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A DEFINITION OF WORLD CLASS MANUFACTURING AND AN EMPIRICAL ANALYSIS OF PRACTICE-PERFOMANCE RELATIONSHIPS IN MANUFACTURING PLANTS

By

Xinyan Wang

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ABSTRACT

A DEFINITION OF WORLD CLASS MANUFACTURING AND AN EMPIRICAL ANALYSIS OF PRACTICE-PERFORMANCE RELATIONSHIPS IN MANUFACTURING PLANTS

By

Xinyan Wang

The topic of World Class Manufacturing (WCM) has attracted a lot of attention in manufacturing industry and operations strategy literature. The wide spread use of benchmarking which involves copying the "best practices" from "best performing" plants makes it compelling to define WCM and investigate how "best practices" and "best performance" are related. Literature in operations strategy has defined WCM based on either practices or performance each offering their own list of "WCM practices" or performance. There has been little empirical research concerning the relationship between the so-called "WCM practices" and performance.

This research is intended to provide a definition of WCM by employing multiple criteria and an empirical investigation of the relationships between the "WCM practices" and performance while taking into consideration technical efficiency of each individual manufacturing plants.

This research first summarized and integrated practice-based and performance-based definitions of WCM in an effort to provide measurement models for WCM practices and performance. Methodology and theory from several fields that are related to manufacturing strategy are employed. Efficiency analysis which is based on traditional ideas in economics relating outputs to inputs was utilized to identify the "best performing" plants which are the most technically efficient. It reconciles the notion of

technical efficiency with the notion of world class by verifying the moderating effect of efficiency on the relationship between practices and performance. Taxonomy analysis, which is a popular tool in segmenting operations strategy, was performed on efficient manufacturing plants in the data sample. The results show that based on which strategy the efficient plants are adopting, the priorities they placed on various "WCM practices" are different.

This dissertation makes four major contributions to operations strategy literature. First, this research represents one of the first efforts to synthesize the dimensions of WCM practices in literature. Comprehensive measurement models, which may provide a foundation for further empirical testing in this area are proposed and empirically tested. Second, using technical efficiency in the traditional economic sense overcomes the weaknesses of existing definitions of WCM in the literature. The research findings suggested that technical efficiency is a valid measure and is one of the three pre-requisites of WCM. Third, results of cluster analysis and comparison among the three clusters within efficient manufacturing plants indicate that these manufacturing plants have adopted different strategies to become efficient. What is more important is that these groups have different priorities on WCM practices. This further indicates that the approach of current WCM literature, which does not realize that differences exist in priorities on manufacturing practices within best performing plants due to strategy differences, is inadequate. This research warrants the need to further investigate how the strategy differences affect the relationship between practices and performance. Finally, the research findings suggested that to be termed WCM requires all three criteria: engage in WCM practices, be technically efficient and perform well on all the performance areas.

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DEDICATED TO MY PARENTS, GEPING WANG AND QINGYANG LI

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CHAPTER 1

INTRODUCTION

1.1. Overview of the Definition of World Class Manufacturing

The term "world class manufacturing" was first introduced by Hayes and Wheelwright in 1984. Since then, various authors have embraced and expanded this concept. Most of the research pieces are descriptive in nature. Generally, there is no agreed upon definition about what world class manufacturing is. There have been two different trends in defining world class manufacturing (WCM): practice-based and performance-based.

Hayes and Wheelwright (1984), Schonberger (1990), and Giffi et al. (1990) have discussed world class manufacturing from the perspective of manufacturing practices.

Hayes and Wheelwright (1984), in their classic book "Restoring Our Competitive Edge: Competing through Manufacturing" (page 375-385), proposed that world class manufacturing is composed of six dimensions: Workforce skills and capabilities, management technical competence, competing through quality, workforce participation, rebuilding manufacturing engineering, incremental improvement approaches. By comparing the practices of Japanese and German manufacturers with U.S. manufacturers, Hayes and Wheelwright claimed that the U.S. plants must focus on these six broad categories of practices in order to achieve their world class manufacturing status.

Schonberger (1986, 1996) provided a list of 16 principles of world class manufacturing which fall into eight categories: general, design, operations, human resources, quality and process improvement, information for operations and control, capacity, promotion and marketing. Schonberger actually asked managers to evaluate their own plants based on these 16 principles. He warned those plants that scored low on the 16 principles to identify their problems and make an effort to improve these practices to keep up with the competition.

