacturing practices. This case study also informs us about the value of the development of proprietary equipment in meeting production requirements, however, people and not technology are considered the more important resource.

4.3.2. Plant 2: Mach

The Mach plant is a medium-volume manufacturer of outdoor landscape equipment. The demand for its products is highly seasonally dependent. The plant hires 700 employees and is primarily responsible for final assembly and painting, but also has a weld shop and a foundry.

It belongs to a company owning several lines of businesses catering to both consumer and commercial customers but the Mach plant focuses on meeting the needs of consumer line products. In recent years, the company has been actively acquiring smaller competitors in the industry; therefore Mach's product line has been expanded. Some of the production in other facilities was also transferred to Mach for product design and process modifications because of the plant management's "can do" attitude and the presence of a strong engineering group.

However, the addition of these new production lines has created further space constraints to the already heavily utilized facility. Since the plant was built piecemeal,

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the layout of the plant is not optimal. The large parts are often transported long distances within the plant and the constrained movements of forklift trucks pose hazards. Management believes that there is no justification in spending a huge amount of money reorganizing the plant layout given the impossible expansion of the facility. Mach is already using all available space within the plant's property.

The plant considers quality an important dimension for competition and prides itself on contributing to the highest customer satisfaction rating for consumer products that its company received last year. Nevertheless, there are unconfirmed reports of two batches of defective products returned to the plant. The plant utilizes random sampling of products for end of line quality auditing and tracks the number of defects under a three-category defect rating system. While final product quality is generally good, high cost of production can be partly attributed to the cost of quality that was not controlled at the source of the quality problem. Furthermore, the plant does not keep good documentation of its production processes and does not have a good information and feedback system. Mach is in the process of hiring a quality manager partly because of its desire to get ISO 9000 certification.

The absence of in-process quality monitoring may be related to the unwillingness of the workers to handle multiple tasks of different nature. Most employees do not understand the value of cross-functional training and opportunity such as job rotation. The culture of the employees can partly account for this. Furthermore, unionization of the workers makes policy changes complicated. Many

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employees have worked in the plant for about twenty years and hiring of new employees is often difficult because of the relatively poor profile of the labor force near the plant's vicinity. The relatively new Director of Operations (in the post for approximately two years) recognizes the importance of employees' trust and buy-in and is aggressively communicating the plant's goals to the employees, encouraging employee involvement and building a team culture.

The plant has about 800 suppliers but less than fifty of these supply 80% of Mach's raw materials. The primary suppliers maintain close communication with Mach and deliver on a just-in-time basis. Mach has inventory turns of about twenty-four times a year despite the seasonal nature of its products. It relies on past sales and seasonal weather conditions for demand forecasts. It produces mixed models of products to balance the line and completes about 94% of daily production as scheduled. Disruptions in production are caused by the need to fulfill customer requests for old products that are not available in the market. The demand for these products is low but Mach's company values and caters to customer requests.

The changeover time for some products is about a day or two but most product changeovers can be accomplished in minutes. Some of the managers believe that the plant has a flexible work force that enables quick product changeover, however, the relatively simple and similar tasks across the various assembly lines certainly contributes to this flexibility.

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Mach has a strong maintenance crew and believes that it has a superior maintenance system compared to its industry. Preventive maintenance constitutes 70% of the maintenance tasks and is believed to save Mach a lot of production time and cost since unplanned downtime rarely occurs. The maintenance crew generally devotes the remaining 30% of their time developing specialized tools and modifying equipment to meet production needs and enhance equipment functionality. The design and development of new equipment is done by a separate design-engineering group but uses input from the maintenance crew. The operators are involved in simple maintenance tasks. The maintenance group differs from the production staff in its emphasis on teamwork, cross-training, and job rotation.

The information obtained from the Mach plant indicates that the implementation of common practices and basic techniques of TQM, JIT, and TPM are correlated. Implementation of techniques such as in-process product inspection by the employees cannot be accomplished without employee training and willingness to get involved. The task distribution of the maintenance department shows that aside from preventive maintenance of equipment condition, the modification of equipment and the development of tooling systems that fit the production process are considered aspects of maintenance.

4.3.3. Plant 3: Filter

The Filter plant is a manufacturer of air and liquid filtration products for use in various industries. It belongs to a global company with diversified product lines

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catering to multiple major markets. The plant reports to the Automotive Division of the company. Filter has 150 employees but plans to hire another 150 in the next two years to support its fast rate of growth.

The production processes in the plant consist of small integrated processes that convert raw materials to finish products. The newer products are being manufactured on a market trial basis and use some manually operated processes, however, as volume increases for these products, the processes are automated. The plant uses 80% nonstandard equipment and some proprietary processes. Filter considers technology its strategic resource. Modification of market available technology to fit into the plant's system is deemed a necessity in the manufacture of products that will meet specific performance criteria. Thus, the development of new technology is closely linked to product development.

Filter's product demand is mostly fulfilled on a make-to-order basis. It focuses on achieving a high level of customer satisfaction with the quality of its products. The plant is clearly competent in product design and innovation. Filter uses statistical process control and provides operators with process information and encourages them to discuss quality problems, causes, and potential solutions. However, most quality inspections are currently performed on the finished goods and are conducted in large batches. The plant is still in the process of improving internal quality to meet its short-range target of having less than 5000 nonconforming parts per million.

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Filter maintains close communication with its suppliers. The plant receives its supplies in small amounts so that carrying of excess inventory is not necessary. However, materials from most suppliers undergo 100% incoming inspection and the plant is just beginning to move toward supplier quality certification.

Filter not only keeps low raw material inventory, it also emphasizes asset management of the work-in-process inventory. Though the release of work orders is based on a modified MRP system, the determination of finish product work orders is based on a pull system. The plant uses a loosely coupled system and maintains high flexibility. Plant management remarks that it is possible to redesign manufacturing overnight. Flexibility is largely assured by a good planning system, ability to get the needed materials, short processing window, ability to run small batches, good quality, and capacity availability.

Equipment is believed to be in a high state of readiness. Planned maintenance is valued but maintenance scheduling sometimes posed conflicts with production scheduling when special make-to-order requests interrupt the schedule. Product managers can influence the type of maintenance activities implemented and operators are actively involved in daily maintenance. The maintenance group is composed of a good mix of people with multi-skills and handles maintenance projects like a self-directed team.

Dedication, leadership by example, and openness to communication characterizes plant management. The plant manager knows something unique about

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each employee. Plant management alludes to behavioral approaches to get employee involvement and suggestions. Filter recognizes the value of its employees, thus it uses a stringent employee selection process even though it has a high recruitment rate. However, the constant addition of new employees inhibits the implementation of cross-training even though management believes strongly in the value of team-based, flexible and multi-skilled workers. Management considers cross-training an investment that will enable job-rotation, which is believed to keep the employees interested and challenged when the nature of their tasks is repetitive.

Filter is QS9000, ISO9001, and ISO9002 certified. While some of these certifications are driven by necessity, management believes that the value comes from being forced to document the fundamental processes and practices. The documentation provides management and employees with a common understanding of the production system and challenges management to understand the drivers of manufacturing performance. Management also realizes that the adoption of new initiatives or implementation of programs such as JIT requires supporting infrastructure or mechanism.

This case study reveals plant management's strong emphasis on human resource and technology development. While hiring of new employees is a major thrust during this period of plant expansion, management tries to select the most qualified people who can work productively in an environment that values and expects active participation from the employees. We learn that proprietary equipment and

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processes that fit well with the whole production system are considered strategic assets for maintaining competitive advantage in the industry. This plant visit also confirms the existence of contextual factors that affect the implementation of manufacturing practices. For instance, the need for capacity leads to constant addition of new workers that inhibit cross-training and postponement of equipment maintenance to accommodate fast order fulfillment.

4.4. RESULTS OF CROSS-CASE ANALYSIS

In this section we summarize the key findings from the three case studies. We also discuss in each of the three sections below how these case studies fulfill our three objectives for conducting case-based research that are presented in section 4.1.

4.4.1. Relevance of the Theoretical Framework

The interviews and discussions with the management of the three plants confirm the relevance of examining the practices of TQM, JIT, and TPM. The plant managers are seeking studies that consider the interrelationship among manufacturing practices and that assess the value and impact of implementing multiple practices rather than studies that focus on one individual program.

When asked about the practicality of the joint implementation of TQM, JIT, and TPM practices, a manager in the Filter Plant with more than thirty years of experience readily remarked that "The important thing when looking at manufacturing organizations is that the systems of manufacturing organizations, whether it be a quality system or, ... all has to be integrated into a strategic plan. And all has to be

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compatible with each other. And nothing is a stand-alone system. ...All have within them the components of being able to achieve the goals that the organizations have."

The managers believe that the practices of TQM, JIT, and TPM are complementary in enabling improvement in the manufacturing performance dimensions of cost, quality, delivery, and flexibility. Some managers in the Disk plant also believe that the joint implementation of TQM, JIT, and TPM practices lays the foundation for instituting other relevant practices. When the fundamentals are in place, it is easier to improve manufacturing processes and performance.

However, there is a general sentiment that difficulty exists in convincing all managers and employees about the importance of a systems viewpoint and the need to integrate the implementation of various practices. It takes great effort to obtain employee buy-in of the significance of coordinating different practices. For instance, meeting production deadlines supersedes adherence to the maintenance schedule when meeting customer delivery requests becomes a priority.

4.4.2. Modifications to the Theoretical Framework

All three plants noted the importance of technology in enabling the manufacture of products with the desired features. When asked about equipment maintenance, the managers automatically related daily and scheduled maintenance tasks with improvement, development, and design of equipment and tools to meet the plant's unique production requirements.

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In the case of the Disk plant, reliance on off-the-shelf equipment is not sufficient in meeting the stringent precision and reliability standard of the products it manufactures. Thus, Disk relies heavily on proprietary processes and equipment. Mach primarily emphasizes the development of tooling systems. On the other hand, Filter considers technology a key resource and primarily seeks the best and state-of-the-art equipment in the market and modifies it to fit its system. Filter regards modified equipment as a proprietary asset that contributes to its competitive advantage.

These findings lead us to modify the basic techniques of TPM. The practice of equipment design and improvement is replaced by two practices—technology emphasis and proprietary equipment development. Since aside from a general emphasis given to the acquisition and use of leading edge technology, the development of proprietary equipment to meet unique production needs and gain competitive advantage is considered a separate and equally important practice. This is consistent with Hayes and Wheelwright's (1984) characterization of firms that pursue a manufacturing-based competitive advantage which include among others the anticipation of the potential of advanced technologies and the development of proprietary equipment.

We also combine the TPM techniques of autonomous and planned maintenance as a single technique since activities that monitor and help sustain the existing equipment condition are generally considered together by plant management.

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Operators and maintenance crew are believed to provide complementary support for preserving equipment and determining how equipment condition can be sustained or improved by doing simple daily and more complex scheduled maintenance.

The changes we made on the basic techniques of TPM are consistent with the emphasis that we place on equipment design and development in the theoretically developed framework of Integrated Manufacturing Practices. While we follow Schonberger (1986) and Nakajima (1988) in emphasizing equipment maintenance and equipment development for maintainability, we also stress the importance of equipment development in meeting production requirements in the conceptual discussion. Thus, the case studies confirm our earlier contention on the need to complement maintenance focused research with the work of Hayes and Wheelwright (1984) in considering a more comprehensive TPM program that emphasizes both maintenance and technological advancement for improving productivity. The modified set of TPM basic techniques highlights the synergy of maintenance practices with other manufacturing practices in improving overall manufacturing performance.

Plant management believes that the techniques of TQM and JIT identified in the theoretical framework provide a good representation of process-oriented practices of TQM and JIT that are important and of practical relevance except for the practice of information and feedback. Managers at the Disk plant pointed out that information and feedback is necessary not only for achieving quality-related objectives but also for understanding machine performance and production scheduling.

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Management of the other two plants also recognized that availability of information is not only useful for management but also for the employees. The provision of information and feedback is a necessary practice in the implementation of TQM, JIT, and TPM since relevant data should be made available to the employees if they are expected to be involved in the problem solving process. For instance, defect rate, schedule delays, and cause of machine breakdowns are relevant information that will enable employees to take an active role in suggesting improvements for process management, schedule adherence, and daily equipment maintenance.

While the use of information and feedback is not explicitly identified in the literature as a practice of JIT, it is understandably an important practice in a time constrained production environment. Up-to-date information on the rate of production and schedule compliance enables the different workstations to coordinate their operations and allows purchasers to determine when suppliers should make their deliveries. On the other hand, the use of information tracking in TPM implementation is considered in the studies of McKone et al. (1999; forthcoming) and Maier et al. (1998).

Thus, there is substantial support from the case studies and in the literature for considering the provision of information and feedback as a practice essential for the successful implementation of TQM, JIT, and TPM. Hence, we now include the practice of information and feedback in the set of common strategic- and human resource-oriented practices rather than in the set of TQM basic techniques.

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Plant managers agree with the separation of TQM, JIT, and TPM basic techniques from the common strategic- and human resource-oriented practices. They believe that the common practices support the implementation of the techniques and form a foundation for the institution of other relevant manufacturing practices. The common practices foster management-employee communication and develop the human resource. It will not be possible to implement the techniques alone without the corresponding development of the employees and work culture.

As a result of the above modifications to the manufacturing practices in the theoretical framework, we have to define the new and modified constructs just as we did for the other constructs in Chapter 3. Following are the definitions for the common practice of information and feedback and the three TPM basic techniques.

1. Information and Feedback: availability of timely information and feedback about production, quality and equipment performance
2. Autonomous and Planned Maintenance: use of daily maintenance by operators and scheduled maintenance by the maintenance crew
3. Technology Emphasis: use and improvement of advanced technology
4. Proprietary Equipment Development: development of proprietary equipment to gain competitive advantage

4.4.3. Contextual Factors

It is clear that the three plants studied belong to different industries and operate under different conditions. The volume of their production ranges from small to large

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scale. Their production processes are a mixture of batch, repetitive, and continuous flow processes. Filter is in a high state of growth while Disk and Mach's operations are more stable. The size of the plants also differs substantially. There are many other contextual differences that characterize the operation of the three plants, however, all of the three plants are implementing and seeking to further improve the level of implementation of practices related to TQM, JIT, and TPM.

While the context of a manufacturing plant does not affect the applicability of the practices of TQM, JIT, and TPM, context does affect the manner and level of their implementation. For instance, Filter's fast growth rate and constant addition of workers currently inhibits cross-training of the workers. Disk managers believe that plant size affects both plant capacity and employee involvement. The unavailability of space discourages Mach's managers from modifying plant layout to facilitate smooth production flow. Mach's worker culture entails more effort from management in implementing cross-training and employee involvement.

The managers believe that there is no one best way for sequencing the implementation of manufacturing practices. The implementation of practices depends on the priorities of the plant, its operating environment, existence of supporting mechanisms, and numerous other unique factors that characterize the plant. However, as a manager in the Disk plant noted, eventually all of the practices should be implemented if all areas of production are to be supportive of performance improvement. On the other hand, the managers would like to know which of the

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practices should be emphasized if improvement in a specific performance dimension is more important than overall manufacturing performance.

We believe that it is important to add context into our framework of Integrated Manufacturing Practices to acknowledge the impact of contextual factors on the implementation of practices and performance. It is impossible however to name and exhaust all the contextual factors that should be captured in the study of manufacturing practices. Many contextual factors are idiosyncratic to a manufacturing plant.

We therefore modify our theoretical framework of Integrated Manufacturing Practices as shown in Figure 4-1 to reflect the following changes: (1) reclassification of basic techniques of TPM, (2) inclusion of information and feedback as a common practice rather than considering it as a TQM basic technique, (3) addition of context into the framework. We will use this modified framework for our succeeding discussion and analysis.

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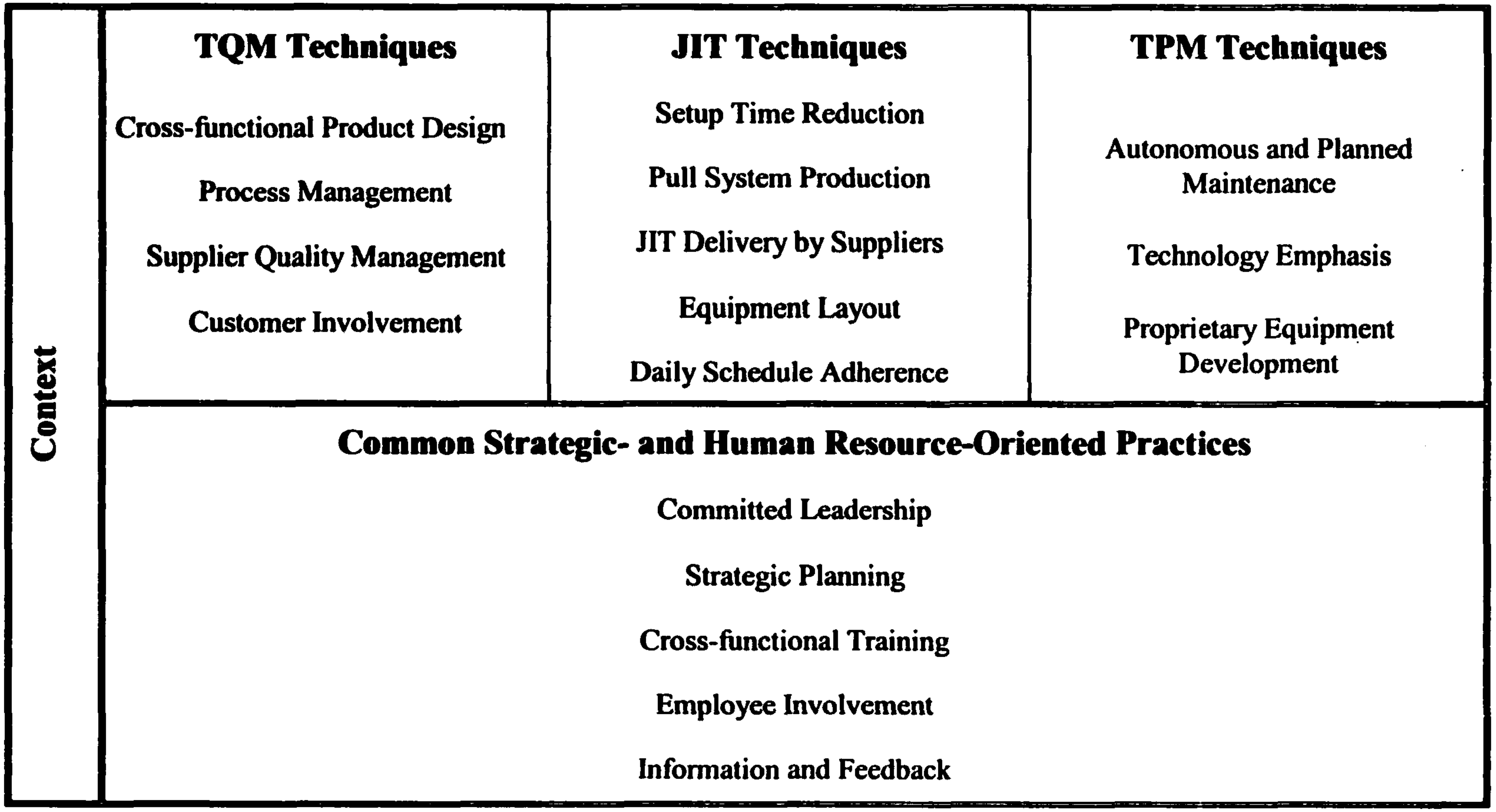
Figure 4-1. Modified Framework of Integrated Manufacturing Practices



CHAPTER 5

PROPOSITIONS AND APPROACHES FOR EMPIRICAL VERIFICATION

In this chapter we synthesize the ideas from the literature review, theoretical discussions, and case studies to derive propositions for empirical verification. Since the research propositions anchor on the concept of fit or integration of manufacturing practices, we first discuss the different approaches for examining fit. Then we consider the theoretical basis for the fit of manufacturing practices and the effect of a good fit on manufacturing performance. Subsequently, we consider the contextual issues and their impact on manufacturing performance. We also state the hypotheses and methods for conducting empirical tests using a large sample cross-sectional database.

5.1. HOLISTIC PERSPECTIVE OF FIT

The case studies, as discussed in Chapter 4, provide concrete evidence of the need for having a systems viewpoint for planning and coordinating the implementation of manufacturing practices. The plant managers acknowledged that manufacturing practices are interdependent and that their successful implementation has a positive impact on plant performance. We find both theoretical and practical support for the consistency of practices within the set of Integrated Manufacturing Practices (see

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chapters 2 to 4). Thus, we seek to understand the interrelationship of multiple practices simultaneously and determine how they fit together.

There are two general perspectives of fit, the 333reductionistic perspective and the holistic perspective (Venkatraman and Prescott, 1990, see also chapter 2). The reductionistic perspective is useful for understanding the specific relation between a pair of variables. Since we are interested in the multivariate relation among a group of practices believed to fit together, it is more appropriate for us to adopt the holistic perspective for modeling fit of the Integrated Manufacturing Practices (IMG).

The recognized approaches for examining fit with respect to the holistic perspective are fit as gestalts, fit as profile deviation and fit as covariation. While it may be tempting to argue for the appropriateness of a particular approach in understanding a phenomenon, this may be a futile exercise since examination of a theoretical question is dependent upon the linkage among theory, method, and data (Venkatraman, 1989).

A theoretical question can be investigated through more than one approach, which would be useful for cumulative theory building. This is consistent with the triangulation concept that advocates testing theoretical relationships using multiple measures and multiple methods (Jick, 1979). Studies have shown that hypotheses on the effect of fit on performance were supported using some approaches and not others (e.g., Joyce et al., 1982; Drazin and Van de Ven, 1985; Venkatraman and Prescott,

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1990). Thus, we will discuss each of the three approaches of holistic fit and use them for investigating our theoretical questions whenever appropriate.