Giffi, Roth and Seal (1990) also provided operating principles of world class manufacturing in the following areas: quality and customer, management approach, manufacturing strategy, manufacturing capabilities, performance measurement, organization, human assets and technology. Giffi et al. (1990) considered these practice dimensions to be interrelated; quality and customer constitue the core of the principles, all the other dimensions interact with quality dimension. This article was the first one that brought competitive capabilities into WCM framework. Their view of competitive capability agrees with both performance-based definition of WCM and cumulative model of competitive capabilities. Similar to the performance-based definition of WCM, they argued that achieving multiple capabilities simultaneously is one of the keys to manufacturing excellence. They also endorsed Ferdows and De Meyer's (1990) cumulative model in that they believe that the time-based competitive capabilities (dependable delivery time, delivery speed, and flexibility) are built upon superior quality.

These practice-based definitions of WCM have a lot in common. All of them imply that adoption of these best practices will lead to superior performance, but none of them went one step further to discuss the prescriptive properties of these practices (how strongly each practice is related to performance). If the strength of the relationship between practice and performance varies, it may be more effective to focus on a subset of practices selectively.

Still, there are quite a few authors who have adopted the performance-based definitions of WCM. The performance-based definitions are generally more straightforward and intuitive.

Todd (1995) defined world-class as being the best in terms of product design and performance, quality and reliability, least manufacturing cost, the ability to keep introducing innovative designs more quickly than your competitors, shorter lead times and more reliable delivery performance, and customer services.

Taninecz (1997 b) asked participants of the Industry Week Census of Manufacturers to assess their plant's or company's progress toward world-class. Taninecz found correlations at the plant level between world-class status and best performance, and identified speed, cost and quality as the best metrics that measured the progress toward world-class status.

The performance-based definitions generally avoided answering questions that have been debated in the operations literature; such as whether there are trade-offs among these performance areas, whether one performance area builds on the others, and whether synergies exist. The performance-based definitions seem to suggest that WCM is a homogenous group in terms of their strategic choices, that is, all WCM plants are working on all the dimensions of competitive performance without placing a priority on one dimension over the others. This definition poses potential difficulties for practitioners. Without identifying strategic differences among the best plants, the concept of WCM is too vague for plants to develop the right benchmarks to use for improvement.

1.2. Missing Link in World Class Manufacturing Literature

Despite the implications of the practice-based definition of WCM that WCM practices will lead to superior performance, there is a lack of both theoretical and empirical investigation of the relationship between practices and performance in WCM literature. The relationship between various manufacturing practices (somewhat overlapping with WCM practices to some degree) and performance, however, has been attracting a lot of attention in manufacturing strategy literature. Most of the research that studied the relationship between manufacturing practices and performance focused only on a small set of either manufacturing practices or performance. Comprehensive and systematic study of the relationship between the so called "world class manufacturing practices" and performance is considered missing in literature, and will be a focus in this dissertation.

As mentioned earlier, both practice-based definition and performance-based definition of WCM have their weaknesses, this dissertation intends to overcome these weaknesses by including multiple criteria and approaches that have been used to identify "best practices" in strategy literature.

Efficiency analysis is one of the tools that has been utilized for performance analysis in economics and finance and has seen increased applications in operations literature. Efficient manufacturing units are defined as those that produce the most amount of output with the least amount of input. Those efficient manufacturing units, if plotted on an output vs. input diagram, are placed on efficient frontiers (also called envelope in data envelopment analysis). From an economic perspective, there is reason to believe that among all the manufacturing plants, those plants that can best utilize the inputs are candidates for the title of "WCM" and should be the plants against which the lower performing plants may want to benchmark themselves.

Taxonomy of strategy is another technique that has been used for identifying the "best" performing plants and is especially useful when a plant wishes to benchmark its way to achieve world class status. Porter's (1980) taxonomy of strategy into cost, differentiation and focus served as the first argument that there are differences among the best. He believed that only these strategies (cost, differentiation or focus) will lead to superior performance, any firm "stuck in the middle" is doomed to low profitability. Yet authors such as Kotha and Orne (1989) provided taxonomy that segmented manufacturing strategy types into both attractive and unattractive positions. Despite the argument that WCM plants can achieve multiple competencies at the same time and equally well, most empirical evidence in taxonomy analysis suggested that there are multiple strategy types even within the best performing manufacturing units. Taxonomy is crucial for benchmarking since strategy is the fundamental building block for tactical and operational decisions. If a plant were to benchmark its practices (i.e. operational decisions) on a plant with totally different strategy, the result can be disastrous. Therefore, it is essential to identify strategy types within the most efficient manufacturing units, be it WCM or not.