When fit is conceptualized as gestalts, the objective is to determine patterns of internally coherent attributes. The degree of internal coherence can be used to identify the different dimensions or configurations of a factor being examined. The common analytical methods for examining fit as gestalts are inductive approaches such as cluster analysis and q-factor analysis (Venkatraman, 1989). The groupings of cases resulting from the empirically related multivariate interconnections of variables are then interpreted through the language of the researchers.

The identification of gestalts is generally difficult because of the lack of a systematic scheme to calibrate the differences in the degree of fit among the underlying variables across the groupings (Venkatraman and Prescott, 1990) resulting from cluster analysis and q-analysis. Some researchers have used discriminant analysis to assess the predictive accuracy of using the underlying variables to determine group membership (e.g., Hambrick, 1983). Thus, when the groups or gestalts need not be identified empirically, discriminant analysis can be used directly to understand the contribution and interconnections of the underlying variables in identifying group membership of the observations.

Another method for assessing holistic fit is the profile deviation approach. In this approach, fit is conceptualized as the degree of adherence to an externally specified "ideal" profile (Venkatraman, 1989). This approach is similar to the pattern-

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analytic approach of Van de Ven and Drazin (1985). The basic argument of this approach is that a profile of attributes can be theoretically or empirically obtained for a set of high performing organizations and any deviation from this profile will result in a negative effect on performance. The test for performance impact of fit is provided by the correlation between the degree of deviation or misfit from the "ideal" profile and performance. This method allows us to test whether plants that have high levels of implementation on all practices have better performance than plants that have low level of implementation on one or more practices.

Modeling fit as covariation is another approach for understanding holistic fit. The objective of this approach is to determine a pattern of covariation or internal consistency among a set of underlying theoretically related variables (Venkatraman, 1989). This approach is useful for examining coalignment of several concurrent dimensions of a factor that are deemed insufficient in describing a system when taken separately.

General linear models such as regression analysis cannot depict the central thread underlying the logical linkage of various explanatory variables even when regression coefficients may have statistical significance (Hambrick, 1980), therefore general linear models are not suitable for examining fit conceptualized as covariation. Instead, covariation can be modeled using exploratory factor analysis or confirmatory factor analysis where fit as covariation is specified as a second-order factor, and the

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first order factors represent the dimensions to be coaligned (Venkatraman and Grant, 1986).

5.2. FIT OF IMG

Most empirical studies on TQM, JIT, and TPM examine these programs in isolation, however, conceptual articles argue for the value of implementing complementary manufacturing practices (Huang, 1991; Roth and Miller, 1992; Imai, 1998). In chapter 3 we showed that there exists compelling historical and theoretical support for the interrelationship of TQM, JIT, and TPM practices. The practices form a comprehensive set of Integrated Manufacturing Practices involving both socially and technically oriented improvement initiatives. The practices are compatible in accordance with the nine principles for designing a socio-technical system.

TQM and JIT are more often emphasized in academic research and prescribed as improvement programs in the popular press than TPM. However, discussions with plant management reveal that management also emphasizes the implementation of maintenance and equipment development initiatives and understands the principles of TPM. When considering improvement mechanisms at the practice level, the practices associated with TQM, JIT, and TPM are all considered essential and fundamental manufacturing practices that affect manufacturing performance. Together the practices help eliminate waste in different aspects of production—product, process and equipment.

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The three plants included in our case-based research recognize the importance of integrating different manufacturing practices. Planning and implementation of the practices of TQM, JIT, and TPM have to be done jointly since the practices are interrelated. While there is no prescribed sequence for the implementation of these practices, the choice and implementation of any one of these practices have to be coordinated with the existing and planned practices. Information that we obtained from the three plants provides empirical support for the synergy among TQM, JIT, and TPM practices.

For instance, the difficulty that Mach encounters in encouraging employee involvement and cross-training hampered the implementation of in-process quality management. On the other hand, Disk and Filter's emphasis on the manufacture of products with stringent quality standards leads to simultaneous product and process improvement by developing proprietary equipment, giving emphasis to technological advancement, and improving process management. Furthermore, the need of Filter to meet the demand of make-to-order products empowers its product managers to coordinate its just-in-time production with productive maintenance scheduling to ensure high and consistent equipment availability.

The systems framework supports the use of an integrated approach in examining the interrelated building blocks of a system (Gerwin, 1976; Galbraith, 1977; Van de Ven and Ferry, 1980) since the effect of a system is derived from the aggregate impact of its parts and not from the actions of its parts taken separately

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(Finnie, 1997). Thus, to understand the combined effects of the interrelated practices of TQM, JIT, and TPM, these practices should be examined within a single framework.

Since there is much overlap in the practices of TQM, JIT, and TPM, we can only appropriately analyze their joint implementation effects when we consider each unique practice within these programs once. This prevents redundancy in accounting for the impact of some practices. The separation of the strategic- and human resource-oriented practices that are common to TQM, JIT, and TPM from the unique basic techniques helps avoid this redundancy. Moreover, this separation highlights the existence of both socially oriented and technically oriented practices within each of the three programs that is consistent with the rationale of socio-technical systems theory. The case studies also confirm that the three programs share the same set of strategic- and human resource-oriented practices.

Given the theoretical and practical evidence of covariation and complementary nature of the practices of TQM, JIT, and TPM, we propose the following.

Proposition 1: The practices associated with TQM, JIT, and TPM should form an integrated set of manufacturing practices to achieve internal holistic fit.

This proposition can be empirically tested using the fit as covariation approach since we believe that the practices of TQM, JIT, and TPM are correlated and are dimensions of a single factor. Given the overlap in the practices of the three programs,

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we examine the consistency of their practices using their distinct sets of common practices and basic techniques. Our empirically testable hypothesis can be stated as:

Hypothesis H1: The common practices and basic techniques of TQM, JIT, and TPM are dimensions of a single factor signifying coalignment of these practices.

5.3. EFFECT OF FIT OF IMG

The manufacturing programs TQM, JIT, and TPM have the common objective of making a production system more efficient and effective through continuous improvement and elimination of waste. TQM is focused on the elimination of defects and rework. JIT primarily emphasizes reduction of waste in inventory and flow time (Brown and Mitchell, 1991). TPM targets waste caused by equipment problems such as failure, unnecessary setup and adjustment time, idling and minor stoppages, reduced speed, process defects, and reduced yield (Nakajima, 1988).

The different emphases of TQM, JIT, and TPM on waste reduction and elimination are complementary. Together the practices of TQM, JIT, and TPM should help reduce non-value added activities and process variability. Therefore, it can be expected that successful implementation of these practices will be associated with good performance. This contention is consistent with the Theory of Swift and Even Flow (Schmenner and Swink, 1998) and a Theory of Internal Variability of Production Systems (Wacker, 1987; 1996) discussed in Chapters 2 and 3.

For instance, Disk uses stringent standards for in-process and final product inspection to ensure product quality. However, due to the strict requirements for

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reliability and precision of its products Disk complements quality management practices with the development of proprietary processes and equipment that helps reduce variability in the production process. Together, product, process, and equipment improvement enabled Disk to win a state quality award and maintain major market share for its products.

While the implementation of the basic techniques of TQM, JIT, and TPM may be directly related to waste reduction and production process improvement their implementation requires supporting mechanisms. A piecemeal approach to the implementation of TQM, JIT, and TPM is observed to lead to failure. The institution of common strategic- and human resource-oriented practices is needed for the successful implementation of the basic techniques as evidenced by Mach's lack of support for in-process quality management due to reluctance of its employees to get involved and be cross-trained.

Moreover, the common practices enable the development of one of the most important resources--the human capital, which is the impetus sustaining flexibility, continuous learning and improvement. The managers of Disk pointed out that while proprietary equipment is an important asset, they still consider people and not technology as their strength. Similarly, Filter gives high emphasis on the recruitment of people who can fit well into the plant's culture and who will be able to contribute to the plant's success through active involvement and informed decision-making.

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Therefore, while certain practices may contribute more towards the improvement of specific manufacturing performance dimensions of low cost, quality, delivery, and flexibility, it can be expected that good performance in all dimensions will be associated with the combined higher level of implementation of a greater number of practices of TQM, JIT, and TPM. Also, the complementary nature of the Integrated Manufacturing Practices suggests that higher levels of implementation of a practice will increase the returns of the implementation of a complementing practice.

Thus, according to the belief that a good fit among relevant factors will lead to better performance (e.g., Venkatraman and Prescott, 1990; Milgrom and Roberts, 1995) we summarize the above ideas by the following proposition:

Proposition 2: Fit of the integrated manufacturing practices is positively associated with the level of manufacturing performance.

This proposition can be empirically examined using all three recognized approaches for understanding holistic fit. We have already hypothesized the covariation of the Integrated Manufacturing Practices in hypothesis H1, and we expect the effect of coalignment of these practices on manufacturing performance to be positive. Another way of investigating this relationship is by adopting the fit as profile deviation approach. We expect that divergence from the ideal scenario of high levels of implementation of all Integrated Manufacturing Practices will negatively affect performance.

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On the other hand, when the effect of the practices is not considered in aggregate, we expect to identify a profile of important practices that can be associated with good performance in specific manufacturing performance dimension. Thus, we can examine proposition 2 through empirical tests of the following two hypotheses:

Hypothesis H2a: Fit of the common practices and basic techniques of TQM, JIT, and TPM is positively associated with each basic dimension of manufacturing performance—cost efficiency, quality, delivery, and flexibility.

Hypothesis H2b: Manufacturing plants that are identified as high performers have higher levels of implementation of both common practices and basic techniques of TQM, JIT, and TPM than low performers.

5.4. CONTEXTUAL EFFECTS

The manufacturing plants that we investigated in our case studies belong to different operational environment. The information we obtained in the case studies provides evidence that the contextual factors of a manufacturing plant affect the implementation and impact of manufacturing practices. However, the different contextual factors did not deter plant management from believing that the implementation of Integrated Manufacturing Practices is suitable for their plants.

Management literature recognizes the role of an organization's context on performance (Lawrence and Lorsch, 1967). Moreover, Hayes and Wheelwright (1984) identify the root cause of "manufacturing crisis" to be the incompatibility of manufacturing policies and people with its facilities and technology choices. Thus,

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apart from the manufacturing practices or policies being implemented, contextual variables also play crucial roles in determining the trajectory of a manufacturing plant.

Two contextual factors that are often considered in the study of organizations are country and industry. Manufacturing performance may differ by country (Porter, 1980; Ferdows et al., 1986; Roth et al., 1991; Noble, 1995). Some of the studies that investigate manufacturing performance differences across country conclude that variation in the amount of emphasis on different manufacturing strategies led to the application of dissimilar practices that may affect performance (Ferdows et al., 1986; Roth et al., 1991). Studies that compare and contrast manufacturing organizations across industries find that factors that may influence manufacturing performance outcomes include, but are not limited to, product complexity, production technologies, capital structure, and management sophistication (Porter, 1980; Kotha and Orne, 1989; Gunn, 1992; Maskell, 1992).

These results reveal that there are more fundamental factors underlying variations in performance of manufacturing organizations belonging to different countries and industries. Thus, in studies where samples are randomly obtained across subpopulations defined by country and industry, it may be more worthwhile to understand differences resulting from contextual variables other than country and industry.

Aside from country and industry, perhaps the most frequently studied contextual variable in research involving the concept of fit is organizational size

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(Powell, 1992). Organizational size is considered one of the best predictors of organizational structure and managerial behavior in the history of organizational design and behavioral research (Drazin, 1995). The number of employees is often used as a measure of the size of an organization (e.g., Powell, 1992; McKone et al., 1999).

Large organizations have an advantage in terms of availability of more financial and human resources (Daft, 1995) that may enable them to experiment with manufacturing programs (e.g., Im and Lee, 1989; McKone et al., 1999). However, more often than not, large organizations are more centralized and formalized than small organizations. For instance, management of the Disk plant expressed concern about the difficulty of coordinating and communicating with employees when the plant size is large. When communication has to be formalized and channeled through several hierarchies, it is more difficult to get active and immediate involvement of the employees. However, manufacturing programs that are generally perceived as requiring high employee involvement have been implemented in both large and small firms. In particular, Inman and Mehra (1990) conclude that JIT is just as applicable to small firms as to large firms.

The type of production process technology has been considered a contextual variable in research studies since the publication of Woodward's (1965) typology of production technologies. Production processes can be classified into several

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categories ranging from job shop production to batch production, repetitive processes, and continuous processes (Woodward, 1965; Hayes and Wheelwright, 1984).

Technologies typically associated with low volume and high variety may result in relatively low conformance quality due to conditions that inhibit quality-related learning (Garvin, 1988). On the other hand, production technologies associated with high volume, low variety production requirements generally provide substantial opportunity for standardization of products and production processes enabling quality-related learning. The degree of product customization that can affect per unit production cost and flexibility is also very closely related to the type of production process that is utilized. High product customization typically entails a job shop production environment while production involving low customization can be accomplished with a repetitive or continuous production process.

Manufacturing practices being implemented have to be compatible with the production process. However, the relationship between specific manufacturing practice and process type is not clear. For instance, while JIT practices are often considered to be best suited for a repetitive manufacturing environment, in recent years these practices have also been successfully employed in non-repetitive manufacturing (Groenevelt, 1993), with the possible exception of the pull system.

Through the case studies, we also observe that the Integrated Manufacturing Practices are used with different production processes in the three plants. Mach employs job shop type production to cater to customer requests for out-of-market

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products and uses an assembly line approach for the rest of its production. Disk and Filter utilizes repetitive and continuous production processes. However, all three plants have incorporated TQM, JIT, and TPM practices successfully.

Manufacturing resources such as plant capacity can certainly affect plant performance. Lack of capacity may result in a plant's inability to meet orders on time and can limit the plant's flexibility in production scheduling. A high level of plant capacity utilization may reduce per unit fixed costs but when high capacity is sustained through overtime, variable cost may increase (Krajewski and Ritzman, 1996). Plants operating at peak capacity may potentially encounter more equipment and process problems that can affect product quality. Schemmer and Swink (1998) also suggest that when the limits of the asset frontier or the structural resources have been reached, the law of trade-offs of manufacturing performance may set-in and inhibit further improvement in multiple dimensions of performance. For instance, to keep up with production requirements and maintain performance standards, the Filter plant has to constantly add capacity and increase the number of employees. While Filter's high growth rate contributes to its additional capacity needs, plant management's desire to maintain a high level of performance and respond quickly to make-to-order customer purchases makes having capacity cushion important.

There are many other contextual factors that can be examined to better understand the effect of environment on manufacturing performance. For instance, unionization and employee culture in Mach are factors that are possibly influencing its

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performance but their effects may have been captured through the level of implementation of the Integrated Manufacturing Practices as evidenced by its inability to involve and cross-train its production crew.

Moreover, it is found that many human resource management practices are similar in unionized and non-unionized JIT firms with workers' resistance to learning new skills as the primary human resource problem even though non-unionized firms tend to report more success in implementing new ideas (Deshpande and Golhar, 1995). In a more general study on the impact of unionization on firm performance, the author concludes that union influences profit distribution but has little impact on factors and output of production (Clark, 1994).

The above discussion suggests that there is no definite argument on the nature of the effect of contextual factors on manufacturing performance. However, we have to acknowledge the possible contribution of contextual factors on performance variations. It is also possible that the effects of contextual factors are manifested through the existence or non-existence and level of implementation of manufacturing practices. Thus, we expect that while contextual factors have an impact on manufacturing performance, the level of implementation of manufacturing practices will explain a larger portion of the variability in performance. Therefore, we propose the following:

Proposition 3: Both contextual factors and manufacturing practices affect manufacturing performance. After accounting for contextual differences, fit of

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Integrated Manufacturing Practices explains a significant portion of the variation in manufacturing performance.

There is a multitude of contextual variables that can be investigated in a research study. We want to keep the focus of this research at the plant level and thus will control for external contextual factors such as country and industry in the empirical investigation. Moreover, when the sample size in each country-industry subgroup is small it will be difficult to make strong generalizable conclusions related to subgroup differences. Due to limitations of the database and the impossibility of capturing all possible contextual factors, we will limit our investigation to the contextual factors of plant size, process type, and capacity utilization. The above discussion provides more compelling evidence on the contribution that these factors can have on manufacturing performance. Unionization itself would not seem to provide significant influence on manufacturing performance, its influence being more related to the human factors of production are likely captured by the level of implementation of common strategic- and human resource-oriented practices.

Since we do not identify the specific nature of the interrelation between contextual factors and Integrated Manufacturing Practices, we will not modify the test for fit as covariation to include contextual factors in the analysis. Extending the empirical investigation of the effect of Integrated Manufacturing Practices on performance to include contextual factors, we will test the following hypotheses using the fit by profile deviation and fit as gestalts approaches respectively.

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Hypothesis H3a: Fit of Integrated Manufacturing Practices explains a significant portion of the variation in manufacturing performance after accounting for contextual differences in plant size, process type, and capacity utilization.

Hypothesis H3b: The level of implementation of Integrated Manufacturing Practices provides significant differentiation of high performers from low performers after accounting for contextual factors such as plant size, process type, and capacity utilization.

We have explicitly stated our hypotheses and the approaches that will be taken for their empirical verification. The results of the tests of hypotheses will be examined together with the information from the literature and case studies to substantiate or modify The Theory of Integrated Manufacturing Practices that is proposed in Chapter 3. This is consistent with the principle of iterative triangulation for gaining cumulative understanding on the fit of Integrated Manufacturing Practices.

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CHAPTER 6

DATA FOR EMPIRICAL ANALYSIS

The goal of Chapter 6 is to summarize the data used in our analysis. First, we provide a description of the database used in this study. Then, special attention is given to the discussion of procedures used in developing multi-item scale measures and testing reliability and validity of the scales.

6.1. DESCRIPTION OF THE DATABASE

This research uses data collected as part of the World Class Manufacturing (WCM) Project (Flynn et al., 1994) conducted by a team of international researchers in 1994-1997. The WCM database consists of data from 164 manufacturing plants located in five countries: Germany, Italy, Japan, the United Kingdom, and the United States. In each country, plants were selected from three industries: automotive suppliers, electronics, and machinery industries. A stratified design was used to select approximately equal number of plants in each country and industry combination (Table 6-1).

Table 6-1. Stratification of the Sample by Country and Industry

Number of Plants		Industry			
		Auto Suppliers	Electronics	Machinery	Total
Country	Germany	13	9	11	33
	Italy	10	11	13	34
	Japan	15	17	14	46
	United Kingdom	7	7	7	21
	United States	10	10	10	30
Total		55	54	55	164

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The study also selected approximately half of the plants with world-class reputations and half from traditional plant lists. World-class reputation was based on published studies of plants' best practices such as Target, Industry Week, and Schonberger's (1986) "honor roll" and also from communication with industry leaders. As a result, many of the best plants in the world are included along with the more typical plants. More details on the selection of manufacturing plants for the WCM Project can be found in Flynn et al. (1994) and Hollingworth (1998).

Members of the WCM project contacted the selected manufacturing plants to request their participation. Two-third of the plants contacted joined the study by having some of their employees complete written surveys. This relatively high response rate was assured by communicating with the plants personally and by promising that they would receive a plant profile for comparison with other plants.

The survey instrument of the WCM study was developed from an extensive review of relevant literature on manufacturing operations and practices. The instrument was pretested at several manufacturing plants and translated into Japanese, Italian, and German by teams of operations management experts from the associated countries. The translations were then translated back to English by a different group of people to check for accuracy of translation. Necessary modifications to the instrument were made for clarity and consistency across translations. Care in the development and pretest of the questions assures us the constructs can be measured to an acceptable degree of content validity.

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The instrument was divided into 15 questionnaires that were administered to 26 informants in a manufacturing plant from direct labor workers to managers. Questionnaires were assigned to informants on the basis of their job title and expertise in order to increase the probability of getting accurate information while allowing data to be collected from multiple sources to provide greater reliability. Approximately 90% of the plants returned at least 24 surveys and only 2% returned fewer than 15. Therefore, there is good representation from the participating plants.

The WCM database consists of data for approximately 750 variables that can be classified into objective and subjective types of data. Objective data provide directly measurable information on approximately 400 variables on topics such as plant environment, accounting data, and the years of adoption of improvement initiatives. Subjective data are Likert-scaled measures for approximately 350 variables assessing constructs related to manufacturing strategy, technology, information systems, human resources, manufacturing practices, and performance. These Likert-scaled items form multi-item psychometric scales. While differentiation is made between objective and subjective data because of the difference in which the survey items were formulated, the data collected are all reported by the informants and are possibly subjected to the same human error and bias.

Many of the psychometric scales were developed for an earlier round of the WCM study and were tested for reliability and validity (see Sakakibara et al., 1993; Flynn et al., 1994; Bates, 1995). Some of the scales in the database used for the

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current research have also been used in other studies (for example, Ahmad, 1998; Cua and Schroeder, 1999; McKone et al., 1999, forthcoming). However, most of these studies only used data of three or four countries in the database. Furthermore, the methods used to test reliability and validity are generally exploratory in nature (but see Cua and Schroeder, 1999 for an exception). Thus, in the next section we will discuss the reliability and validity of the scales used in this study.

6.2. MEASUREMENT ITEMS

The constructs of interest in this study were explicitly defined in Chapters 3 and 4. We can find appropriate measures for these constructs from the WCM database since the WCM project seeks to understand the implementation and impact of manufacturing practices as one of its main objectives and provides comprehensive data on manufacturing practices and performance. We do not use data from one of the 164 manufacturing plants in the database due to missing values for most of its performance measures. Thus, our effective sample size is 163 manufacturing plants after excluding a manufacturing plant in the electronics industry located in the United Kingdom.