1.3. Research Objectives and Steps

There are two major objectives in this dissertation. First, a definition of World Class Manufacturing that overcomes the weaknesses of both practice based and performance based definitions, establishes linkage between practices and performance i

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and one that includes multiple criterion will be attempted. Second, an empirical investigation of the relationship between manufacturing practices and performance will be carried out in this dissertation. These two goals will be achieved by applying the procedures discussed below.

Despite the popularity of the WCM topic and ongoing framework that is related to this topic, there is a lack of theory in WCM literature. As stated by Bacharach (1989), the primary goal of a theory is to answer the questions of how, when and why rather than to answer the question of what. In more detailed terms, Bacharach (1989) described theory as a system of constructs and variables in which the constructs are related to each other by propositions and the variables are related to each other by hypotheses.

Both the practice-based definition and the performance-based definition are basically descriptions, which are used to answer the question of what. They did not answer the questions of how, when and why. Neither did they attempt to establish a system of variables related to the constructs in discussion. Therefore, in order to establish a system that leads to propositions and hypotheses, the first step is to establish a system of measurement for the constructs.

The process of identifying World Class Manufacturing plants start with identifying "best practice" plants among the peers. Efficiency analysis provides a way to accomplish this. Efficiency analysis is a non-parametric approach which does not require the functional form between input and output to be specified. The focus of such analysis is to find out the "best practice" units that can produce the most amount of outputs with the least amont of inputs. These characteristics make efficiency analysis an ideal tool for performance analysis in this scenario. The critical decision in efficiency analysis is to pick the correct set of inputs and outputs. A reasonable approach is to select a list of inputs and outputs based on the combination of theoretical foundation from literature and practical considerations. After having established the measurement models for practice and performance, and selected the variables for efficiency analysis, the next step in this dissertation was to apply this efficiency analysis and identify the frontier in the data sample.

Taxonomy on the efficient plants may reveal the strategy differences of the most efficient plants and provide insight for benchmarking effort. Are the plants that are efficient in producing the most amount of output using the least amount of input homogenous in terms of strategy or are there inherently different strategic groups among the efficient plants? The answer to this question has significant implications for operations strategy literature and makes significant difference for benchmarking effort. In order to solve this puzzle and provide insights for more interesting topics in WCM research, a cluster analysis on the efficient plants was performed. If more than one strategic group is found in data samples, taxonomic analysis will be performed to study the differences among these groups.

If there is more than one strategic group in efficient plants, one may contemplate on whether these strategic groups focus on different sets of practices. If this is the case, what implications do the differences reveal and what should manufacturing managers do to adjust their actions according to these differences and make the best use of resources?

In summary, this dissertation will try to achieve the two major objectives by the following procedures:

1. Establish practice and performance measurement models from literature and empirically test these measurement models.
2. Provide an efficiency analysis of manufacturing plants in the data sample and identify efficient plants on the data envelope.
3. Empirically investigate the relationship between manufacturing practices and performance.
4. Provide taxonomy of efficient manufacturing plants.
5. If there is more than one strategic group in efficient manufacturing plants, study whether these strategic groups emphasize different sets of practices.

1.4. Structure of the Dissertation

Chapter 1 of this dissertation outlines the gaps identified in literature related to world class manufacturing, major objectives in this dissertation, and procedures that will be followed to achieve these objectives. Chapter 2 offers a comprehensive review of literature on several research streams that are related to taxonomy of manufacturing strategy, competitive performance and world class manufacturing. Chapter 3 develops a conceptual framework based on literature and the rationale for the research hypotheses. Chapter 4 describes research design, data collection and data analysis methodology related issues. Chapter 5 presents the results and validity issues of data analysis. Chapter 6 discusses the implication and contribution of the research results, points out the limitation of this dissertation and directions for future research.

CHAPTER 2

LITERATURE REVIEW

Chapter 1 provided an overview of literature in the field of world class manufacturing and theories that may contribute to a better understanding of WCM but have been overlooked by researchers in WCM area. These areas together with WCM literature will be examined in detail in this chapter. The existing literature will be summarized, evaluated and critiqued. Gaps and limitations will be identified.

Literature review will be organized around four major research streams: taxonomy of manufacturing strategy, competitive performance, relationship between practices and performance, and world class manufacturing.

2.1. Taxonomy of Manufacturing Strategy

Porter, in his most cited and debated work "Competitive Strategy", classified strategy types (1980) into cost, differentiation and focus. His work has influenced a lot of researchers in the field of manufacturing strategy.

Porter identified a two dimensional, strategic target by strategic advantage matrix. Both the two dimensions are dichotomy, as strategic target being either industry wide or particular segment only and strategic advantage being either uniqueness perceived by the customer or low cost position. The two by two matrix yielded three strategy types: industry wide low cost as cost strategy, industry wide uniqueness as differentiation strategy, particular segment only (either unique or low cost) as focus strategy. Porter argued that firms "stuck in the middle" -- those that failed to develop their strategies in at least one of the three directions, are almost guaranteed low profitability.

Porter's taxonomy has been criticized for a lot of reasons. For example, only using two variables to segment strategies was viewed as too simplified and not comprehensive. Even for the variables chosen, the dichotomy between uniqueness and low cost does not seem to capture all the essence of strategic advantage.

Kotha and Orne (1989), upon realizing the criticism faced by Porter, proposed a three dimensional cube for manufacturing structures. The three dimensions have been labeled process structure complexity, product line complexity, and organizational scope. The dichotomy on each of these dimensions is labeled low and high. High process structure and low product line complexity corresponds with low cost position in Porter's model. High product line complexity and low process complexity corresponds with differentiation. High organizational scope corresponds with industry-wide, low organizational scope corresponds with segmented. This three dimensional cube yielded eight manufacturing strategies at the corners, among which four strategies which corresponded with Porter's three generic strategies are identified as highly attractive, two as reasonably attractive and two as highly unattractive. The authors argued that any other strategies (represented by the remaining portions of the cube) are also highly unattractive.

Kotha and Orne's taxonomy purports to be an improvement to Porter's model in the way that these three variables are now independent with each other. However, the choice of categorical variable to characterize these variables is arbitrary and makes the model less persuasive. Even the authors described some industries as having medium complexity in these variables. It seems contradictory that the authors then characterized these positions as highly unattractive.

Ward and Leong (1996)'s taxonomy took into account the linkage among four constructs: competitive strategy dimensions, environmental dimensions, structural dimensions, and strategic manufacturing capabilities. They identified sixteen item measurement on these four construct. Unlike Kotha and Orne, who discussed all possible combinations of low/high dimensions of the variables, Ward and Leong did not make an effort to provide such a combination. They only identified four feasible strategies, each of which has either high or low or insignificant relationship with each of the sixteen items.

Miller and Roth (1994) took a different approach from any of above studies. Instead of classifying manufacturing strategy theoretically, they did an empirical classification. They sampled 164 American manufacturers and found three clusters based on competitive capabilities measures. They identified eleven competitive capabilities that are relevant to their study: low price, design flexibility, volume flexibility, conformance, performance, speed, dependability, after sale service, advertising, broad distribution and broad line. Instead of using categorical scales, they utilized 1 to 7 Likert scales for these items. The three clusters identified from the sample are caretakers, marketers, and innovators.

Miller and Roth's approach improved upon the other taxonomies significantly in several ways:

1. The taxonomy is aimed at manufacturing leading business units. Therefore the clusters generally served similar purpose as Porter's: provide a benchmark for the non-leading firms. Kotha et al. 's taxonomy itself does not provide such

functionality. In Ward et al.'s taxonomy, the definition of leaders is based only upon the authors' judgement.

2. Continuous scale is utilized. This is a step forward in the taxonomy research. The dimensions are inherently continuous. Using categorical variable to characterize these continuous variables as is done in other research is a limitation.
3. It is empirically tested.

However, there are still some weaknesses in Miller and Roth's taxonomy. As mentioned before, their strength is that their study examines leading manufacturing business units. However, there was no explanation provided in their paper about what leading manufacturing business units mean. Nor did they describe how they selected those leading manufacturing business units. The sample size is small. Therefore, the generalizability of their research is weak.