We use subjective measures for manufacturing practices and performance. Unless otherwise indicated, the items for measuring implementation of practices were answered by indicating the extent to which an informant agrees or disagrees with the statement provided using a five point Likert scale: strongly agree (5), agree (4), neutral (3), disagree (2), and strongly disagree (1). Items that are reverse worded are reverse scored to maintain the same measurement format. For the performance

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measures, the informants were asked to choose the best description of how their plant compares to its industry competitors on a global basis. The contextual variables are measured using objective data.

The measurement items used in this study can be found in Appendix B. In the succeeding sections we discuss how the different measures are evaluated and developed into forms suitable for empirical analysis of this study's hypotheses.

6.3. MANUFACTURING PRACTICES SCALES

The items in the WCM database that can be used to measure the 17 Integrated Manufacturing Practices form multi-item scales. The items for the scales were carefully developed from a thorough review of relevant literature and were subjected to rigorous pretest as discussed in the previous section, hence we can be assured of an acceptable degree of content validity. To further ensure that the items of a scale are internally consistent across informants we conduct item analysis for each scale and modify the scale when necessary. We assess the psychometric properties of the resulting scales using a confirmatory factor analysis approach to test convergent validity, unidimensionality, discriminant validity, reliability, and nomological validity.

6.3.1. Item Analysis of Informant Level Data

Since there are multiple informants for each plant, we conduct item analysis of the scales at the individual respondent level to ensure internal consistency of the items of a scale across informants. We use weighted least square (WLS) estimation of a one-factor model to assess the measures for each of the 17 Integrated Manufacturing

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Practices. We use WLS estimation because the measures are ordinal with values 1 to 5.

It is commonly suggested that WLS estimation should be used with large samples however there is no agreed upon criterion of what is considered "large". WLS has been used with a sample of size 200 (Jöreskog and Sörbom, 1996) and a sample of size 75 and no serious problems were found (Bollen, 1989b, p. 432). We believe that our sample sizes ranging from 333 to 1831 for the 17 models are sufficient. Moreover, our samples are at least 22 times the minimum size (k * (k-1)/2, where k is the number of observed variables) needed to estimate an asymptotic covariance matrix (Bryne, 1998) in WLS estimation.

Using iterative estimations of the models, we exclude the lowest loading item from a scale when it loads less than 0.50 and when its removal does not reduce the reliability of the scale. We also make sure that the remaining items of a scale still capture the essence of the construct they are intended to measure.

All the resulting scales exhibit good measurement model fit. All modification indices are associated with expected parameter changes that are less than |0.30| so further investigation of lack of fit is not necessary (Koufteros, 1999). All item loadings are greater than 0.50 and significant at the 0.01 level. The composite reliability of the scales are greater than 0.73 except for the JIT delivery by suppliers scale that has a composite reliability of 0.67. Thus all scales have composite reliability better the suggested lower limit of 0.60 (Bagozzi and Yi, 1988).

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Eight scales extract at least 52% of the variance in their items and another eight scales have average variance explained of at least 45%. The JIT delivery by suppliers scale has an average variance explained of 40%. It would be ideal if we can have all scales meeting the general rule-of-thumb that expects a scale to explain at least 50% of the items' variance (Fornell and Larcker, 1981; Bagozzi and Yi, 1988). However, we retained all scales because their scale items are conceptually consistent with the constructs they intend to measure and the percentage of variance explained may have been negatively affected by the existence of variability due to differences in the level of implementation of practices across plants. Overall, we can be relatively confident that the items for each scale are consistently interpreted across the informants in the different plants and measure a common underlying construct. The scale items can be found in Appendix B.

6.3.2. Plant Level Data

The unit of analysis of this study is a manufacturing plant thus we are interested in obtaining measures for the constructs at the plant level. Since multiple informants responded to each of the scale items according to their area of expertise we average the responses from the same plant to form the plant level measure for an item. Aggregation of responses is justified since informants from the same plant are reporting on the condition of a similar entity and also helps reduce the potential bias and variability in the informants' report.

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It is ideal to assess the psychometric properties of all measures together, however, given the large number of variables in our scale measures we have to use several models to examine our measures. Since the Integrated Manufacturing Practices are grouped into four categories according to the literature and the classification is supported in the case studies, we follow this classification to develop four models for examining validity and reliability of the most interrelated measures together.

The implementation of specific subsets of the Integrated Manufacturing Practices can be considered relatively comprehensive manifestations of the emphasis and initiatives placed on strategic- and human resource-oriented practices, TQM basic techniques, JIT basic techniques or TPM basic techniques. Thus we can represent the practices within subsets of the Integrated Manufacturing Practices as dimensions of a factor representing the relevant category of the Integrated Manufacturing Practices. The models showing the specific practices represented by first-order factors of a second-order factor depicting one of the four dimensions of the Integrated Manufacturing Practices together with the items used to measure them are provided in Figure 6-1 to Figure 6-4. We will discuss the models' parameters and fit measures in the succeeding sections.

Since the plant level data are obtained by aggregating the informants' responses they provide continuous measures. However, the resulting variables exhibit

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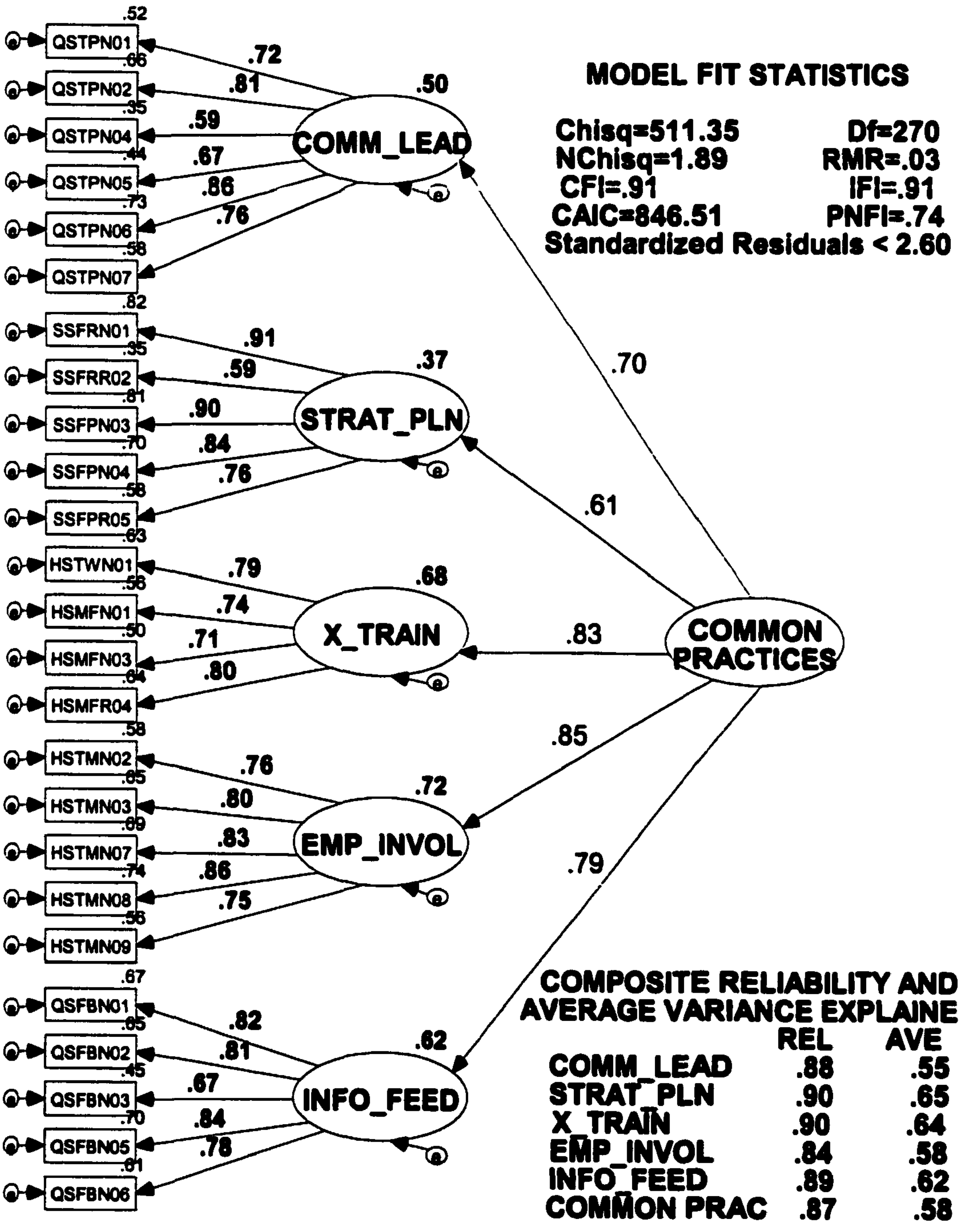
Figure 6-1. Confirmatory Factor Analysis of Common Practices



MODEL FIT STATISTICS

Chisq=511.35 Df=270
NChisq=1.89 RMR=.03
CFI=.91 IFI=.91
CAIC=846.51 PNFI=.74
Standardized Residuals < 2.60

COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXPLAINE

	REL	AVE
COMM_LEAD	.88	.55
STRAT_PLN	.90	.65
X_TRAIN	.90	.64
EMP_INVOL	.84	.58
INFO_FEED	.89	.62
COMMON PRAC	.87	.58

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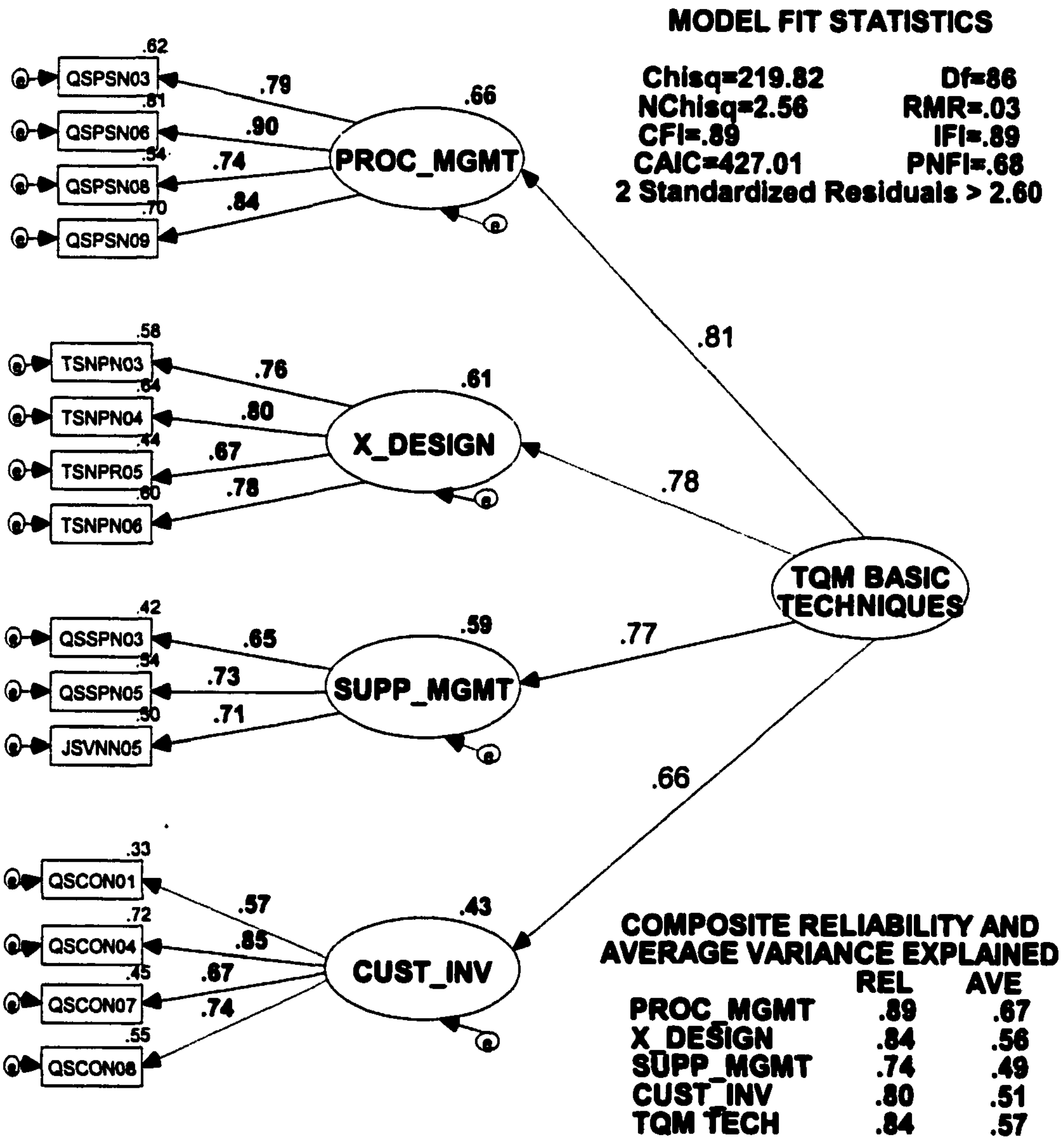
Figure 6-2. Confirmatory Factor Analysis of TQM Basic Techniques



MODEL FIT STATISTICS

Chisq=219.82 Df=86
NChisq=2.56 RMR=.03
CFI=.89 IFI=.89
CAIC=427.01 PNFI=.68
2 Standardized Residuals > 2.60

COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXPLAINED

	REL	AVE
PROC_MGMT	.89	.67
X_DESIGN	.84	.56
SUPP_MGMT	.74	.49
CUST_INV	.80	.51
TQM TECH	.84	.57

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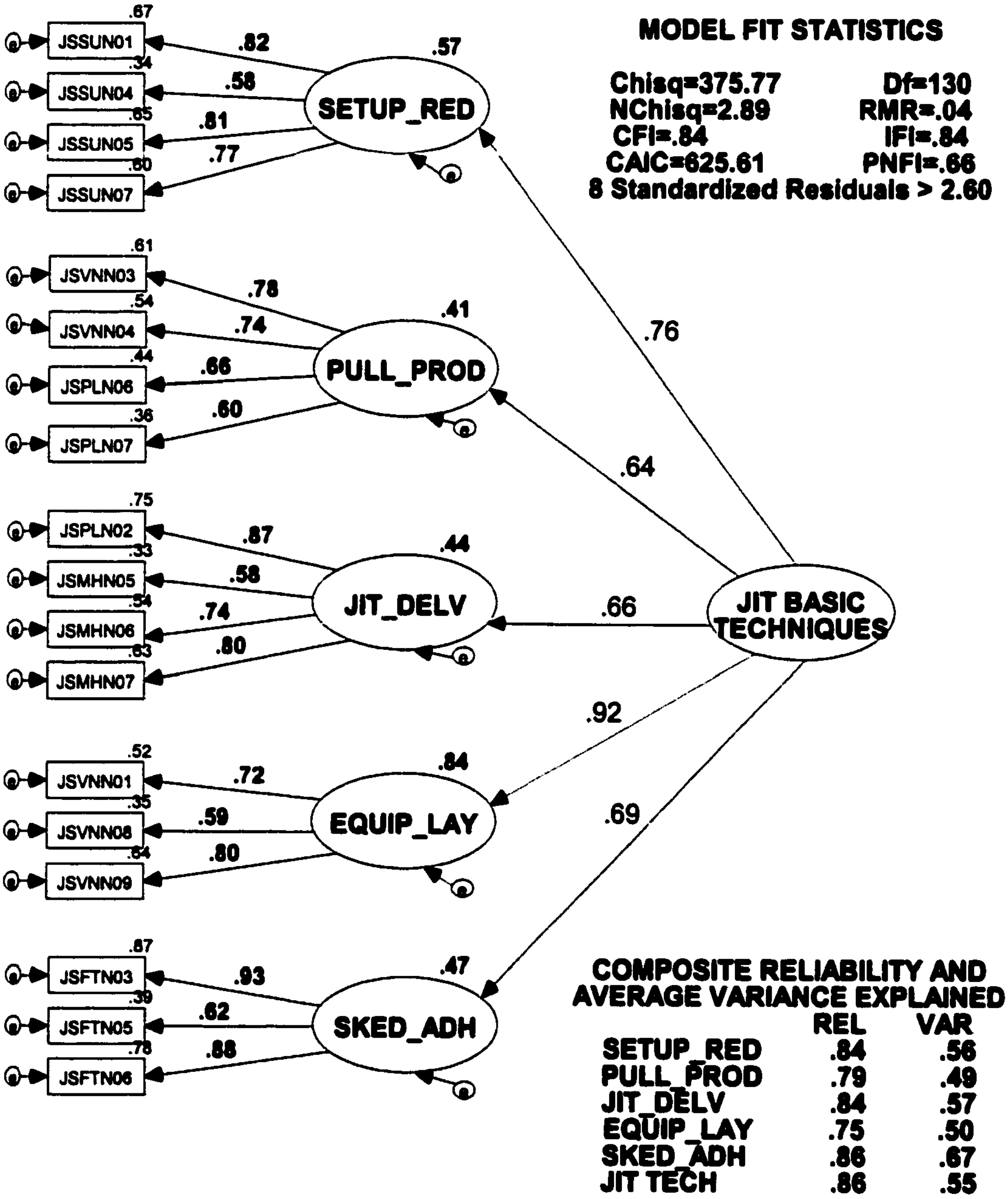
Figure 6-3. Confirmatory Factor Analysis of JIT Basic Techniques



MODEL FIT STATISTICS

Chisq=375.77 Df=130
NChisq=2.89 RMR=.04
CFI=.84 IFI=.84
CAIC=625.61 PNFI=.66
8 Standardized Residuals > 2.60

COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXPLAINED

	REL	VAR
SETUP_RED	.84	.56
PULL_PROD	.79	.49
JIT_DELV	.84	.57
EQUIP_LAY	.75	.50
SKED_ADH	.86	.67
JIT TECH	.86	.55

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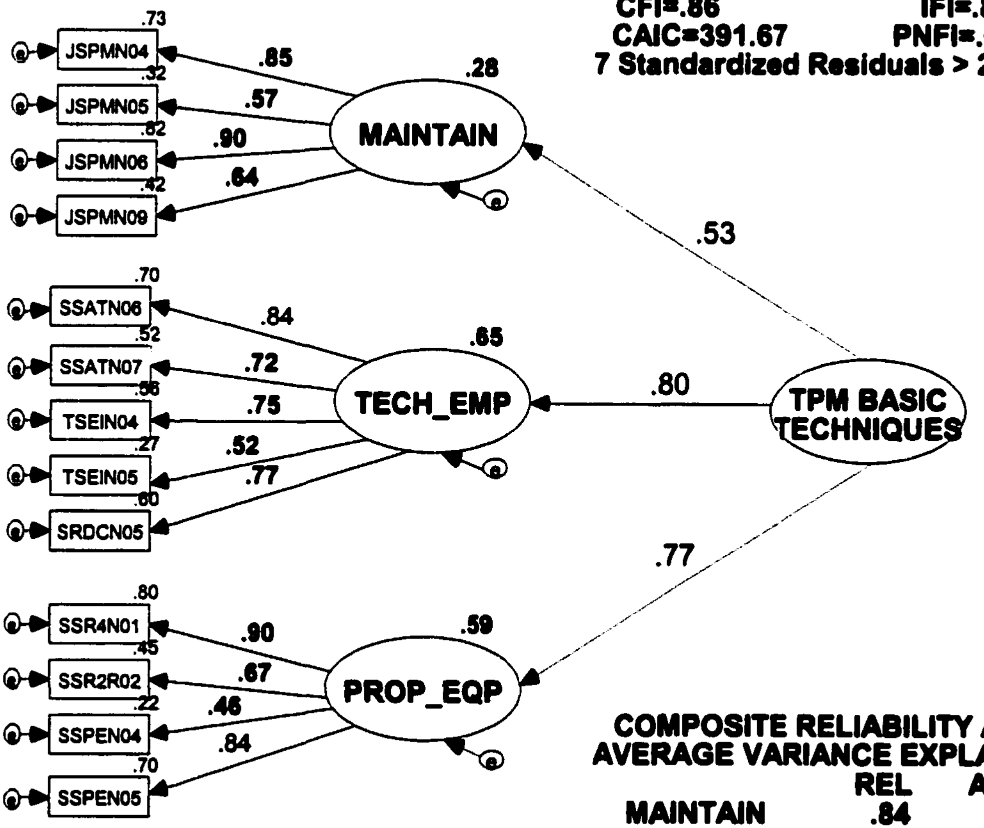
Figure 6-4. Confirmatory Factor Analysis of TPM Basic Techniques



MODEL FIT STATISTICS

Chisq=214.95	Df=62
NChisq=3.47	RMR=.05
CFI=.86	IFI=.86
CAIC=391.67	PNFI=.65

7 Standardized Residuals > 2.60

COMPOSITE RELIABILITY AND AVERAGE VARIANCE EXPLAINED

	REL	AVE
MAINTAIN	.84	.57
TECH_EMP	.85	.53
PROP_EQP	.82	.54
TPM TECH	.75	.51

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moderate multivariate non-normality. Since our sample size of 163 is less than the required minimum to obtain an asymptotic covariance matrix, we use maximum likelihood method to estimate our models. Maximum likelihood estimation has been found to be relatively robust under conditions of moderate non-normality.

6.3.3. Convergent Validity and Unidimensionality

We assess convergent validity and unidimensionality of each of the 17 practice scales by using the four practices models (see Figure 6-1 to Figure 6-4). Overall, all four models have acceptable fit with NChisq < 3.50, RMR ≤ 0.05, CFI > 0.84, IFI > 0.84, PNFI > 0.60 though some of these fit indices do not have ideal values (see Appendix C for a summary discussion of model fit measures). Less than 10% of the standardized residuals are greater than |2.58| in each of the four models. The Q-plots of standardized residuals show curves that are approximately linear with slopes of one and no apparent outliers. There is no significant evidence of items cross-loading on factors that they are not intended to measure since all large modification indices are associated with expected parameter changes that are less than |0.30|. Modification indices suggest that the models may be improved by correlating some of the item measures.

Item loadings for the first-order factors are greater than 0.50 except for one loading of 0.46, have the expected signs, and are significant at the 0.01 level (t > |2.58|) indicating that convergent validity of the scales for specific practices is supported (Bagozzi et al., 1991). The convergence of items to the factors they are

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purported to measure, lack of evidence for unwarranted cross-loading, and overall model fit provide support for the unidimensionality of each of the 17 manufacturing practice scales.

6.3.4. Discriminant Validity

While our scales satisfy convergent validity and unidimensionality indicating that correspondence exists among items intended to measure a single construct, we also have to verify discriminant validity of the scales to make sure that measures of distinct but closely related constructs can be differentiated. We evaluate all pairwise correlation (ϕ) between every two factors in a model. This assures us that we are comparing each scale to several scales that it is most theoretically related. For each comparison between two factors we use two methods to test for discriminant validity. In the first method we test whether the average variance extracted (AVE) by each of the two factors is greater than their squared correlation (see section 6.3.5 for more discussion on AVE). When the test is passed, there is evidence that the measures differentiate the two factors (Fornell and Larcker, 1981).

In the second method, discriminant validity is supported when the value 1 is not included in the 95% confidence interval $\phi \pm 2\sigma_e$ of ϕ, constructed from the correlation between two factors plus or minus twice the standard error of its estimation. The second method is similar to performing a chi-square difference test between models that free or fix the correlation between two factors. All the 29 factor pairs pass the two tests (Table 6-2 to Table 6-5), thus we are confident that the scales

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satisfy discriminant validity and are not confounded measures of highly related constructs.

Table 6-2. Tests of Discriminant and Nomological Validity of Common Practices

	COMM_LEAD (1)	STRAT_PLN (2)	X_TRAIN (3)	EMP_INVOL (4)	INFO_FEED (5)
(1)	AVE = .55	$\phi^2 = .29$	$\phi^2 = .30$	$\phi^2 = .31$	$\phi^2 = .35$
(2)	(.48, .59)	AVE = .65	$\phi^2 = .21$	$\phi^2 = .22$	$\phi^2 = .26$
(3)	(.51, .59)	(.40, .51)	AVE = .64	$\phi^2 = .57$	$\phi^2 = .38$
(4)	(.52, .59)	(.43, .51)	(.71, .79)	AVE = .58	$\phi^2 = .44$
(5)	(.54, .64)	(.44, .57)	(.56, .68)	(.62, .71)	AVE = .62

Note: A value above the diagonal is the two associated variables' squared correlation and a value below the diagonal is the 95% confidence interval $\phi \pm 2\sigma_e$. A value on the diagonal is the variable's average variance extracted.

Table 6-3. Tests of Discriminant and Nomological Validity of TQM Techniques

	PROC_MGMT (1)	X_DESIGN (2)	SUPP_MGMT (3)	CUST_INV (4)
(1)	AVE = .67	$\phi^2 = .40$	$\phi^2 = .36$	$\phi^2 = .31$
(2)	(.58, .69)	AVE = .56	$\phi^2 = .39$	$\phi^2 = .23$
(3)	(.55, .64)	(.58, .67)	AVE = .49	$\phi^2 = .26$
(4)	(.51, .60)	(.44, .52)	(.48, .55)	AVE = .51

Note: A value above the diagonal is the two associated variables' squared correlation and a value below the diagonal is the 95% confidence interval $\phi \pm 2\sigma_e$. A value on the diagonal is the variable's average variance extracted.

Table 6-4. Tests of Discriminant and Nomological Validity of JIT Techniques

	SETUP_RED (1)	PULL_PROD (2)	JIT_DELV (3)	EQUIP_LAY (4)	SKED_ADH (5)
(1)	AVE = .56	$\phi^2 = .21$	$\phi^2 = .26$	$\phi^2 = .49$	$\phi^2 = .25$
(2)	(.41, .51)	AVE = .49	$\phi^2 = .15$	$\phi^2 = .44$	$\phi^2 = .11$
(3)	(.47, .56)	(.34, .43)	AVE = .57	$\phi^2 = .30$	$\phi^2 = .34$
(4)	(.64, .76)	(.60, .72)	(.50, .59)	AVE = .50	$\phi^2 = .39$
(5)	(.45, .55)	(.28, .38)	(.54, .63)	(.57, .68)	AVE = .67

Note: A value above the diagonal is the two associated variables' squared correlation and a value below the diagonal is the 95% confidence interval $\phi \pm 2\sigma_e$. A value on the diagonal is the variable's average variance extracted.

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Table 6-5. Tests of Discriminant and Nomological Validity of TPM Techniques

	MAINTAIN (1)	TECH_EMP (2)	PROP_EQP (3)
(1)	AVE = .57	$\phi^2 = .18$	$\phi^2 = .17$
(2)	(.37, .47)	AVE = .53	$\phi^2 = .39$
(3)	(.33, .48)	(.52, .73)	AVE = .54

Note: A value above the diagonal is the two associated variables' squared correlation and a value below the diagonal is the 95% confidence interval $\phi \pm 2\sigma_e$. A value on the diagonal is the variable's average variance extracted.

6.3.5. Reliability

We assess the reliability of a scale by evaluating its composite reliability and average variance extracted using formulas proposed by Fornell and Larker (1981). Composite reliability provides an aggregate measure of the degree of internal consistency or intercorrelation among measures of the same construct. A reliability value that is greater than about 0.60 is desirable (Bagozzi and Yi, 1988).

The average variance extracted by a factor measures the shared variance of the items captured by the factor. A factor is generally expected to account for at least half of the variance in the items (Fornell and Larcker, 1981; Bagozzi and Yi, 1988) so that we can be confident that common variance of the items is greater than variance due to measurement error.

As shown in Figure 6-1 to Figure 6-4, all first-order factors have composite reliability greater than 0.74 and average variance extracted greater than 0.50.

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Therefore, there is empirical support that our scale items provide consistent and dependable measures of the constructs.

6.3.6. Nomological Validity

Nomological validity denotes the degree to which predictions from a theoretical network containing the constructs under scrutiny are confirmed in the relationships of the scale measures (Bagozzi, 1980). In the previous chapters we discussed how the Integrated Manufacturing Practices are related and can be classified. In section 6.3.2 we have explained how these relationships can be represented through second-order factor models shown in Figure 6-1 to Figure 6-4.

Thus, we can test for nomological validity of the scales by determining whether or not the relationships of the Integrated Manufacturing Practices (IMP) are supported in each of the four models by assessing the following criteria:

1. the fit of the second-order factor model shown in Figure 6-1 to Figure 6-4 depicting the overall relationship of the practices belonging to the same dimension of the IMP,
2. significant loading of the first-order factors on the second-order factor to support the convergence of the practices to the dimension of IMP that they purport to represent,
3. significant correlation between every pair of first-order factors in a model to substantiate the interrelation of the implementation of practices belonging to the same dimension of IMP, and

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4. acceptable reliability and average variance explained of the second-order factor to signify the internal consistency of the practices represented by the first-order factors and sufficiency of the second-order factor in capturing the variability of the first-order factors.

Referring to Figure 6-1 to Figure 6-4 we can observe that the fit of the four models are acceptable as already discussed in section 6.3.3. All loadings of the first-order factors on second order factors are no less than 0.53 and significant at the 0.01 level indicating convergences of the practices to the dimension of IMP that they represent. The pairwise correlations between any two first-order factors in a model are significant at the 0.01 level and the squared value of these correlations are reported in Table 6-2 to Table 6-5. All second-order factors have composite reliabilities no less than the 0.75 and all average variance explained are greater than the 0.50 (Figure 6-1 to Figure 6-4) satisfying the benchmarks for these measures (Fornell and Larcker, 1981; Bagozzi and Yi, 1988).

Since all of the four criteria stated above are satisfied we have convincing evidence supporting the nomological validity of our scales. This result also provides empirical support for the classification of specific practices into the groupings used to define the four dimensions of Integrated Manufacturing Practices. Overall, the test results for the different psychometric properties support the reliability and validity of the scale measures for Integrated Manufacturing Practices and confirm the theoretical and practical relationships among practices as classified in the theoretical framework.

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6.3.7. Composite Measures

The hypotheses of this study require the examination of the Integrated Manufacturing Practices together. However, the large number of variables does not warrant modeling a complete structural model with all measurement items included in the model. Thus, we have to create composite measures from the 17 Integrated Manufacturing Practices scales and use these in the subsequent structural equation models for testing hypotheses. The structural models will therefore be similar to Bagozzi and Heatherton's partial disaggregation models (Bagozzi and Heatherton, 1994).

We calculate the composite measures for the 17 Integrated Manufacturing Practices by taking a simple average of the item measures for these practices. We perform optimal Box-Cox transformation on the variables that are found to violate univariate normality. We also standardize the variables by country and industry to control for possible country-industry differences that may affect the relationship of these variables with manufacturing performance in subsequent analyses. The bivariate covariances between the composite manufacturing practices variables can be found in Table 6-6.

6.4. MANUFACTURING PERFORMANCE VARIABLES

We are interested in measuring the performance of manufacturing plants with respect to the four basic dimensions of cost, quality, delivery, and flexibility (Skinner, 1969). In Chapter 3 we discussed some of the possible performance measures such as

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Table 6-6. Covariances of Manufacturing Practices Composite Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1)	0.99																
(2)	0.44**	0.99															
(3)	0.46**	0.31**	0.99														
(4)	0.50**	0.41**	0.64**	0.99													
(5)	0.43**	0.34**	0.44**	0.56**	0.99												
(6)	0.57**	0.40**	0.45**	0.59**	0.69**	0.99											
(7)	0.60**	0.33**	0.49**	0.62**	0.46**	0.53**	0.99										
(8)	0.43**	0.24**	0.37**	0.40**	0.46**	0.52**	0.51**	0.99									
(9)	0.45**	0.28**	0.41**	0.47**	0.46**	0.48**	0.43**	0.54**	0.99								
(10)	0.38**	0.36**	0.35**	0.44**	0.33**	0.35**	0.30**	0.25**	0.25**	0.99							
(11)	0.18*	0.12	0.20**	0.30**	0.29**	0.25**	0.25**	0.11	0.07**	0.40**	0.99						
(12)	0.42**	0.31**	0.34**	0.48**	0.38**	0.39**	0.47**	0.41**	0.33**	0.55**	0.41**	0.99					
(13)	0.40**	0.30**	0.37**	0.37**	0.33**	0.42**	0.32**	0.22**	0.19**	0.54**	0.36**	0.40**	0.99				
(14)	0.35**	0.19*	0.29**	0.38**	0.37**	0.45**	0.35**	0.30**	0.27**	0.50**	0.33**	0.52**	0.52**	0.99			
(15)	0.37**	0.22**	0.48**	0.49**	0.53**	0.54**	0.43**	0.39**	0.42**	0.50**	0.33**	0.45**	0.42**	0.42**	0.99		
(16)	0.52**	0.42**	0.35**	0.38**	0.29**	0.43**	0.50**	0.41**	0.28**	0.41**	0.24**	0.45**	0.40**	0.40**	0.43**	0.99	
(17)	0.28**	0.24**	0.25**	0.25**	0.19*	0.30**	0.33**	0.14	0.12	0.21**	0.22**	0.31**	0.37**	0.19*	0.31**	0.50**	0.99

A ** indicates significance at the 0.01 level and a * indicates significance at the 0.05 level.

The variables are:

Common Practices	TQM Baisc Techniques	JIT Basic Techniques	TPM Basic Techniques
Comm Lead (1)	Proc Mgmt (6)	Set-up Red (10)	Maintain (15)
Strat Pln (2)	X Design (7)	Pull Prod (11)	Tech Emp (16)
X Train (3)	Supp Mgmt (8)	JIT Delv (12)	Prop Eqp (17)
Emp Invol (4)	Cust Inv (9)	Equip Lay (13)	
Info_Feed (5)		Sked_Adh (14)	

unit cost, inventory, conformance quality, product reliability and capability, on-time delivery, cycle time, volume flexibility, and mix flexibility. The plant managers responded to the items that can be used to measure performance by comparing their plant's operation with that of its industry competitors on a global basis. These items are measured on a semantic differential scale of 1 to 5 where a value of 3 represents average performance (see Appendix B).

We can observe from Table 6-7 that the means of the performance variables are all greater than 3. There may be a tendency towards an upwardly biased assessment of performance. However, the relatively good performance can be expected since half of the manufacturing plants included in the WCM database were randomly selected from lists of excellent plants as discussed in section 6.1. Moreover, comparing our measures with those in existing Operations Management studies suggests that we need not be concerned, for example, Jayaram's et al. (1999) study have performance means greater than 4.9 on a scale of 1="poor" to 7="excellent".

There is significant difference in the level of performance between manufacturing plants with world-class reputation and the more traditional plants (Table 6-7). The world-class plants have higher levels of performance across all performance measures being used in this study. Consistency of this result with existing studies and industry reports is reassuring and provides some support for the validity and reliability of the performance measures.

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Table 6-7. Means of Performance Variables by Plant Type

Variables	All	World-Class	Traditional	P-value of F-test
Unit Cost Efficiency	3.32	3.46	3.18	0.028
Inventory	3.23	3.42	3.04	0.012
Conformance Quality	3.99	4.22	3.75	0.000
Reliability and Capability	3.98	4.19	3.76	0.000
On-time Delivery	3.75	3.98	3.51	0.001
Cycle Time	3.33	3.54	3.10	0.001
Volume Flexibility	3.69	3.88	3.49	0.001
Mix Flexibility	3.78	3.93	3.63	0.019

Note: The p-value indicates result of F-test of mean performance differences across the two plant types.

The performance measures exhibit some country differences. Japanese plants perform significantly better in three performance measures than some plants in the other countries (Table 6-8). Means of the performance measures do not differ significantly across industry groups tough manufacturing plants in the automobile parts supplier industry consistently have slightly higher mean performance in six of the measures (Table 6-9). Industry differences cannot be examined from the performance measures since survey informants were asked to compare the performance of their plants with competitors in the same industry. Furthermore, as discussed in Chapter 5 we will not be able to evaluate country and industry differences and make generalizable conclusions due to small sample size, thus, we control for possible differences in the performance measures by standardizing the variables by country and industry. We also replace four missing values with their respective country-industry mean.

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Table 6-8. Means of Performance Variables by Country

Variables	Germany	Italy	Japan	U.K.	U.S.	P-value
Unit Cost Efficiency	3.44	3.12	3.49	3.15	3.30	0.239
Inventory	3.03	3.12	3.22	3.35	3.53	0.288
Conformance Quality	3.79	3.79	4.33	3.65	4.13	0.004
Reliability and Capability	3.85	3.88	4.35	3.85	3.76	0.002
On-time Delivery	3.67	3.50	4.07	3.65	3.70	0.072
Cycle Time	3.33	3.06	3.43	3.35	3.43	0.362
Volume Flexibility	3.76	3.76	3.72	3.40	3.67	0.499
Mix Flexibility	3.79	3.88	3.74	3.45	3.93	0.301

Note: The p-value indicates result of F-test of mean performance differences across country groups.

Table 6-9. Means of Performance Variables by Industry

Variables	Auto Parts	Electronics	Machinery	P-value
Unit Cost Efficiency	3.39	3.38	3.20	0.419
Inventory	3.38	3.15	3.17	0.719
Conformance Quality	4.07	3.96	3.93	0.649
Reliability and Capability	3.92	4.04	3.98	0.330
On-time Delivery	3.89	3.70	3.65	0.353
Cycle Time	3.49	3.24	3.24	0.226
Volume Flexibility	3.87	3.59	3.59	0.096
Mix Flexibility	3.85	3.80	3.69	0.556

Note: The p-value indicates result of F-test of mean performance differences across industry groups.

Manufacturing performance has often been modeled in Operations Management studies as a weighted average of several performance dimensions where the weights usually represent the strategic importance of the dimensions (Cleveland et al., 1989; Vickery, 1991; Vickery et al., 1993; Bozarth and Edwards, 1997). This is akin to the latent variable composite score obtained from formative or cause indicators.

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If we follow the tradeoff perspective of manufacturing performance (Skinner, 1969; Porter, 1980), it is reasonable not to model manufacturing performance using reflective or effect indicators since overall performance does not define improvement or deterioration of specific performance dimensions. However, there are concerns associated with using the formative mode (Bollen and Lennox, 1991) in representing manufacturing performance. There is no consensus on what is a complete set of performance measures (Corbett and Van Wassenhove, 1993; Swink and Hegarty, 1998), hence it is difficult to have a convincing census of measures needed in the formative mode. While high correlations of reflective indicators are desired, high correlations of formative indicators are indicative of multicollinearity problems.

The bivariate correlations of the performance variables seem to reflect internal consistency among several variables (Table 6-10) as desired in modeling latent variables using reflective indicators. However, exploratory factor analysis using maximum likelihood estimation extracted three factors with low variance explained (Table 6-11). While the first factor seem to indicate that the performance measures form one factor, examination of the second factor reveal that quality and flexibility can also be negatively related. The third factor may indicate that cost efficiency, inventory, on-time delivery and cycle time constitutes one factor, however, a separate factor analysis of these variables extracted one factor with low variability explained of 41% indicating that together the variables constitute more error variance than what a factor can capture.

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Table 6-10. Correlations of Performance Variables

Variables		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Unit Cost Efficiency	(1)	1							
Inventory	(2)	0.334**	1						
Conformance Quality	(3)	0.255**	0.273**	1					
Reliability and Capability	(4)	0.067	0.124	0.526**	1				
On-time Delivery	(5)	0.242**	0.421**	0.422**	0.138	1			
Cycle Time	(6)	0.345**	0.578**	0.332**	0.251**	0.408**	1		
Volume Flexibility	(7)	0.285**	0.305**	0.273**	0.188*	0.414**	0.242**	1	
Mix Flexibility	(8)	0.167*	0.188*	0.170*	0.139	0.229**	0.197*	0.530**	1

A ** indicates significance at the 0.01 level and a * indicates significance at the 0.05 level.

Table 6-11. Exploratory Factor Analysis of Performance Variables

	Factors		
Variables	1	2	3
Unit Cost Efficiency	0.339	-2.55E-02	0.314
Inventory	0.363	-2.65E-02	0.67
Conformance Quality	0.798	0.602	-1.06E-03
Reliability and Capability	0.447	0.281	-6.54E-03
On-time Delivery	0.524	6.63E-03	0.326
Cycle Time	0.361	7.49E-02	0.675
Volume Flexibility	0.798	-0.602	-9.74E-04
Mix Flexibility	0.439	-0.299	5.62E-02
Variance Explained	28.96%	11.26%	13.91%

Given the empirical results above and the common manner of using composite measure to represent manufacturing performance we will use a strategically weighted composite measure of manufacturing performance. Since there is no consensus on what will constitute a complete measure of manufacturing performance, we choose to use one measure per performance dimension to avoid redundancy or multicollinearity among measures.

The measures of unit cost efficiency, conformance quality, on-time delivery, and volume flexibility are the most common measures for the four basic dimensions of

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manufacturing performance. Interviews with managers at the three plants that we visited reveal that these performance measures are the most straightforward and often used benchmarks. For traditional plants, inventory may not even be considered as a cost. The measure of product reliability capability may have more variability across plants since product features differ extensively. While on-time delivery is expected for all orders, cycle time is more dependent on the complexity of the product. Some managers believe that mix flexibility is a variable that can be highly affected by manufacturing capability as well as market demand and the strategic intent of the plant.

While inventory, product reliability and capability, cycle time and mix flexibility may not be as easily measured as their corresponding measures of the four basic performance dimensions, it is reassuring to observe that they are generally most highly correlated with unit cost efficiency, conformance quality, on-time delivery, and volume flexibility respectively (Table 6-10). Thus, we will use the latter four variables in our subsequent analysis together with a strategically weighted performance measure defined by these four variables (Appendix B). The strategic weights are calculated from the rankings on the importance of different manufacturing objectives as provided by informants in the WCM database. Since all of the performance variables have standardized skewness and standardized kurtosis statistics of less than 2, we do not further transform these variables to satisfy univariate normality for subsequent analysis.

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6.5. CONTEXTUAL VARIABLES

In Chapter 5 we discussed the contextual factors that will be included in empirical tests of hypotheses and these are plant size, capacity utilization and type of production process. The items in the WCM database that can be used to measure these contextual factors are in Appendix B and their mean values by country and industry are given in Table 6-12 and Table 6-13 respectively.

Table 6-12. Means of Contextual Variables by Country

Variables	Germany	Italy	Japan	U. K.	U. S.	All	P-value
Hourly Employees	704	292	1276	951	359	754	0.052
Salaried Employees	297	355	661	552	174	426	0.114
Total Employees	1001	647	1937	1503	533	1180	0.018
PROCESS TYPE							
One-of-a-kind (%)	14	13	15	8	10	13	0.797
Small Batch (%)	34	39	16	45	20	29	0.000
Large Batch (%)	25	20	6	13	19	16	0.014
Repetitive/Line Flow (%)	11	24	34	32	39	28	0.017
Continuous (%)	15	4	28	1	12	14	0.002
Capacity Utilization (%)	88	79	79	76	77	80	0.060

Note: The p-value indicates result of F-test of mean contextual differences across country groups.