Bozarth and McDermott (1998) after reviewing the existing taxonomies in manufacturing strategy research also called for the empirical testing of theoretical frameworks.

The literature review of taxonomy of manufacturing strategy gives the direction for the future research:

1. A rigorous definition of "leading manufacturing business unit" is needed. Otherwise the clusters generated from this sample may be biased by the researchers' opinion as to what is good or bad.

2. The taxonomy on the leading manufacturing business units is needed. This taxonomy, therefore, can provide benchmark for majority of the manufacturing business units.
3. Performance measure has to be carefully chosen. If a variable is inherently continuous, continuous measurement should be chosen over categorical measurement.
4. Empirical testing is needed to verify the theoretical framework.

2.2. Competitive Performance

Competitive performance is often employed in operations literature to measure the outcome of manufacturing strategy. It is some operations capability that is unique and forms the primary basis for competition. (Anderson, Cleveland, and Schroeder, 1989, Swink and Hegarty, 1998) It is a bridge that links a company's manufacturing competence with its product and market competence (Hayes and Wheelwright 1979). When used to describe the outcome of manufacturing strategy, it is often interchangeable with competitive capability, comparative advantage, distinctive competence, production competence etc. The same concept is sometimes used to describe the objective or goals of a manufacturing unit. When used to describe objective or goals, it is often called manufacturing objective, competitive priority. The difference between these terms is largely semantic, although some authors do propose using two constructs to describe objective and outcome (Vickery, 1991, Swink and Hegarty, 1998).

It has been viewed as a multi-dimensional construct from the time the concept was formed. Its theoretical components are evolving over time. Its empirical realization varied from study to study. The trade-off vs. synergy view of its various dimensions is becoming a hot topic. The following literature review on competitive performance is divided into three parts: theoretical components, empirical realization, trade-off vs. synergy.

2.2.1. Theoretical Components

Most writers have focused on four components of competitive performance: cost, quality, dependability (delivery), flexibility (Hayes and Wheelwright 1984, Swamidass and Newell 1987, Hill 1989, New 1992, Krajewski and Ritzman 1993, Schemnner 1993, Boyer 1998). Recent literature has included reliability, customer satisfaction, innovation, service etc (Nobel 1995, Garvin 1993). Some authors have tried to break some items down into smaller sub-components.

The concept was first proposed by Hayes and Schmenner (1978) as competitive priority. It was composed of five dimensions: price, quality, dependability, product flexibility, and volume flexibility. They argued that manufacturing functions best when its facilities, technology, and policies are consistent with recognized priorities.

Seven key competitive edge criteria was first presented in New's (1979) Cranfield Manufacturing Strategy Model and later modified by New and Sweeney (1984). These seven key competitive edge criteria included delivery lead time, delivery reliability, quality capability, quality consistency, flexibility design, flexibility volume and price.

Schroeder, Anderson and Cleveland (1986) asked managers to rate the importance of manufacturing objectives on similar dimensions. Those items, from highly ranked to lowly ranked, are quality, delivery performance, unit cost, flexibility to change volume, C

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flexibility to change product, employee relations, inventory turnover, and equipment utilization.

Garvin (1993) in proposing strategic manufacturing initiatives (SMI), argued that strategic priorities are too highly aggregated to direct decision making. He decomposed five strategic priorities (cost, quality, delivery, flexibility, and service) into thirty-six items. Garvin's list of decomposed strategic priorities is the one of the most comprehensive lists in literature.

2.2.2. Measurement Issue

The empirical realization of competitive performance varied from study to study. Generally speaking, empirical research included more detailed items to measure and describe the construct. The actual items included often varied by the authors' interest of study.

For example, Cleveland et al. (1989) offered a single, overall measure of production competence based on individual firm's performance in "nine key areas. Strength or weakness in these key areas could mean the difference between success or failure of the business plan". These nine key areas are: adaptive manufacturing, cost-effective of labor, delivery performance, logistics, production economies of scale, production technology, quality performance, throughput and lead-time, vertical integration. For six midwestern firms, a company representative first rank-ordered the nine key areas according to their relative importance to the firm. Each respondent then rated his or her firm's strength or weakness (S/W) in each area using a (-1, 0, or +1) scale. Logarithms of the reversed ranking values were multiplied by their respective S/W ratings and summed together to derive the measure of production competence.