Table 6-13. Means of Contextual Variables by Industry

Variables	Auto Parts	Electronics	Machinery	All	P-value
Hourly Employees	1256	509	492	754	0.026
Salaried Employees	467	608	202	426	0.030
Total Employees	1724	1116	693	1180	0.052
PROCESS TYPE					
One-of-a-kind (%)	6	11	22	13	0.000
Small Batch (%)	23	30	33	29	0.171
Large Batch (%)	22	14	11	16	0.075
Repetitive/Line Flow (%)	26	30	28	28	0.787
Continuous (%)	23	15	5	14	0.012
Capacity Utilization (%)	77	83	80	80	0.149

Note: The p-value indicates result of F-test of mean contextual differences across industry groups.

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Number of employees is commonly used as a measure for the size of an organization (e.g., Kraft et al., 1995; McKone et al., 1999; White et al., 1999). We use the sum of the number of hourly and regular salaried employees as a measure of plant size since many plants rely heavily on both types of employees as evidenced by their distribution in Table 6-12 and Table 6-13. In preparation of this variable for subsequent analysis, we perform the natural logarithmic transformation on this variable so that its values will be normally distributed. Moreover, from a conceptual standpoint the relationship between organization size and structure is not linear because increasing size creates a *critical mass* that changes an organization from less centralized and formalized to highly centralized or formalized (Ahmad, 1998).

The distribution of process types in Table 6-12 and Table 6-13 suggests that manufacturing plants use multiple types of production processes. This can be expected since some manufacturing plants produce a wide variety of products that entail different types of processes. Thus, we calculate a weighted sum of the proportion of volume produced using the different process types. The resulting variable, process type = 5 * one-of-a-kind % + 4 * small batch % + 3 * large batch % + 2 * repetitive/line flow % + 1 * continuous %, represents the extent to which the production process is continuous or discrete. The higher the value of process type the more discrete the production process. This variable does not exhibit significant departure from normality, thus we do not transform the variable.

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We measure capacity utilization by an objective item that asks the informant to indicate the average percentage of plant capacity utilization in the past year. Since this variable is not normally distributed, we will use the squared value of this variable in subsequent analysis following suggestions from optimal Box-Cox transformation. Furthermore, the squared transformation is appropriate in that we can expect decreasing rate of return when effective capacity utilization is close to the theoretical or design optimum capacity.

Examination of Table 6-12 and Table 6-13 reveals that there are country and industry differences in the level of the contextual variables. Japan and the United Kingdom have larger plant sizes while Germany has a higher percentage of capacity utilization. Japan uses more continuous production process than the other countries. Plants in the machinery industry hire significantly fewer employees than plants in the other industries. There is no obvious difference in capacity utilization across industry. The automobile parts suppliers tend to use a higher percentage of continuous process while plants in the machinery industry have more one-of-a-kind production. Thus, to account for country and industry differences in the contextual variables that may affect these variables' relation with manufacturing performance we standardize the variables by country and industry. We also replace about 7% missing values across the three contextual variables with their respective country-industry mean values.

In this chapter we are able to summarize how we screen and develop our data into forms appropriate for use in subsequent analysis. Whenever necessary we

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transform and standardize the variables so that they do not show significant departure from a normal distribution. We also provide evidence for the reliability and validity of our scale measures. Now that we have data suitable for empirical analysis, we will discuss the methodologies and results of tests of hypotheses in the next chapter.

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CHAPTER 7
METHODS AND RESULTS OF EMPIRICAL ANALYSIS

The focus of this chapter is the empirical analysis that is conducted using data from 163 manufacturing plants in the WCM database. We first discuss the methodologies used in the analysis. Then we present the analysis results and discuss whether they support the hypotheses that were stated in Chapter 5.

7.1. METHODS OF ANALYSIS

In Chapter 5 we delineated the different approaches and their associated statistical methods for testing hypotheses formulated on the basis of the concept of fit. In the following sections we discuss how different statistical methods are used in this study and how results obtained using these methods can be evaluated. The statistical methodologies used are multiple regression analysis, discriminant analysis, and structural equation modeling.

7.1.1. Multiple Regression Analysis

Regression analysis is a widely used methodology in social science research. In this study we use multiple regression analysis to examine the effect of fit of manufacturing practices on performance when fit is modeled using the profile deviation approach. Fit or more appropriately misfit can be operationalized as the weighted Euclidean distance in a multidimensional space between a point defined by

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the ideal profile and a point representing an experimental unit (Drazin and Van de Ven, 1985).

For this study, the ideal profile corresponds to the highest level of combined implementation of the 17 Integrated Manufacturing Practices and is represented by the value "5" in the survey items used to measure manufacturing practices implementation. Since as discussed in Chapters 2 to 4 each of the 17 practices can contribute to good performance, we do not differentiate the weights or degrees of contribution to misfit that can result from varying levels of implementation of these practices. Overall, larger distance or deviation from the ideal profile signifies greater misfit and can be calculated according to the following formula:

$$\mathrm{MISFIT}_j = \sqrt{\sum_{k=1}^{17} W_{jk}(X_k - X_{jk})^2} = \sqrt{\sum_{k=1}^{17} (5 - X_{jk})^2}$$

where,

MISFIT_j = deviation of a particular plant j from an ideal plant type

X_{jk} = score for the *k*th variable of a particular plant j

X_k = score for the *k*th variable of the ideal plant type = 5

W_k = weight of the *k*th variable = 1

k = index for the 17 variables

After standardizing by country and industry, the misfit variable is related to five manufacturing performance variables through regression analyses. A significant negative relationship between misfit and performance would support a hypothesis that considers fit of practices to be positively associated to performance. Since contextual differences may account for performance differences, we also use a hierarchical

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regression approach to determine the contribution of contextual variables on performance and the relationship between misfit and performance after accounting for contextual differences.

We evaluate the regression models to determine if assumptions of independence of predictors, linearity, normality, and homoscedasdicity are satisfied. While the predictor variables are not completely independent there is no substantial collinearity among them since all variance inflation factors are less than 1.30 and there is no autocorrelation since the data are cross-sectional. There is no significant evidence that the condition of linearity is violated. Normal probability plots of residuals for each regression model show points that cluster close to a straight line with a 45 degree inclination. Plots of residuals against predictor and response variables suggest that constancy of error variance is not violated.

7.1.2. Discriminant Analysis

Some researchers have used discriminant analysis to understand the concept of fit when fit is approached as gestalts and when the groupings of observations have been identified (e.g., Hambrick, 1983). Discriminant analysis allows understanding of group membership and investigation of group differences with respect to several factors simultaneously (Hair et al., 1998). There are two types of discriminant analysis based on the purpose of analysis, i.e., predictive discriminant analysis and descriptive discriminant analysis. This study adopts the descriptive approach since the objective

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is to reveal major differences among the groups of manufacturing plants with high and low performance and not to predict group membership.

Since the performance measures are standardized by country and industry a manufacturing plant is classified as either a high or low performer depending on whether its score is higher or lower than the country-industry mean respectively. The number of plants classified as high or low performers in the five performance measures discussed in Chapter 6 is provided in Table 7-1. High and low performers are coded as belonging to group 1 and 0 respectively in the discriminant analysis.

Table 7-1. Group Sizes in Discriminant Analysis

	Cost Efficiency	Conformance Quality	On-time Delivery	Volume Flexibility	Weighted Performance
Low Performer-Group 0 Size	92	71	70	69	80
High Performer-Group 1 Size	71	92	93	94	83
Total Sample Size	163	163	163	163	163

The explanatory variables used in discriminant analysis are the 17 Integrated Manufacturing Practices and the three contextual variables described in Chapter 6. We evaluate these variables to determine if the assumptions of discriminant analysis such as multivariate normality, equal dispersion matrices, lack of multicollinearity, and linearity of relationships are met.

As discussed in Chapter 6, these variables have been transformed to adjust for departures from univariate normality where necessary. While there is moderate departure from multivariate normality on the basis of the critical ratio of Mardia's coefficient of joint multivariate kurtosis and skewness, there are no significant outliers upon examination of the Mahalanobis distances. Since it is difficult to achieve

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multivariate normality and there have been criticisms on the sensitivity of Mardia's coefficient, we proceed with the analysis and make certain that the group predictions made by the discriminant analysis are acceptable on the basis of other measures.

Box's M tests are not significant (p-values > 0.05) for the analyses involving the four basic performance measures, thus there is insufficient evidence to reject homogeneity of variance-covariance matrices of the explanatory variables for the performance groups. While the test of homogeneity of variance-covariance matrix for the analysis involving the weighted performance measure is significant, classification results obtained using within and separate groups covariance matrices are the same and Box's M test of the homogeneity of variance-covariance matrix of the discriminant functions is not rejected. Thus, we use within groups variance-covariance matrix for classifying the cases to the two performance groups.

Variance inflation factors of the explanatory variables are all less than 3.05 and do not exhibit serious problem of multicollinearity. Some of the explanatory variables are not linearly related to the grouping variable. We realize that the result of discriminant analysis will not depict the total relationship between the variables since nonlinear relationships are not captured. Overall, there is no significant violation of the assumptions of discriminant analysis.

First, we run a set of five models of discriminant analysis, one for each of the five performance measures and use the practice variables as explanatory variables to determine the contribution of practices in differentiating between high and low

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performers. Then, we run two sets of five models that are similar to taking a hierarchical regression approach. In the first set we only include the contextual variables and in the second set we add the practice variables. The five models in each set correspond to the five performance measures. The use of two sets of analyses allows us to determine whether or not contextual variables and implementation of manufacturing practices discriminate between high and low performers and also helps us determine whether the practices add significant explanation to performance variation after accounting for contextual differences.

In discriminant analysis, the explanatory variables are weighted and combined linearly to form a discriminant function that classifies observations into the predetermined groups with as much separation between the groups as possible. Smaller values of Wilks' lambda indicate larger between group dispersion and greater implied significance of the discriminant function. Chi-square tests are used to provide approximate significance test of Wilks' lambda. Significant chi-square differences between corresponding models with and without the manufacturing practice variables can be used as evidence that the practices provide significant improvement in discriminating between high and low performers after accounting for contextual differences.

Another way of measuring a model's discriminating power is by assessing the percentage of manufacturing plants that are correctly classified into the high and low performance groups. Since the group sizes are unequal (see Table 7-1), group sizes

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are used as prior probabilities for classification and the proportional chance criterion (C_{pro}) is used for assessing predictive accuracy of discriminant function. When the hit ratio or percentage of correct classification is at least 25% greater than the corresponding chance-based proportion C_{pro} a model is considered to have an acceptable level of classification accuracy (Hair et al., 1998). Moreover, percentages of correct classification using a jackknife approach to the discriminant analyses can also be compared with C_{pro}. While we are not interested in making predictions, we would want to have good classification results to give us more confidence in the overall results of discriminant analysis.

To determine the importance of each explanatory variable in differentiating between groups, researchers have increasingly used discriminant loadings (also referred to as structure correlations or coefficients) as a basis of interpretation (Pedhazur, 1982; Hair et al., 1998). The discriminant loadings can be deduced like factor loadings in assessing the relative contribution of each explanatory variable to the discriminant function. A variable with discriminant loading of at least 0.30 in absolute value is considered a substantive discriminator worthy of note (Hair et al., 1998), however, a more stringent cutoff of 0.40 is usually used in determining significance of factor loadings (Carmines and Zeller, 1979). In this study, we adopt the higher cutoff of 0.40 in considering the contribution of explanatory variables in differentiating performance.

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7.1.3. Structural Equation Modeling

When fit is modeled as covariation, the recommended method of analysis is exploratory or confirmatory factor analysis (Venkatraman and Grant, 1986). In order to explicitly model the structure of a second-order factor signifying the coalignment of first-order factors, we take a confirmatory factor analysis approach using Structural Equation Modeling (SEM). We also extend the second-order factor model to four structural models relating the coalignment of practices to the four basic manufacturing performance measures. The coalignment model (Figure 7-1A) is compared to models that reflect other possible relationships between practices and performance, such as direct relationship between common practices and basic techniques with performance (Figure 7-1B), and indirect relationship between common practices and performance through the basic techniques (Figure 7-1C).

We verify that the assumptions required for SEM are met. The observed variables exhibited moderate departure from multivariate normality, however, Mahalanobis distances of the observations do not indicate existence of significant outliers. For each of the models, maximum likelihood estimation is used since this method of estimation has been found to be robust against moderate non-normality when the variables are continuous. All estimations converge and all models are identified and have positive residual variances. Chi-square plots of all residuals do not exhibit systematic curvature.

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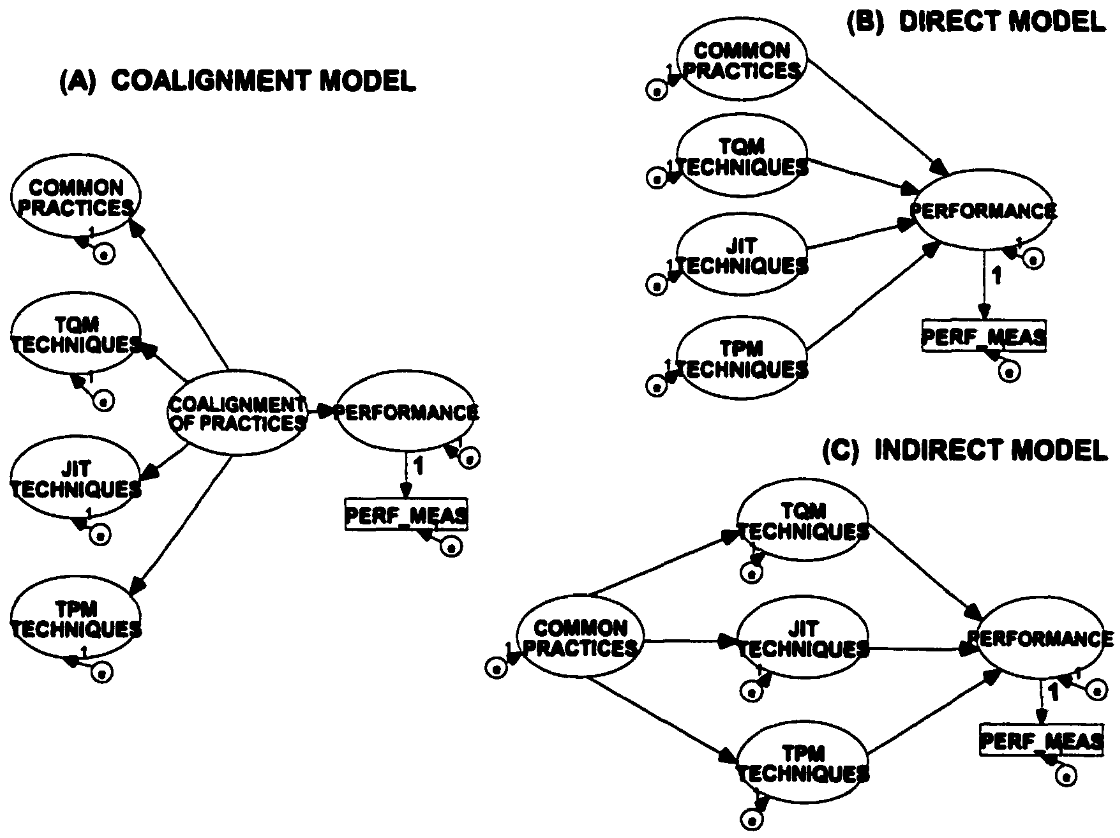
An issue of much debate in SEM is the evaluation of model fit. Every index of model fit has fundamental flaws in that it collapses the multifaceted notion of fit into a single number (Hayduk and Glaser, 2000; Steiger, 2000). There are also disagreements on the validity and usefulness of many rules of thumb used to determine what constitutes a good model (Hu and Bentler, 1999; Little et al., 1999; MacCallum et al., 1999). Moreover, it is unclear how the heuristics for assessing fit established in one field of study can be applied to evaluate models in a different context of research.

Figure 7-1. Models of Effect of Practices on Performance



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While there exist many disagreements on how to assess model fit we do not suggest that the issue of fit be avoided. Rather, we support the arguments of using multiple fit measures and that no strict universal cutoffs of fit should be used without consideration of the "reasonableness" and substantive contribution of a model.

We also examine the residuals to alleviate some of the problems associated with using fit indices. When the residuals are small the model is clearly good no matter what the chi-square test or fit indices seem to imply (Hu and Bentler, 1995). Standardized residuals with absolute values less than 2.58 are considered small (Bryne et al., 1989). Jöreskog (1993) notes that well-fitted models will be characterized by standardized residuals that generally cluster symmetrically close to zero with a few in the tails. Thus, it will not be surprising to have a few standardized residuals greater than 2.58 in a model with good fit.

To provide a more comprehensive model assessment we use different types of fit indices--absolute, relative and parsimonious fit indices. We choose indices that are more appropriate for small samples. Following are the seven indices that we use as measures of model fit whenever applicable.

(1) An absolute measure of fit is the normed chi-square. In light of problems associated with the χ^2 statistic, it has been proposed as a badness measure of fit rather than a goodness-of-fit measure in the sense that a small χ^2 relative to its degrees of freedom is indicative of good fit whereas a large χ^2 reflects bad fit (Jöreskog and Sörbom, 1993; MacCallum et al., 1996). A value of less than 3 for the normed chi-

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square indicates good fit (Carmines and McIver, 1981), but values in the range (3, 5) are also acceptable (Jöreskog, 1970; Wheaton et al., 1977; Marsh and Hocevar, 1985).

(2) Another measure of absolute fit is the Root Mean Square Residual (RMR). The RMR is the square root of the average squared amount by which the sample covariances differ from their estimates under the assumption that the model is correct. In a well-fitting model, the standardized RMR will be about 0.05 or less (Bryne, 1998).

(3) Bentler (1990) recommends the Comparative Fit Index (CFI) as the relative index of choice. The CFI is computed by comparing a model's fit to that of its corresponding independence or null model. The CFI has been found to be more appropriate in a model development strategy or when a smaller sample is available (Rigdon, 1996). A model is believed to exhibit acceptable fit when CFI is at least 0.90 (Bentler, 1992).

(4) Another relative fit index is the Incremental Fit Index (IFI) developed by Bollen (1989a) to address the issues of parsimony and sample size in comparing a model with its baseline model. Similar to CFI, it ranges in value between 0 and 1 with values close to 1 indicating good fit. There is no established cutoff for IFI but values of relative fit indices that are at least 0.90 are generally considered to exhibit good fit (e.g., Hull et al., 1991).

(5) An adjusted measure of fit is the Parsimonious Normed Fit Index (PNFI). The PNFI is an adjustment to Bentler-Bonnet's (1980) Normed Fit Index by taking

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into account the number of degrees of freedom used to achieve a level of fit. Mulaik et al. (1989) suggest that goodness of fit indices in the range of 0.90 accompanied by parsimonious fit indices in the range of 0.50 are not unexpected. When comparing between models, differences of 0.06 to 0.09 in PNFI are indicative of substantial model differences (Williams and Holahan, 1994).

(6) Another parsimonious fit index is Bozdogan's Consistent Akaike Information Criterion (CAIC). The CAIC can be used to compare non-nested models where the model with a smaller CAIC is the better fitting model (Maruyama, 1997).

(7) The relation between the fit of a first-order structure and the corresponding fit of a nested, more restrictive model such as a higher order factor structure can be examined using the target coefficient (T) proposed by Marsh and Hocevar (1985). This index is the ratio of the chi-square of the first-order model to the chi-square of the more restrictive model. As with other relative fit indices such as CFI and IFI, the target coefficient has an upper limit of 1, which would only be possible if the relations among the first-order factors could be totally accounted for in terms of the more restrictive model. The application of the target coefficient has the advantage of separating lack of fit due to the second-order structure from lack of fit in the definition of first-order factors. When T is at least 0.90, the higher order structure is chosen over the first-order model because of its more parsimonious representation (see for example Venkatraman, 1990; Segars et al., 1998).

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We assess model fit by using a combination of the indices discussed above and by examining residuals. While we recognize the popular cutoffs for good fit, we do not follow the rules of thumb strictly. Models should be assessed in the context of prior studies in the area. Less stringent standards may be acceptable in fields where little research has been done than in areas with more well-developed theory (Bollen and Long, 1993). Since Operations Management is less developed in the application of SEM when compared to Psychology, Marketing and other fields, we consider the overall evidence of fit provided by the different model assessment measures in making conclusions rather than accepting a model only when all the cutoffs for model fit are satisfied. We also make inferences from a model on the basis of significant path coefficients and determine whether or not they are consistent with theoretical evidence.

7.2. RESULTS OF ANALYSIS

In the following sections, we discuss the results of our empirical analysis using the different statistical methodologies described above. The discussion is organized according to the hypotheses that were proposed in Chapter 5. We consider the fit of Integrated Manufacturing Practices, the effect of fit of these practices and the contextual issues affecting manufacturing performance.

7.2.1. Fit of Integrated Manufacturing Practices

The literature and case studies as discussed in the previous chapters support the close interrelation among the Integrated Manufacturing Practices. To empirically test

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the fit of these practices within a single framework, we adopt the fit by covariation approach. We use a second-order factor model to represent the integration of manufacturing practices associated with TQM, JIT, and TPM (Figure 7-2). The second-order factor model has a satisfactory fit (e.g., NChisq=2.19, CFI=0.89, IFI=0.89, PNFI=0.69). The loadings of the first-order factors on the second-order factor are all high and significant at the 0.01 level indicating that there is a common underlying thread among the practices.

While the factors of *common practices* and *TQM techniques* have very high loadings on the second-order factor they do not cause serious concern since the factor loadings of *JIT and TPM techniques* are also high. We compare this second-order factor model (Figure 7-2) to a simplified model (Figure 7-3) having three factors wherein *common practices* and *TQM techniques* are combined. The difference in the PNFI values of the two models is 0.02 and is less than the 0.06 cutoff used to determine significant model differences (Williams and Holahan, 1994). However, the *TPM techniques* factor has a loading of 1.01 in the simplified model indicating an estimation problem.

We retain our original model (Figure 7-2) since for effect indicators there is no reason to prefer indicators with moderate correlations more than those with high correlations (Bollen and Lennox, 1991) and the simplified model does not fit better. However, we recognize that the *common practices* and *TQM techniques* factors cannot be statistically differentiated. The high correlation between these two factors may be

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Figure 7-2. Second-Order Factor Model of Coalignment of Practices

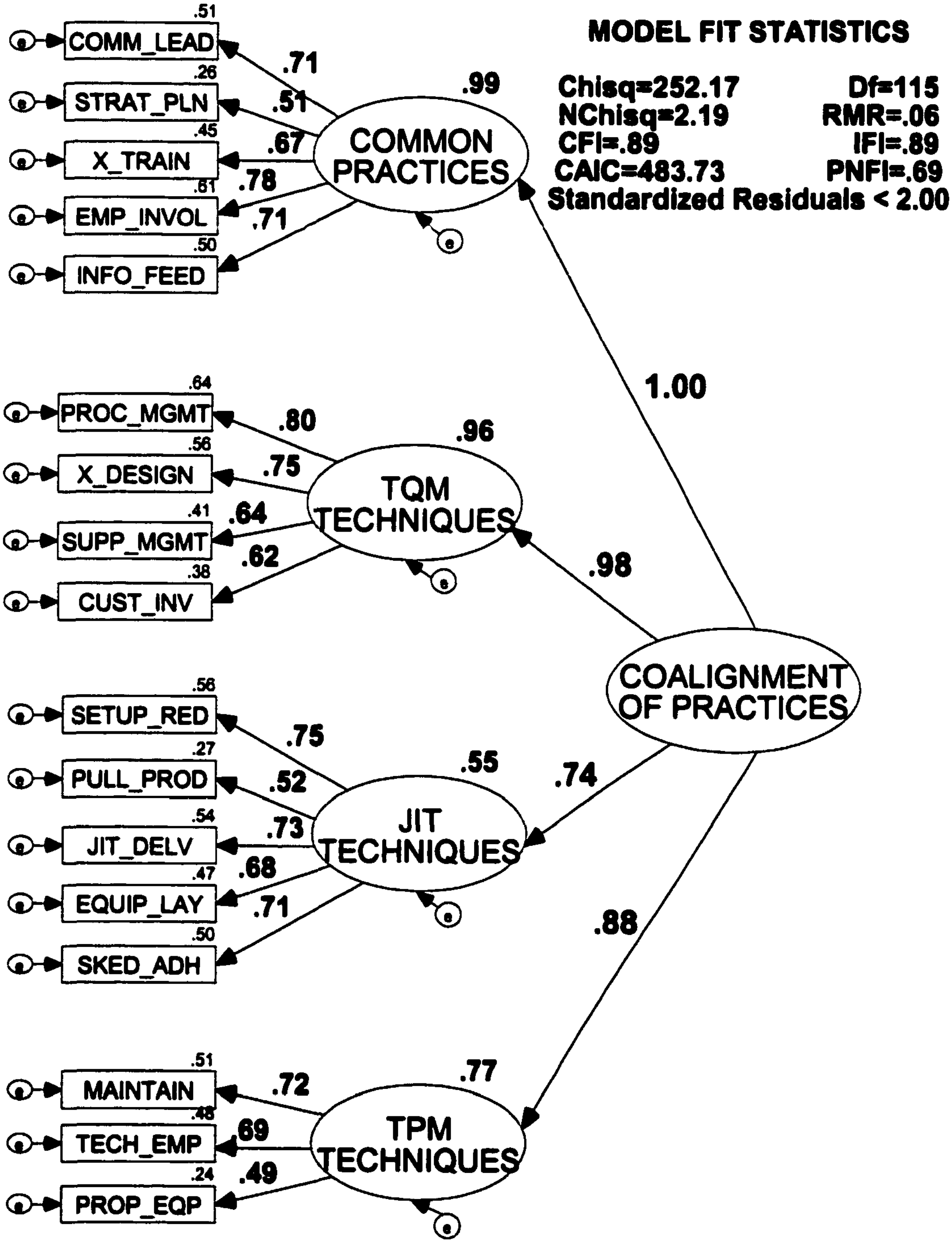

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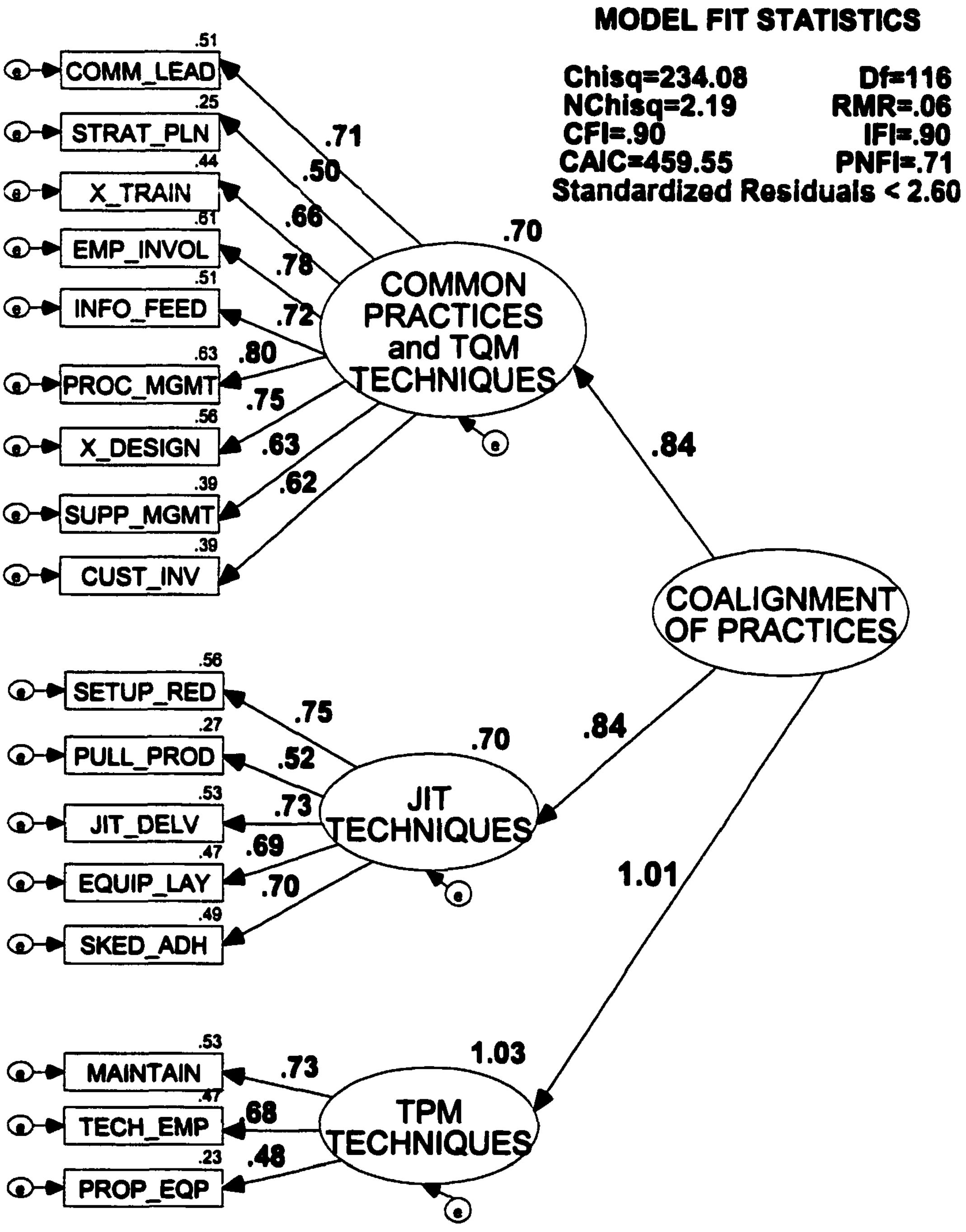
Figure 7-3. Simplified Second-Order Factor Model of Practices



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due to the generally earlier adoption of TQM and common practices than JIT and TPM by the manufacturing plants in the database.

Examination of the modification indices in our original second-order factor model does not reveal problems of cross-loading of practices on factors that they are not conceptually identified to represent. Furthermore, our model fits better than a single first-order factor model (Figure 7-4) because our model's CAIC and standardized residuals are smaller and its PNFI value is significantly larger by 0.06. Thus, the high correlation among practices is not a reflection of a hodge-podge of interrelated practices but rather there is support for modeling the practices with a systemic structure of their conceptual relations. There is statistical evidence that the Integrated Manufacturing Practices can be modeled as having several factors, but at the same time these factors covary and form a single higher order factor. Therefore, this finding is consistent with Hypothesis H1 that construes that the dimensions of the Integrated Manufacturing Practices coalign to form a single factor.

These results strengthen the rationale for using our framework of Integrated Manufacturing Practices in classifying the practices into the four dimensions of common strategic- and human resource-oriented practices and the TQM, JIT, and TPM techniques. This suggests that while confusion exists in the current literature on what constitute the practices of TQM, JIT, and TPM, it is possible to identify the fundamental practices of these programs by segregating them into their common elements and unique techniques. Management should try to implement practices

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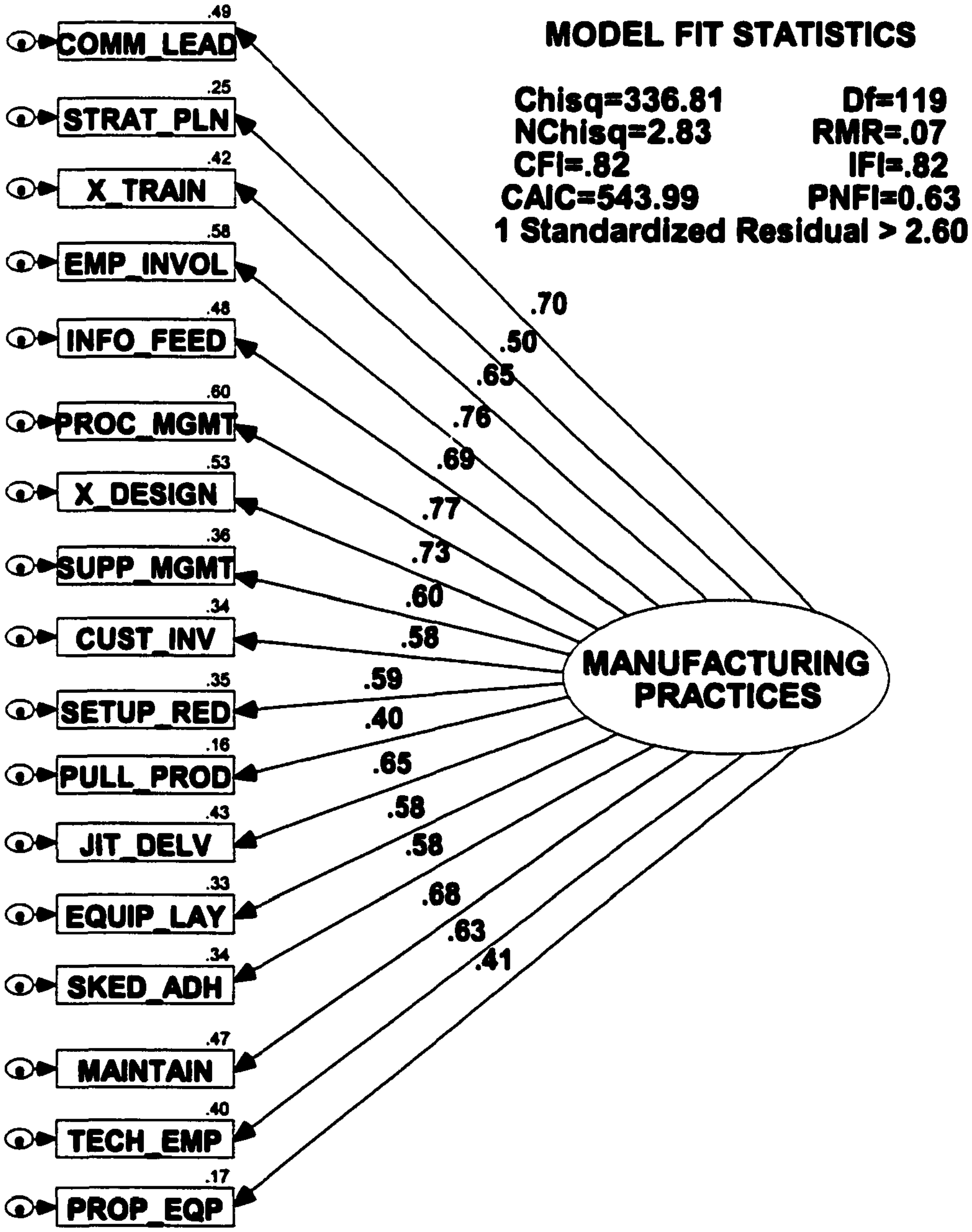
belonging to each of the four dimensions of the Integrated Manufacturing Practices in order to initiate changes in different aspects of the manufacturing operations.

Figure 7-4. Single First-Order Factor Model of Practices



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7.2.2. Effect of Fit of Integrated Manufacturing Practices

Plant managers are interested in the implementation of manufacturing best practices because they are often prescribed as a panacea for poor performance. However, we believe that the practices being implemented should be compatible and directed towards consistent improvement goals. We proposed in Chapter 5 that the Integrated Manufacturing Practices should be consistent and the fit of these practices will be positively associated with manufacturing performance. This proposition can be empirically tested using the three generally accepted methodologies for understanding holistic fit discussed in Chapter 5, namely, fit as covariation, fit as profile deviation, and fit as gestalts (also see Venkatraman, 1989). We use all three approaches to provide methodological triangulation for hypothesis testing and also to understand both the general and specific nature of the effects of coalignment of practices on performance.

Fit as Covariation

We extend the coalignment model discussed in section 7.2.1 to examine the effect of fit or integration of practices on performance so that we can explicitly represent the coalignment of practices as a factor. We find that the combined higher level of implementation of manufacturing practices is positively associated with manufacturing performance. We show the model where cost efficiency is the performance measure in Figure 7-5. The link between coalignment of practices and cost efficiency is positive and significant with a path coefficient of 0.36. The path

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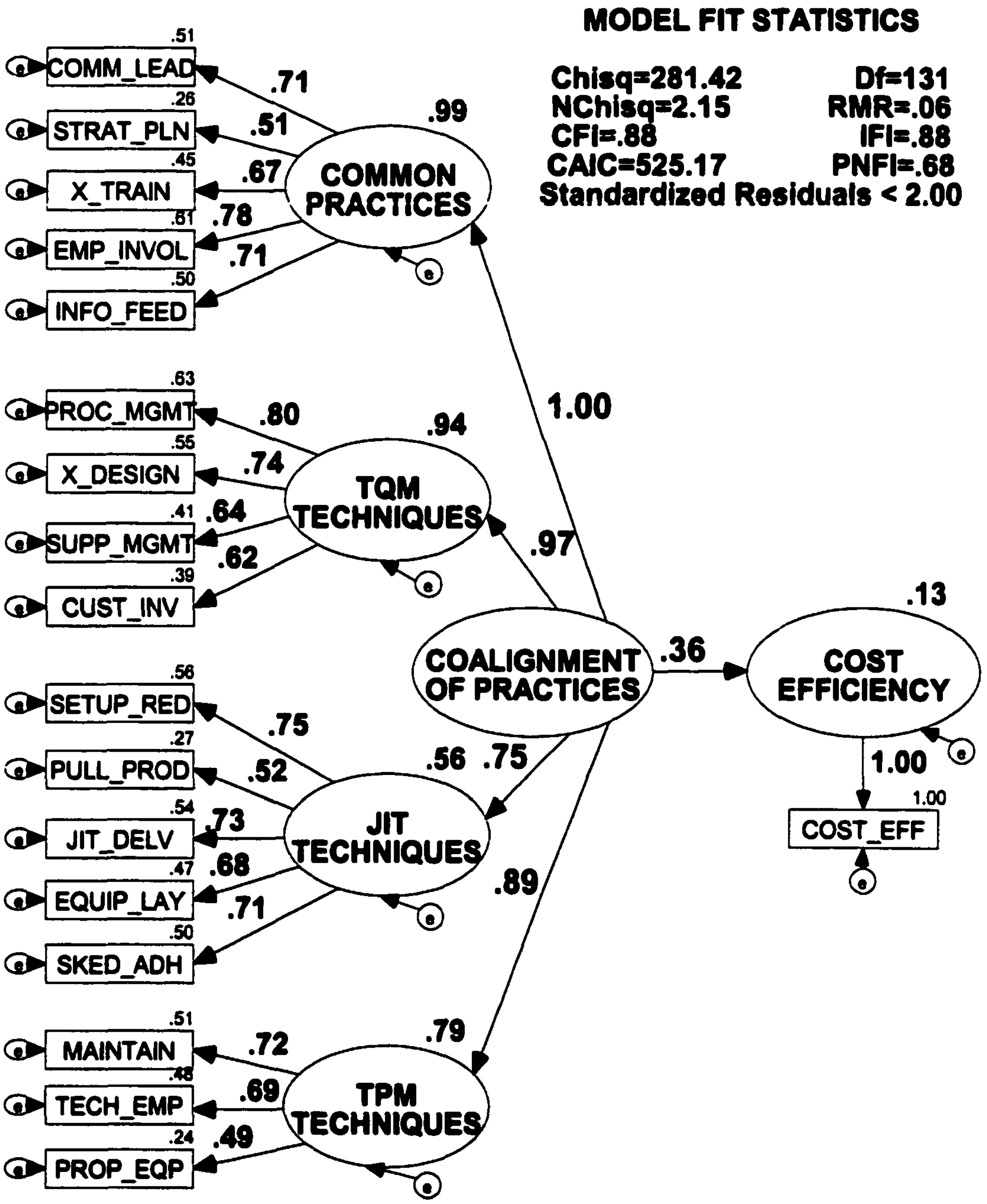
Figure 7-5. Effect of Coalignment of Practices on Cost Efficiency



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coefficients for the measures of the second-order factor of coalignment of practices remain stable with the addition of the performance factor (comparing Figure 7-5 with Figure 7-2).

When the performance factor of cost efficiency is replaced by the other three measures of performance, similar significant positive relations hold between the coalignment of practices and performance factor. The path coefficients between coalignment of practices and performance are 0.37, 0.35, and 0.31 for performance measured by conformance quality, on-time delivery, and volume flexibility respectively (Table 7-2).

When modeling fit by the covariation approach, the coalignment model is often compared to a model that directly relates the first-order factors of practices to performance (e.g., Venkatraman, 1990; Segars et al., 1998). The direct model (Figure 7-6) fits about the same as the coalignment model where cost efficiency is the performance measure. Some of the path coefficients between practices and performance are greater than 1 in the direct effect model, and the variance of cost efficiency is negative signifying a problem with model identification. Moreover, the target coefficient for the comparison of these two models is 0.89 which is close to the heuristic cutoff of 0.90. Thus, we choose to accept the coalignment model for its simplicity and congruence with our conceptual formulation of the relationship between practices and performance.