Table 2.1 Garvin's Decomposed Strategic Priorities

Strategic Priorities	Decomposed Strategic Priorities
Cost	Initial cost
	Operating cost
	Maintenance cost
Quality	Performance
	Features
	Reliability
	Conformance
	Durability
	Serviceability
	Aesthetics
	Perceived quality
Delivery	Accuracy
	Completeness
	Availability
	Speed
	Information Accessibility
	Quality
	Ease of Ordering
	Ordering Flexibility
	Shipment Flexibility
	Ease of Return
Flexibility (Product Flexibility)	New Products
	Customization
	Modification
(Volume Flexibility)	Uncertain Forecasts
	Ramp-ups
(Process Flexibility)	Mix Flexibility
	Changeover Flexibility
	Rerouting Flexibility
	Material or Factor Flexibility
	Sequencing Flexibility
Service	Customer Support
	Sales Support
	Problem Solving
	Information

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Vickery et al. (1993) tested a refined measure of production competence, which they define as "the degree to which manufacturing performance supports the strategic objectives of the firm". The new measure centered on 31 components of production competence, such as delivery speed and process flexibility. In a study of 65 firms, a representative from each firm evaluated the importance of each component to the business strategy (7-point scale), assessed manufacturing's relative performance with regard to each component (-3 to +3), and estimated manufacturing responsibility for the component (%). These three values were then multiplied together for each component and summed to derive the production componence score. A stated objective of Vickery et al. (1993) is to test a model linking production competence, business strategy, and the interaction between these two constructs and business performance. As such, these measures needed to be broad-based, generalizable, and easy to apply across large samples.

Pannesi (1989) offered a detailed list of characteristics of every dimension of manufacturing capability. His proposal was to pick several key characteristics for a specific industry, then have managers to rate company performance on these key characteristics.

2.2.3. Trade-off vs. Synergy

Skinner's (1969) conceptual framework was the origin of the trade-off theory. He contended that the facility can not be expected, or be required, to perform well on multiple manufacturing tasks simultaneously, and that some manufacturing tasks must be traded off for others. The task of manufacturing strategy is, therefore, to configure t

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production systems to reflect the priorities and tradeoffs inherent in an organization's competitive situation and strategy.

Porter (1980) applied the idea of tradeoffs among competitive priorities to his taxonomy of general strategy. He divided competitive priorities into cost and differentiation, which included quality, dependability, flexibility etc. He warned that those firms attempting to simultaneously pursue both competitive priorities are firms "stuck in the middle" and will be guaranteed low profitability.

Hayes and Wheelwright (1984) defined the competitive priorities as the ways in which a firm chooses to compete in the marketplace and the types of markets it pursues. They explicitly advise against the pursuit of multiple competitive priorities, stating,

"It is difficult (if not impossible), and potentially dangerous, for a company to try to compete by offering superior performance along all of these dimensions simultaneously, since it will probably end up second best on each dimension to some other company that devotes more of its resources to developing that competitive advantage."

The work of more recent authors, including Hill (1989), Anderson et al. (1989), Hayes and Pisano (1994), Miller and Roth (1994) continues to support the tradeoff model. Most common examples of tradeoffs included cost versus quality and short delivery times versus low inventory investments.

There have been increasing amount of research that questioned the trade-off model in the field of operations management. There are two research streams that challenged the tradeoff model. Some authors including Nakane, De Meyer, Ferdows, Hall, and Nobel proposed or empirically tested a cumulative model that argued manufacturers should build one capability upon another sequentially. The other authors confronted the trade-off model conceptually, contending that the world class firms seem to compete on the basis of quality, dependability, cost, delivery and flexibility, all at the same time.

While studying Japanese manufacturers, Nakane (1986) suggested a cumulative model with quality improvement as the basis of all other improvement, followed by dependability. One should only improve on dependability if the quality level in the company has reached a critical level. His sequence continued by asserting that quality and dependability improvements are pre-conditions to cost efficiency improvements; cost efficiency becomes almost a consequence of quality and dependability improvements. Finally, flexibility improvements can only be obtained if a company has its quality, dependability and cost efficiency under control.