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Table 7-2. SEM Analyses of Coalignment Model of Effect of Fit

Path Coefficients	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility
COMMON → Comm_Lead	0.71	0.72	0.72	0.72
COMMON → Strat_Pln	0.51	0.52	0.51	0.51
COMMON → X_Train	0.67	0.66	0.67	0.67
COMMON → Emp_Invol	0.78	0.78	0.78	0.78
COMMON → Info_Feed	0.71	0.70	0.71	0.71
TQM TECH→ Proc_Mgmt	0.80	0.79	0.80	0.79
TQM TECH → X_Design	0.74	0.75	0.75	0.75
TQM TECH → Supp_Mgmt	0.64	0.64	0.64	0.64
TQM TECH → Cust_Inv	0.62	0.62	0.62	0.62
JIT TECH → Setup_Red	0.75	0.75	0.75	0.75
JIT TECH → Pull_Prod	0.52	0.52	0.52	0.52
JIT TECH → JIT_Delv	0.73	0.74	0.73	0.74
JIT TECH → Equip_Lay	0.68	0.68	0.68	0.68
JIT TECH → Sked_Adh	0.71	0.71	0.71	0.71
TPM TECH → Maintain	0.72	0.71	0.71	0.71
TPM TECH → Tech_Emp	0.69	0.70	0.70	0.70
TPM TECH → Prop_Eqp	0.49	0.50	0.49	0.49
COALIGN → COMMON	1.00	1.00	1.00	0.99
COALIGN → TQM TECH	0.97	0.98	0.98	0.98
COALIGN → JIT TECH	0.75	0.74	0.75	0.74
COALIGN → TPM TECH	0.89	0.88	0.88	0.88
COALIGN → PERF	0.36	0.37	0.35	0.31

Model Fit Statistics	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility
Chi-square	281.42	285.16	270.88	282.48
Degrees of Freedom	131	131	131	131
Normed Chi-square	2.15	2.18	2.07	2.16
RMR	0.06	0.06	0.06	0.06
CFI	0.88	0.88	0.89	0.88
IFI	0.88	0.88	0.89	0.88
CAIC	525.17	528.91	514.63	526.23
PNFI	0.68	0.68	0.69	0.68
Standardized Residuals	< 2.00	< 2.00	< 2.00	< 2.00
Target Coefficient for Comparing with Direct Effect Model	0.89	0.92	0.90	0.91

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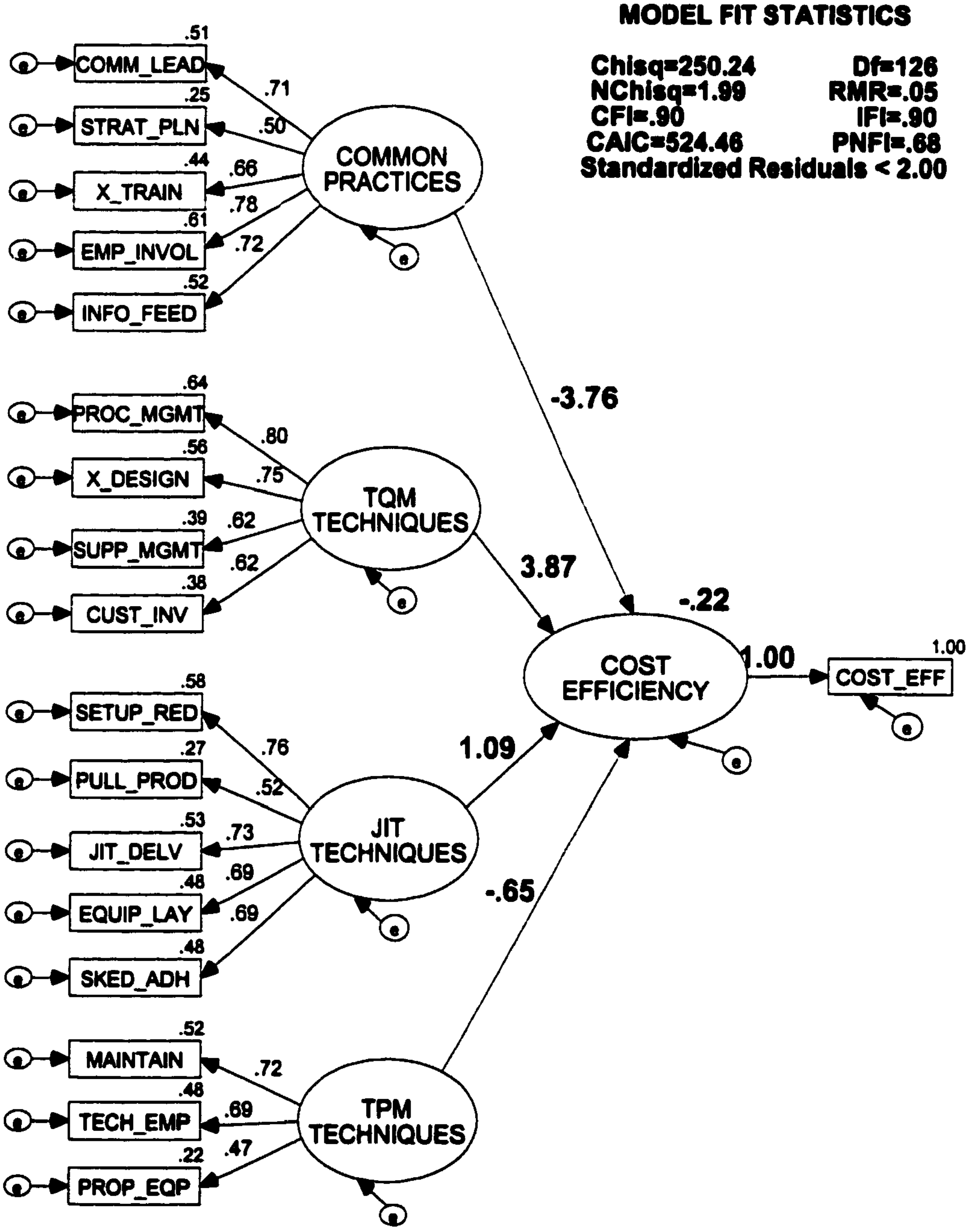
Figure 7-6. Direct Effect of Practices on Cost Efficiency



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The direct effect models involving the other three performance measures are identified and do not have negative variances, however, the path coefficients between practices and performance are not significant. Furthermore, the target coefficients for comparing the direct and coalignment models are 0.92, 0.90, and 0.91 for the models with conformance quality, on-time delivery, and volume flexibility as performance measures, respectively. Therefore, we also choose the coalignment model over the direct effect model for these performance measures.

Another model that can be used to compare with the coalignment model is the indirect model. The common practices are important in the implementation of the basic techniques of TQM, JIT, and TPM and the effect of the common practices may be manifested through their facilitation of the implementation of these techniques. These relationships can be modeled by an indirect effect of the common practices on performance with the basic techniques as intervening variables (see Figure 7-7 for example).

The fit of the indirect model with cost efficiency as the performance measure (Figure 7-7) is about the same as that of the corresponding coalignment model (Figure 7-5), however, the only path coefficient between practices and cost efficiency that is significant is the one for TPM techniques. The corresponding indirect and coalignment models with the other performance measures also fit about the same. The common practices are significantly related to the basic techniques but the path coefficients between practices and performance are not significant. This shows that

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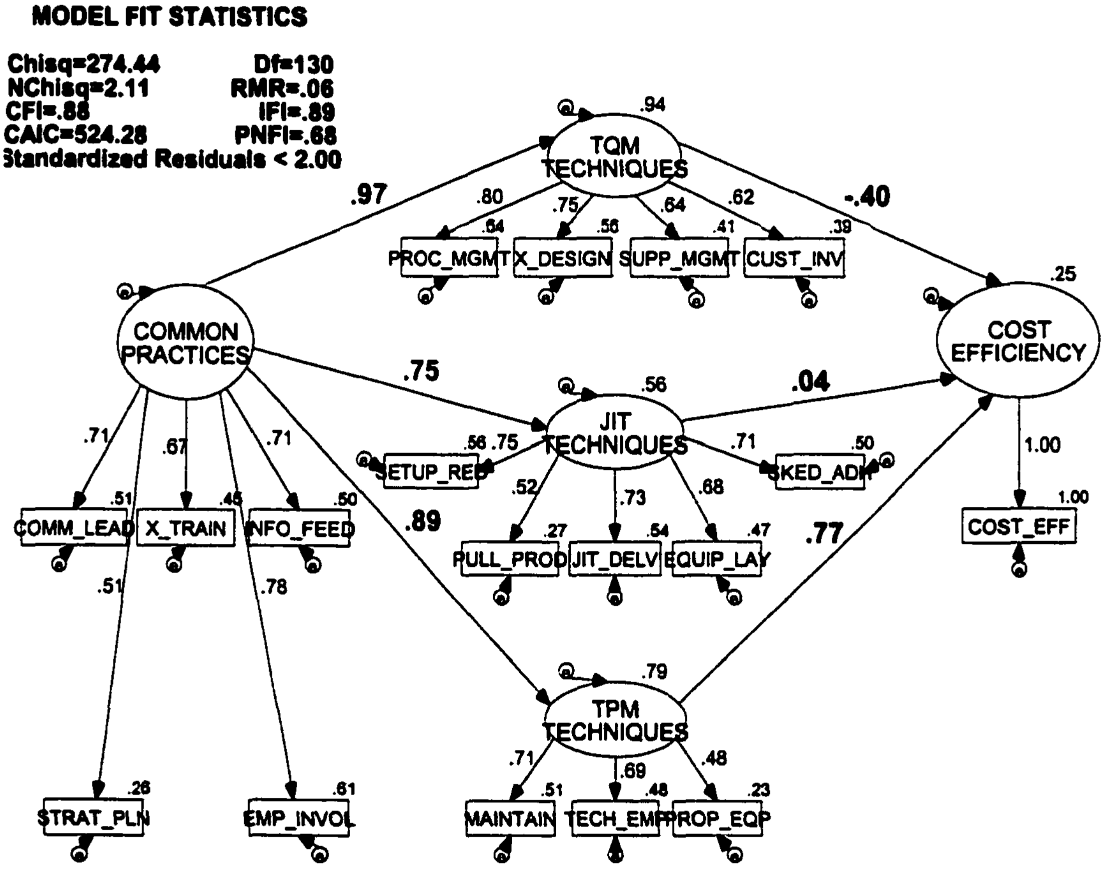
Figure 7-7. Indirect Effect of Common Practices on Cost Efficiency



the effect of common practices on performance may not necessarily be manifested through the basic techniques though the institution of common practices may facilitate the implementation of basic techniques.

The above findings are consistent with the experiences of the manufacturing plants that we visited. The managers believe that there is no particular sequence in the implementation of practices that will optimize the performance of any manufacturing organization but rather coherent and reinforcing practices should be simultaneously

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instituted. Moreover, when the common practices and basic techniques are combined as the coalignment of practices, their joint effect on performance is positive and significant. This is in line with Milgrom and Roberts' (1995) notion of complementarity, that doing more of one thing increases the return of doing more of another. Thus, we believe that the coalignment model is a better representation of the relationship between practices and performance.

Fit as Profile Deviation

The results of hypothesis test using the fit by covariation approach suggest that the combined higher levels of implementation of manufacturing practices is positively associated with manufacturing performance. We want to further investigate whether deviation from the theoretically highest feasible level of implementation of manufacturing practices will have any negative impact on performance. Such examination will provide a better understanding of the importance of optimizing the implementation of manufacturing practices. This can be investigated by the fit as profile deviation approach.

We use regression analysis to statistically model the relationship between performance and the misfit of a plant's level of implementation of practices from the ideal profile. In all five regression analyses (Table 7-3) the term misfit is significant and negatively related to the performance measures. This implies that deviation in the implementation of practices from the theoretical highest level of their implementation will adversely affect performance. While the amount of variation in performance

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captured by the misfit variable may be considered small all five regression equations are significant at the 0.01 level.

Together the results of the covariation and profile deviation approaches to fit suggest that manufacturing plants should not only strive to implement complementary practices but should also aim to achieve a high level of their implementation. This provides empirical support for the positive effect of fit of Integrated Manufacturing Practices on performance as stated in Hypothesis H2a.

Table 7-3. Regression Analyses of Effect of Fit

	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Performance
Misfit	- 0.359 ***	- 0.332 ***	- 0.355 ***	- 0.283 ***	- 0.456 ***
R^2	0.129	0.110	0.126	0.080	0.208
ADJUSTED R^2	0.123	0.104	0.120	0.075	0.203
SIGNIFICANT F	0.000	0.000	0.000	0.000	0.000
*** Sig at 0.01 level					

Fit as Gestalts

We also examine the effect of the implementation of practices on performance using discriminant analysis (Table 7-4). This allows us to determine which specific practices are important in improving particular performance dimensions and help differentiate between high and low performance. All five models of discriminant analysis have discriminant functions that are significant and have acceptable hit ratios that are at least 25% greater than C_{pro} giving us confidence that the significant explanatory variables provide good differentiation between the two performance groups.

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Committed leadership and *emphasis in technology* have significant positive loadings on all five discriminant functions. The support and commitment of management in the institution of new programs has often been heralded as the single most important factor in determining program success. Emphasis in technology acquisition and development reflects the importance given to the manufacturing function. Manufacturing plants that invest in process technology are more likely to use manufacturing as a source of competitive advantage and excel on all performance dimensions.

Cost efficiency and on-time delivery are positively associated with a greater number of practices spanning the three programs of TQM, JIT, and TPM. It is not surprising that the implementation of manufacturing practices that are meant to reduce variability and increase productivity will minimize cost and improve delivery. Conformance quality is more strongly associated with the implementation of common practices and TQM techniques. Volume flexibility has significant positive relation with *committed leadership, customer involvement,* and *technology emphasis* only. The fewer number of variables discriminating between high and low performers in the measure of volume flexibility may be due to the complexity involved in improving volume flexibility as compared to the other performance measures. The number and mix of products being produced can largely affect volume flexibility.

All of the practice variables have significant structure loading on at least one dimension of performance except for *equipment layout and proprietary equipment*

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Table 7-4. Discriminant Analyses of Effect of Fit

Structure Loadings * Sig loading ≥ 0.40	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Perform
Comm_Lead	0.425*	0.668*	0.597*	0.636*	0.650*
Strat_Pln	0.360	0.510*	0.482*	0.245	0.459*
X_Train	0.555*	0.352	0.405*	0.212	0.296
Emp_Invol	0.411*	0.534*	0.472*	0.195	0.279
Info_Feed	0.577*	0.238	0.413*	0.217	0.350
Proc_Mgmt	0.311	0.496*	0.529*	0.314	0.422*
X_Design	0.356	0.484*	0.746*	0.334	0.444*
Supp_Mgmt	0.559*	0.609*	0.552*	0.244	0.428*
Cust_Inv	0.418*	0.369	0.434*	0.526*	0.321
Setup_Red	0.491*	0.243	0.271	0.142	0.169
Pull_Prod	0.441*	0.162	0.326	0.313	0.356
JIT_Delv	0.616*	0.571*	0.468*	0.404*	0.504*
Equip_Lay	0.373	0.251	0.262	0.171	0.357
Sked_Adh	0.314	0.398	0.593*	0.329	0.415*
Maintain	0.538*	0.302	0.477*	0.283	0.359
Tech_Emp	0.514*	0.502*	0.650*	0.544*	0.603*
Prop_Eqp	0.181	0.141	0.244	0.196	0.283

Statistics	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Perform
Sample Size	163	163	163	163	163
Group 0 Size	92	71	70	69	80
Group 1 Size	71	92	93	94	83
Cpro	50.83%	50.83%	51.00%	51.18%	50.02%
Hit Ratio	68.70%	72.40%	69.30%	77.90%	79.10%
Jackknife Hit Ratio	60.10%	64.40%	60.70%	71.20%	74.20%
Canonical Corr	0.450	0.473	0.414	0.510	0.593
(Canonical Corr)^2	0.203	0.224	0.171	0.260	0.352
Wilk's Lambda	0.798	0.776	0.829	0.740	0.649
Chi-square	34.47	38.64	28.67	45.92	65.97
Degrees of Freedom	17	17	17	17	17
Significance	0.007	0.002	0.038	0.000	0.000

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development. While general emphasis on improvement and investment in new and advanced process technology is important across all performance dimensions, the manufacturing plants included in this study may not have emphasized implementation of more specific practices related to equipment design and layout. It appears that the common practices and TQM basic techniques better differentiate high and low performance than JIT and TPM techniques.

For each of the performance dimensions there are different practices that have significant positive loading and these practices belong to the different components of the Integrated Manufacturing Practices—common practices, TQM techniques, JIT techniques, and TPM techniques. While it is not conclusive which particular practices have stronger effects on specific performance dimension, this study shows that there are different configurations of practices that should be implemented depending on the strategic importance attributed to a performance measure.

Moreover, the consistent positive discriminant loadings of the practices signify their compatibility and suggest that improvement should be directed towards multiple aspects—process and product quality, streamlining of the production process, and equipment maintenance and improvement. These results support Hypothesis H2b which construes that high and low performers can be differentiated by their level of implementation of Integrated Manufacturing Practices.

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7.2.3. *Effect of Context*

While the implementation of manufacturing practices provides significant differentiation of performance, we have discussed in Chapter 5 that contextual factors may also contribute to the explanation of performance variation. Contextual factors such as plant size, process type, and capacity utilization are believed to affect performance, however, only *process type* is significantly related to on-time delivery, volume flexibility, and weighted performance in the regression analyses (Table 7-5).

Table 7-5. Regression Analyses of Effect of Context

	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Performance
Plant Size	- 0.113	- 0.051	- 0.125	- 0.079	- 0.126
Process Type	0.062	- 0.049	- 0.133 *	- 0.229 ***	- 0.149 **
Cap Utilization	0.079	- 0.004	- 0.055	- 0.030	0.001
Misfit	- 0.409 ***	- 0.337 ***	- 0.375 ***	- 0.247 ***	- 0.459 ***
R^2	0.149	0.113	0.152	0.126	0.233
ADJUSTED R^2	0.128	0.091	0.131	0.104	0.213
SIGNIFICANT F	0.000	0.001	0.000	0.000	0.000
SIG F-CHANGE	0.000	0.000	0.000	0.004	0.000

* Sig at 0.10 level, ** Sig at 0.05 level, *** Sig at 0.01level

On the other hand, the term misfit has a significant and negative coefficient in all five-regression analyses. The inclusion of the term misfit after accounting for contextual differences provides additional significant explanation of variance to the dependent variable in the regression equations (Table 7-5). This shows that manufacturing plants should emulate the ideal plant profile and aim for higher levels of implementation of practices.

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We also investigate the effect of context using discriminant analyses. When the higher cutoff of 0.40 is used to determine significance of structure loadings in discriminant analysis, only *process type* is a significant differentiator between high and low performers for the measures of volume flexibility and weighted performance (Table 7-6). However, when using the lower cutoff of 0.30 *process type* is also a significant variable in the discriminant functions of conformance quality and on-time delivery, *plant size* is significant for differentiating conformance quality, and *capacity utilization* is a significant explanatory variable for cost efficiency.

All practice variables that have significant loadings in the discriminant analyses on the effect of fit of practices on performance as discussed in section 7.2.2 remain significant in similar analysis with the inclusion of the contextual variables (Table 7-6). While the loading of *JIT delivery by suppliers* variable decreases from 0.404 to 0.371, this variable can still be considered significant by the less stringent 0.30 standard for significant loading. Furthermore, chi-square difference tests for the addition of practice variables to models accounting for contextual differences are significant.

The results of regression and discriminant analyses are consistent. On the basis of these statistical results we can conclude that among the contextual factors that are examined, *process type* provides significant differentiation of performance. There is support for both hypothesis H3a and H3b that the fit and level of implementation of Integrated Manufacturing Practices provide significant explanation of manufacturing

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Table 7-6. Discriminant Analyses of Effect of Context

Structure Loadings * Sig loading ≥ 0.40	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Performance
Comm_Lead	0.407*	0.655*	0.569*	0.584*	0.621*
Strat_Pln	0.345	0.501*	0.460*	0.225	0.439*
X_Train	0.531*	0.346	0.387	0.194	0.283
Emp_Invol	0.393	0.524*	0.450*	0.179	0.267
Info_Feed	0.552*	0.233	0.394	0.199	0.334
Proc_Mgmt	0.298	0.487*	0.504*	0.288	0.403*
X_Design	0.340	0.475*	0.712*	0.307	0.424*
Supp_Mgmt	0.535*	0.597*	0.527*	0.223	0.409*
Cust_Inv	0.400*	0.362	0.414*	0.483*	0.307
Setup_Red	0.470*	0.238	0.259	0.130	0.162
Pull_Prod	0.422*	0.159	0.311	0.287	0.340
JIT_Delv	0.589*	0.561*	0.447*	0.371	0.482*
Equip_Lay	0.357	0.246	0.250	0.157	0.342
Sked_Adh	0.300	0.391	0.566*	0.302	0.397
Maintain	0.515*	0.297	0.455*	0.260	0.343
Tech_Emp	0.492*	0.493*	0.620*	0.499*	0.577*
Prop_Eqp	0.173	0.138	0.233	0.180	0.270
Plant Size	0.141	0.303	0.167	0.223	0.252
Process Type	-0.110	-0.370	-0.360	-0.489*	-0.429*
Cap Utilization	0.311	0.166	0.106	-0.067	0.089

Statistics	Cost Efficiency	Conform Quality	On-time Delivery	Volume Flexibility	Weighted Perform
Sample Size	163	163	163	163	163
Group 0 Size	92	71	70	69	80
Group 1 Size	71	92	93	94	83
Cpro	50.83%	50.83%	51.00%	51.18%	50.02%
Hit Ratio	68.10%	74.20%	69.90%	77.30%	77.30%
Jackknife Hit Ratio	58.90%	60.10%	57.70%	70.60%	71.80%
Canonical Corr	0.466	0.480	0.430	0.543	0.610
$(\text{Canonical Corr})^2$	0.217	0.230	0.185	0.295	0.372
Wilk's Lambda	0.783	0.770	0.815	0.706	0.628
Chi-square	36.889	39.536	30.931	52.643	70.223
Degrees of Freedom	20	20	20	20	20
Significance	0.012	0.006	0.056	0.000	0.000
Chg in $(\text{Can Corr})^2$	0.188	0.177	0.154	0.197	0.275
Sig Chi-sq Change	0.014	0.021	0.074	0.004	0.000

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performance after accounting for contextual differences in plant size, process type and capacity utilization.

It is not unexpected that *process type* plays a significant role in differentiating performance. Researchers since the time of Woodward (1965) have known the importance of matching process type with the other aspects of the production environment. When production involves low volume and high variety it may be more difficult to manage on-time delivery and flexibility because of the complexity involved in customizing the products. Conformance quality may also be adversely affected by the lack of opportunity for quality-related learning especially when the products being manufactured have unique features. While it is often believed that one-of-a-kind products cost more, production efficiency can reduce cost regardless of the process type being used.

Organizational size is considered one of the best predictors of organizational structure and managerial behavior (Drazin, 1995) which are factors that may affect performance. Thus, it is not surprising that *plant size* is not a strong factor in differentiating performance based on our analyses because leadership commitment and other practices that reflect the organizational setup are also modeled as explanatory variables. Moreover, the relationship between plant size and performance is not necessarily linear. While larger organizations may have more resources to deploy, the management of large organizations may entail more stringent structure that is not

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compatible with the implementation of practices that require high employee involvement.

A higher level of capacity utilization often provides reduction in per unit fixed cost which may be the reason for the significant loading of the *capacity utilization* variable on the discriminant function for cost efficiency. While the extent of capacity utilization may determine the availability of resources that can be deployed for the improvement of several performance dimensions simultaneously, we cannot completely investigate this effect because of the separate analysis made on the performance measures.