Hall (1987) echoed Nakane in stating that manufacturers should follow a stepwise progression through the capabilities in order to maintain a unity of purpose. The typical goal progression according to Hall is (1) quality improvement, (2) dependability or lead time, (3) cost reduction and (4) flexibility.

De Meyer et al. (1989) surveyed 574 Japanese, North American, and European manufacturers. Their result suggested that Japanese manufacturers were focusing on the trade-off between cost efficiency and flexibility. De Meyer et al. reasoned that Japanese manufacturers could do so because they had already reached prerequisite levels of quality, dependability, and cost efficiency sequentially over time. Their data showed that North American manufacturers were focusing on quality, with flexibility being low on their list of competitive priorities. Therefore they suggested that North American manufacturers were still on a lower level of competitive priority sequence. The findings for the European manufacturers were less clear.

Hall and Nakane (1990) expanded the preceding goal progression by adding new goals as follows: (1) a company-developed culture, (2) quality, (3) dependability, (4) waste reduction, (5) flexibility, and (6) innovation. They suggested that Japanese manufacturers had begun their goal progression in the 1950s and 1960s by starting with the quality capability, had progressed through the other high level goals, and by the mid-1980s were concentrating on the flexibility capability. In contrast, the U.S. manufacturers were focusing equally on quality and cost.

Ferdows and De Meyer (1990), in the light of increasing evidence of goal progression, formally proposed a cumulative model, which they called "sand cone model". They argued that many of the excellent manufacturers in Europe, North America, and especially Japan followed a distinct sequence of improvement programs which aim at building one capability upon, and not instead of, another. Their purpose was not to defy trade-off theory completely. Instead, they suggested that the trade-off theory is not valid under all contingencies and certain approaches change the trade-off into a cumulative one. They suggested that the approach which avoids trade-offs and ensures cumulative buildup of manufacturing capabilities in the long run is one which focuses on quality first, then quality and dependability, then quality, dependability, and flexibility, and finally on all three plus cost efficiency.

They used data from 1988 European Manufacturing Futures survey (167 respondents) to test and illustrate their model. Testing a sequential model on a static data set is arguable and they only claimed to find partial support to their model. They found in their data that 25% on respondents improved on only one capability, a large majority (62%) of the respondents improved on more than one capability simultaneously. They reasoned that trade-off theory would have predicted that the group of companies which have improved only one of the four measures would be the most numerous, therefore trade-off theory is refuted! Another support for cumulative model came from the observation that the "better than average" performers in quality conformance, in on-time delivery, in speed of new product development, and in inventory turnover have all emphasized zero-defect programs significantly more than "worse-than-before" group. They argued that this is the evidence that quality capability is at the bottom of the sand-cone -- the other capabilities all build upon quality capability. They attributed the lack of additional evidence to the use of a pre-existing database not designed for this particular study.

Ferdows and De Meyer's testing of cumulative model is far less than rigorous. First, the evidence of more than one capability is improved does not necessarily refute trade-off theory since trade-off theory does not make the assumption that only one capability can be improved over some period of time. Second, the association between zero-defect program and other capabilities is hardly enough to prove that quality is at the bottom of the sand-cone. They acknowledged this by saying that their purpose was not to "prove" the cumulative model but to provide some evidence for it.

Nobel (1995) extended previous studies by statistically testing the cumulative model in a multi-country context. She compared and contrasted the manufacturing strategies of 265 North American, 129 European, and 167 Korean factories by region. Similarly to Ferdows and De Meyer's finding, her result showed that competing on the basis of multiple capabilities simultaneously is associated with higher performance and better performing plants often compete with multiple capabilities-- usually with quality in the group.

The other stream of conceptual research that confronted trade-off model included Schonberger (1986), Roth and Miller (1990, 1992), Collins and Schmenner (1993), Schmenner (1993). They argued that the trade-off theory has been outdated by world class manufacturing.

New (1992) represented another opinion in this debate: he suggested that under the impact of world class manufacturing model, traditional trade-offs have changed over time: some disappeared, some still exists. For example, the trade-off between lead time and delivery reliability can be eliminated by high process repeatability and low buffers. However, the trade-off between quality and price still exists and may not be eliminated. New believed that a firm can not be the best in the world at all seven criteria simultaneously from the same manufacturing mix, which defies the belief of world class manufacturing model and is one of the major points this study wants to address.