7.2.4. Conclusions of Empirical Analysis

In this chapter, we have provided the results of different empirical analyses for investigating the relationship among manufacturing practices and performance. All the hypotheses stated in Chapter 5 are supported in the empirical analyses. There is evidence of the coalignment of the practices of TQM, JIT, and TPM. Together these practices exhibit consistent positive effects on multiple dimensions of manufacturing performance and provide significant explanation of variation in performance after accounting for contextual differences.

The findings from these empirical analyses demonstrate the importance of implementing the practices belonging to all three programs of TQM, JIT, and TPM. While the practices are closely related, each component of the Integrated Manufacturing Practices cannot stand-alone and represent a different aspect of

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improvement initiative aimed towards product, process, and equipment development. In addition, our discriminant analysis indicates that different configurations of practices are best suited for improving specific performance dimensions. However, each of these configurations consists of practices belonging to all three programs and includes both socially and technically oriented practices.

Plant management should take into account the possible effects of contextual factors on performance. In particular, the type of production process being used can differentiate between high and low performance. Production involving one-of-a-kind products may be more difficult to manage but the implementation of compatible practices can help improve performance regardless of the process type being used. Further investigation should be undertaken to better understand the effect of contextual factors.

The results are consistent with the concept of equifinality that there are multiple ways of achieving good performance by having the right combination of practices depending on the strategic importance of the different performance dimensions. It is reassuring that the findings of the empirical analysis are consistent with the literature and observations from the case studies. In the next chapter, we will state the overall contributions of this study taking into account the conceptual and empirical results.

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CHAPTER 8

CONTRIBUTIONS OF THE STUDY

In this chapter we state the contributions of our multi-method examination of the composition, structure, effect, and contextual issues related to the Integrated Manufacturing Practices of TQM, JIT, and TPM. We also discuss the direction for future research.

8.1. DEVELOPMENT OF A CLASSIFICATION FRAMEWORK

Past studies have either examined manufacturing programs in isolation or interrelated them at the program level. In this study we provide a careful and systematic development, verification, and documentation of a single framework for understanding interrelated world-class manufacturing practices of TQM, JIT, and TPM. We provide support for our framework through literature review, case-based research, and empirical large sample data analysis. Investigation of TQM, JIT, and TPM simultaneously and at the practice level enables a more detailed examination while disentangling the confusion on what constitutes the practices of these programs.

The conceptual framework of Integrated Manufacturing Practices provides structure for the classification of the practices of TQM, JIT, and TPM into the common strategic- and human resource-oriented practices and basic techniques. This highlights the existence of both socially- and technically-oriented practices within the three programs and separates out their common elements. The applicability of the

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conceptual framework is supported in the case studies and the second-order factor analysis of the coalignment of the four components of the Integrated Manufacturing Practices—common practices, TQM basic techniques, JIT basic techniques, and TPM basic techniques.

As a result of the literature review and case studies we extend the focus of TPM to include productivity oriented equipment maintenance and development. However, the importance of development of proprietary equipment is not supported in the empirical data analysis. Proprietary equipment may not be a necessity for good performance but may be a significant factor for achieving competitive advantage as evidenced by the experiences of the manufacturing plants that we visited.

We also highlight the importance of providing information and feedback to the employees to enable their active participation in the decision-making process. The classification of this practice under the category of common practices brings out its implied significance in facilitating the implementation of basic techniques discussed in the literature.

Overall, the conceptual framework of Integrated Manufacturing Practices provides a fundamental set of TQM, JIT, and TPM practices that manufacturing plants should consider when choosing improvement initiatives. The framework also reminds practitioners to implement practices targeting different aspects of operation—product, process, and equipment, and to develop the infrastructure needed to support the organizations to implement these practices successfully.

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8.2. *FORMULATION OF A THEORY*

In chapter 3, we explicitly articulated a theory that states the relationship between the Integrated Manufacturing Practices and performance that is grounded on the concept of fit, socio-technical systems theory, and operations management theories. The case studies lead to the inclusion of contextual factors in our investigation. We adopt the holistic perspective of fit in our empirical large sample data analysis and examine the effect of contextual differences and coalignment of practices on manufacturing performance.

The holistic approach to fit enables the investigation of the systemic nature of the components of Integrated Manufacturing Practices. By using different statistical techniques for modeling fit, we are able to find empirical support for the importance of the implementation of complementary practices in improving performance. There exist different configurations of practices for discriminating between high and low performance depending on the strategic significance attributed to the performance dimensions. This is in line with the systems approach to fit that upholds the criticality of the internal consistency of each design and the match between the structural patterns of practices to the contingencies facing the organization.

The results of the inclusion of contextual issues in our analysis suggest that the institution of manufacturing practices should be coordinated within the contextual limits of the organization. Thus, we propose a modified Theory of Integrated Manufacturing Practices which holds that multiple configurations of the simultaneous

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and higher levels of implementation of the common practices and basic techniques of TQM, JIT, and TPM practices will lead to higher levels of manufacturing performance depending on the contextual factors and manufacturing goals of the organization.

8.3. CONTRIBUTION TO THE RESEARCH PROCESS

We hope that this study encourages investigation of interrelated practices and promote rigorous development and explicit articulation of theories in Operations Management (OM). It is necessary to increase theory development in OM that is grounded on relevant established theories and empirical evidence from OM and related disciplines so that empirical investigations of related phenomenon can be integrated into the building and modification of useful and interesting theories.

This study demonstrates the value of methodological triangulation in the development and verification of a classification framework and theory of Integrated Manufacturing Practices using literature review, case-based research, and empirical large sample data analysis. The use of different methods of investigation provides complementary assessment of the same issue and brings out the salient details that cannot be obtained by a single method of analysis.

The case-based research draws attention to the existence of contingencies and the need to further investigate the ambiguous role of contextual factors in affecting manufacturing practices and performance. Previous studies often prescribe TQM, JIT, and TPM practices as best practices that can improve manufacturing performance, however, our study suggests that the implementation and impact of manufacturing

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practices can be affected by contextual factors. In this study, we validate psychometric properties of multi-item scales using confirmatory methods that are more rigorous than exploratory analysis often performed in OM. The resulting scales can be used in subsequent studies to investigate other issues involving manufacturing practices. Researchers should try to use existing scales to further validate and refine the measurements for manufacturing practices.

In summary, this research contributes to theory-grounded empirical research. This is a worthwhile endeavor because contributions to valid and reliable measurements and explicit theory development help lay a foundation for future OM studies. By identifying and testing theories we encourage the development of a stream of cumulative research.

8.4. CONTRIBUTION TO PRACTICE

This study offers conceptual clarity and specificity on the practices of TQM, JIT, and TPM that managers can use as a guideline for choosing the fundamental practices that they can implement. We provide conceptual and empirical evidence on the coalignment of Integrated Manufacturing Practices encouraging managers to plan and implement manufacturing practices with a systemic view of the production environment. Manufacturing programs should not be implemented piecemeal. The results of this study highlight the importance of optimizing both the social and technical aspects of operation. The institution of common practices can facilitate the

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implementation of basic techniques and alleviate the problem often encountered with the adoption of new manufacturing practices.

We show that multiple manufacturing performance dimensions can be simultaneously improved with the implementation of Integrated Manufacturing Practices while particular configurations of practices may have stronger effects on the achievement of specific performance goals. Furthermore, there is empirical evidence of the importance of committed leadership in the implementation of manufacturing practices regardless of the strategic importance attributed to any performance dimension. We also find that a general emphasis on technology adoption and development is significant in differentiating high and low performance. Emphasis on technology may be considered a reflection of the extent to which an organization can consider manufacturing as a source of competitive advantage.

We find that the process type used in production is a significant differentiator of performance. Discrete processes are generally more complex than continuous processes and can adversely affect performance. Since the type of production process that should be used depends on the nature of the products being manufactured, plant management may not be able to use only continuous processes. Our empirical analyses show that while contextual factors should be taken into account, the implementation of Integrated Manufacturing Practices provides greater differentiation of performance. Thus manufacturing plants can implement compatible Integrated

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Manufacturing Practices to enhance performance regardless of the process type being used.

8.5. DIRECTION FOR FUTURE RESEARCH

The current investigation uses a holistic approach to fit and examines the impact of the integration of manufacturing practices using the World Class Manufacturing database. This is one of the first studies that explicitly examine the interrelationship among TQM, JIT, and TPM. In order to better understand the complex interactions among these programs, more research on their practices should be conducted using a systemic approach. Furthermore, the results of this study can be further validated using other databases.

Future research should also determine the nature of the specific relation between the practices that are found to be significant differentiators of performance in this study. A reductionistic approach to fit can be used to model interaction effects and understand the impact of contextual factors on the level of implementation of practices and performance.

While there are many studies prescribing best manufacturing practices, there is little recommendation on how these practices should be implemented. Future studies should use longitudinal data to investigate the best implementation process. Such studies may be able to provide prescriptions on the sequence for implementing practices that is most suitable for specific manufacturing context.

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Any single study cannot exhaust the examination of all possible contextual factors that may affect the manufacturing operation. Furthermore, the literature is scant in the theoretical underpinnings for understanding the role of specific contextual factors. Thus, we need to explore the effect of context in a more detailed level by conducting case studies before venturing into large-scale empirical research.

This study controls for the effect of country and industry in the empirical analysis since the small sample size of the database does not allow detailed investigation of country and industry differences. Researchers should collaborate with each other to build larger databases that will include more samples from different countries and industries. This will enable investigation of cultural and industry specific differences that are important for companies to compete globally and to better understand their partners in the supply chain that belong to other countries and industries.

While there is continuing research interest on the manufacturing programs of TQM, JIT, and TPM since the 1980s, studies on these topics should be expanded to examine the effect of similar programs in other industries. The improvements that these programs have brought to numerous manufacturing organizations suggest that the application of their basic principles in other industries should be considered. It will be worthwhile to investigate how the principles of continuous improvement of process quality, reduction of waste in operations, maintenance of equipment and

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development of technology can be applied to other operations such as services and electronic commerce.

Since good theory testing can only be accomplished with valid and reliable measures, researchers should use rigorous statistical methodologies to develop and test the psychometric properties of measurement scales. Existing multi-item measures of manufacturing practices such as the ones used in this study should be used whenever applicable so that measurement scales can be cross-validated. In general, the development of new theories and measures should be based on the established principles to enable cumulative research rather than fragmented experimentation.

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Appendix A. Guide Questions for Semi-Structured Interview*

1. What is the nature of your job in this plant?
2. Do you participate in the decision making process to determine what manufacturing practices should be implemented?
3. Currently, what are the manufacturing practices related to quality management (or just-in-time production or maintenance) that are being implemented at this plant?
4. Please describe the process of implementation when the practices were first implemented.
5. What are the challenges that the plant encountered while implementing these practices?
6. Are changes made to the structure or operations of the plant to facilitate the implementation of these practices?
7. What are the effects of the implementation of these practices on the production process and performance?
8. Are practices related to just-in-time production and maintenance (or quality management) also being implemented at this plant?
9. Did the plant take into account the existence of other practices when it decided to implement practices related to quality management (or just-in-time production or maintenance)?

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10. Do you think the different practices complement each other? In what way?
11. If given the chance to implement the practices differently, what will you change?
12. What do you think is the most important thing that managers should be concerned about when implementing manufacturing practices?
13. What do you think of this Framework of Integrated Manufacturing Practices (Figure 3-1 is provided to the interviewee)? Is there anything that should be modified and why?

*Each interview is focused on one of the three programs of TQM, JIT, and TPM and then relates the practices of this program to the other two programs.

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Appendix B. Measurement Items

COMMON STRATEGIC- AND HUMAN RESOURCE-ORIENTED PRACTICES		
Committed Leadership (COMM_LEAD)	QSTPN01	All major department heads within our plant accept their responsibility for quality.
	QSTPN02	Plant management provides personal leadership for quality products and quality improvement.
	QSTPN04	All major department heads within our plant work towards encouraging just-in-time production.
	QSTPN05	Our top management strongly encourages employee involvement in the production process.
	QSTPN06	Plant management creates and communicates a vision focused on quality improvements.
	QSTPN07	Plant management is personally involved in quality improvement projects.
Strategic Planning (STRAT_PLN)	SSFRN01	Our plant has a formal strategic planning process which results in a written mission, long-range goals and strategies for implementation.
	SSFRR02	Plant management is not included in the formal strategic planning process. It is conducted at higher levels in the corporation.
	SSFPN03	The plant has a strategic plan which is put in writing.
	SSFPN04	Plant management routinely reviews and updates a long-range strategic plan.
	SSFPR05	The plant has an informal strategy which is not very well defined.
Cross-functional Training (X_TRAIN)	HSTWN01	Employees receive training to perform multiple tasks.
	HSMFN01	Employees at this plant learn how to perform a variety of tasks/jobs.
	HSMFN03	Employees are cross trained at this plant so that they can fill in for others if necessary.
	HSMFR04	At this plant, employees only learn how to do one job/task.
Employee Involvement (EMP_INVOL)	HSTMN02	During problem solving sessions, we make an effort to get all team members' opinions and ideas before making a decision.
	HSTMN03	Our plant forms teams to solve problems.
	HSTMN07	In the past three years, many problems have been solved through small group sessions.
	HSTMN08	Problem solving teams have helped improve manufacturing processes at this plant.
	HSTMN09	Employee teams are encouraged to try to solve their problems as much as possible.
Information & Feedback (INFO_FEED)	QSFBN01	Charts showing defect rates are posted on the shop floor.
	QSFBN02	Charts showing schedule compliance are posted on the shop floor.
	QSFBN03	Charts plotting the frequency of machine breakdowns are posted on the shop floor.
	QSFBN05	Information on quality performance is readily available to employees.
	QSFBN06	Information on productivity is readily available to employees.

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TOTAL QUALITY MANAGEMENT BASIC TECHNIQUES		
Process Management (PROC_MGMT)	QSPSN03	A large percent of the equipment or processes on the shop floor are currently under statistical quality control.
	QSPSN06	We make extensive use of statistical techniques to reduce variance in processes.
	QSPSN08	We use charts to determine whether our manufacturing processes are in control.
	QSPSN09	We monitor our processes using statistical process control.
Cross-functional Product Design (X_DESIGN)	TSNPN03	Direct labor employees are involved to a great extent (on teams or consulted) before introducing new products or making product changes.
	TSNPN04	Manufacturing engineers are involved to a great extent before the introduction of new products.
	TSNPR05	There is little involvement of manufacturing and quality people in the early design of products, before they reach the plant.
	TSNPN06	We work in teams, with members from a variety of areas (marketing, manufacturing, etc.) to introduce new products.
Supplier Quality Management (SUPP_MGMT)	QSSPN03	Quality is our number one criterion in selecting suppliers.
	QSSPN05	We use mostly suppliers which we have certified.
	JSVNN05	Our suppliers are certified, or qualified, for quality.
Customer Involvement (CUST_INV)	QSCON01	We frequently are in close contact with our customers.
	QSCON04	Our customers give us feedback on quality and delivery performance.
	QSCON07	We strive to be highly responsive to our customers' needs.
	QSCON08	We regularly survey our customers' requirements.

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JUST-IN-TIME BASIC TECHNIQUES

Setup Time Reduction (SETUP_RED)	JSSUN01	We are aggressively working to lower setup times in our plant.
	JSSUN04	We have low setup times of equipment in our plant.
	JSSUN05	Our crews practice setups to reduce the time required.
	JSSUN07	Our workers are trained to reduce set-up time.
Pull System Production (PULL_PROD)	JSVNN03	Suppliers fill our kanban containers, rather than filling purchase orders.
	JSVNN04	Our suppliers deliver to us in kanban containers, without the use of separate packaging.
	JSPLN06	We use a kanban pull system for production control.
	JSPLN07	We use kanban squares, containers or signals for production control.
JIT Delivery by Suppliers (JIT_DELV)	JSVNN01	Our suppliers deliver to us on a just-in-time basis.
	JSVNN08	Our suppliers deliver to us on short notice.
	JSVNN09	We can depend upon on-time delivery from our suppliers.
Equipment Layout (EQUIP_LAY)	JSPLN02	We have laid out the shop floor so that processes and machines are in close proximity to each other.
	JSMHN05	Our machines are grouped according to the product family to which they are dedicated.
	JSMHN06	The layout of the shop floor facilitates low inventories and fast throughput.
	JSMHN07	Our processes are located close together so that material handling and part storage are minimized.
Schedule Adherence (SKED_ADH)	JSFTN03	We usually meet the production schedule each day.
	JSFTN05	Our daily schedule is reasonable to complete on time.
	JSFTN06	We usually complete our daily schedule as planned.

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TOTAL PRODUCTIVE MAINTENANCE BASIC TECHNIQUES		
Autonomous & Planned Maintenance (MAINTAIN)	JSPMN04	We dedicate a portion of every day solely to maintenance.
	JSPMN05	We emphasize good maintenance as a strategy for achieving quality and schedule compliance.
	JSPMN06	We have a separate shift, or part of a shift, reserved each day for maintenance activities.
	JSPMN09	Our maintenance department focuses on assisting machine operators perform their own preventive maintenance.
Technology Emphasis (TECH_EMP)	SSATN06	Our plant stays on the leading edge of new technology in our industry.
	SSATN07	We are constantly thinking of the next generation of technology.
	TSEIN04	We are a leader in the effective use of new process technology.
	TSEIN05	We search for continuing learning and improvement after installation of the equipment.
	SRDCN05	Please circle the number which indicates your opinion about how your plant compares to its competition in your industry, on a global basis. 5 = Superior or better than average, 4 = Better than average, 3 = Average or equal to the competition, 2 = Below average, 1=poor or low end of the industry. 1 2 3 4 5 Process technology
Proprietary Equipment Development (PROP_EQP)	SSR4N01	We actively develop proprietary equipment.
	SSR2R02	We rely on vendors for most of our equipment.
	SSPEN04	We have equipment which is protected by the firm's patents.
	SSPEN05	Proprietary equipment helps us gain a competitive advantage.

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CONTEXTUAL VARIABLES	
Plant Size: Number of Employees	**Number of personnel employed (Hourly personnel) in the current year** _______ **Number of personnel employed (Salaried personnel) in the current year** _______ **Number of Employees = number of hourly personnel + number of salaried personnel**
Process Type	**The production process in this plant is best characterized as follows (what percent of product volume fall into each category?)** ____% One of a kind (T5) ____% Small batch (T4) ____% Large batch (T3) ____% Repetitive/line flow (T2) ____% Continuous (T1) **Process Type = 5 * T5 + 4 * T4 + 3 * T3 + 2 * T2 + 1 * T1**
Capacity Utilization	**During the past year, what was the average percentage of plant capacity utilization?** ______%

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MANUFACTURING PERFORMANCE MEASURES

Manufacturing Performance

Please circle the number which indicates your opinion about how your plant compares to its competition in your industry, on a global basis. 5 = Superior or better than average, 4 = Better than average, 3 = Average or equal to the competition, 2 = Below average, 1 = Poor or low end of the industry.

(P1)	Unit cost of manufacturing	5	4	3	2	1
(P2)	Inventory turnover	5	4	3	2	1
(P3)	Quality of product conformance	5	4	3	2	1
(P4)	Product capability and performance	5	4	3	2	1
(P5)	Delivery performance (on-time delivery)	5	4	3	2	1
(P6)	Cycle time	5	4	3	2	1
(P7)	Flexibility to change volume	5	4	3	2	1
(P8)	Flexibility to change product mix	5	4	3	2	1

Weighted Manufacturing Performance

Please rank the importance of the following objectives or goals for manufacturing at your plant over the next five years. Rank #1 for the most important objective, #2 for the next most important and so on. You may rank several objectives the same if they are of equal importance.

		Rank
(W1)	Low unit cost	______
(W2)	Consistent quality	______
(W3)	Dependable delivery	______
(W4)	Ability to make rapid volume changes	______

The rankings are converted into weights of 2.5, 2, 1.5 and 1 and when two rankings are equal, the weights are adjusted so that the sum of the weights always equals 7.

Weighted Performance = W1 * P1 + W2 * P3 + W3 * P5 + W4 * P7

Appendix C. Measures of Model Fit

The following is a summary of major fit measures used in this study. A more detailed discussion can be found in Chapter 7. We consider absolute, relative, and parsimonious indices and residual analysis in our assessment of model fit. We also provide cutoff values for test of good fit suggested in some studies though we support the view of some researchers that these cutoffs should not be held as strict standards.

Fit measure	Cut-off value for good fit
Normed chi-square (Nchisq)	≤ 3.00 (Carmines and McIver, 1981)
Root mean square residual (RMR)	≤ 0.05 (Bryne, 1998)
Comparative fit index (CFI)	≥ 0.90 (Bentler, 1992)
Incremental fit index (IFI)	≥ 0.90 (Hull et al., 1991)
Parsimonious normed fit index (PNFI)	≥ 0.50 (Mulaik et al., 1989)
Standardized residuals	≤ 2.58 for most residuals (Bryne, 1998)

A model with normed chi-square value in the range (3, 5) can be considered to exhibit good fit (Jöreskog, 1970; Wheaton et al., 1977; Marsh and Hocevar, 1985). While there is no established cutoff for IFI, the cutoff of 0.90 proposed by Bentler and Bonnet (1980) is commonly adopted for relative fit indices. Mulaik et al. (1989) suggest that goodness-of-fit indices greater than 0.90 accompanied by parsimonious-fit-indices of 0.50 are not unexpected. The Modified Akaike Information Criteria (CAIC) can be used to compare non-nested models where the model with a smaller CAIC is the better fitting model (Maruyama, 1997). The target coefficient (T) proposed by Marsh and Hocevar (1985) can be used to compare corresponding first-order and higher order models where T of at least 0.90 is taken to indicate preference for the higher order model (Venkatraman, 1990; Segars et al., 1998).

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