2.3. World Class Manufacturing

As discussed in section 1, there have been two different trends in describing world class manufacturing: practice-based and performance-based. A majority of literature has been practice-based. The researchers have been engrossed in describing what a manufacturer needs to do step by step in order to achieve world class status.

Hayes and Wheelwright (1984) were the first to use the term "world class manufacturing". Through an in-depth analysis and comparison of the practices implemented by Japanese, German and U.S. firm, they developed six practices that world class manufacturers must adopt.

The first practice Hayes and Wheelwright proposed is to "build the skills and capabilities of your workforce". They found that German and Japanese firms do much more ongoing training than their U.S. counterpart. They criticized the assumption made by American manufacturers that motivation and work habits were developed elsewhere or that they would develop naturally as the worker matured on the job. Therefore, training must focus on both skills and attitude. They recommended that U.S. manufacturers take a proactive stance on developing workforce skills and capabilities through apprenticeships, internal training institute, and cooperative arrangements with vocational technical institutes.

They also found that "build technical competence throughout management" is a necessity for world class manufacturing and is where Japanese and German performed better than Americans. They suggested providing technical training for managers, developing more managers with engineering or technical degrees and rotating managers through technical functions in their organizations.

Hayes and Wheelwright's third practice "competing through quality" recognized that quality involves all parts of the organization as well as the customer's organization. They emphasized the coordination among marketing, manufacturing, and design engineering in achieving customer orientation.

In terms of "real worker participation", they went beyond recognizing the value of teamwork and of close bonds between functions and organizational levels. They pointed out that a long period of preparation and confidence building is required: workers and managers have to develop a common vocabulary, knowledge base and set of competences; production workers, engineers, and mangers have to be brought together so that interaction is natural and unavoidable.

Hayes and Wheelwright's fifth practice, "rebuild manufacturing engineering", describes the internal development of equipment with unique characteristics, which is difficult for competitors to copy.

They proposed "incremental progress" in their last topic "tortoise and hare approaches to industrial competition". While U.S. firms have traditionally pursued strategic leaps (referred to as the hare approach) as a means of manufacturing improvement, they suggest that the path of the race that leads to world class manufacturing be by incremental improvement (referred to as the tortoise approach). They also stressed the importance of measurement systems that can track this kind of progress, compensation and promotion systems that encourage it and resource allocation systems that support it for firms that adopt the incremental approach.

Other authors (Schonberger 1986, 1990, 1996, Giffi et al. 1990) have been more detailed in describing the attributes or practices of world class manufacturing. They added more dimensions and did not fully agree with what Hayes and Wheelwright proposed.

Schonberger (1996) proposed 16 principles for world class manufacturing. He claims that these principles apply in nearly every case. The 16 principles fall into eight categories. These 16 principles are:

General

1. Team up with customers; organize by families of customers or products (what customers buy/use).

2. Capture and apply customer, competitive, and best-practice information
3. Dedicate to continual, rapid improvement in quality, response time, flexibility, and value.
4. Frontline employees involved in change and strategic planning -- to achieve unified purpose.

Design

5. Cut to the few best components, operation and suppliers.

Operations

6. Cut flow time, distance, start-up, and changeover times all along the chain of customers.
7. Operate close to customers' rate of use or demand.

Human Resources

8. Continually enhance human resources through cross-training, job and career-path rotation, and improvements in health, safety, and security.
9. Expand the variety of rewards, recognition, pay, and celebration -- to match the expanded variety of employee contributions.

Quality and Process Improvement

10. Continually reduce variation and mishaps.
11. Frontline teams record and own process data at the workplace.

Information for Operations and Control

12. Control root causes of cost and performance, thereby reducing internal transactions and reporting; simplify external communications.
13. Align performance measures with universal customer wants: quality, speed, flexibility, and value (QSFV).

Capacity

14. Improve present equipment and human work before considering new equipment and automation.
15. Seek simple, flexible, movable, low-cost, readily available equipment and work facilities - in multiples, one for each product/customer family.

Promotion and Marketing

16. Promote, market, and sell your organization's increasing capability and competence -- every improvement (the results of the other fifteen principles).

Schonberger's 16 principles have slightly different focus on the same aspects from Hayes and Wheelwright's definition of world class manufacturing. Schonberger has incorporated more aspects and sometimes disagrees with Hayes and Wheelwright in defining the key practices of world class manufacturing. While Hayes and Wheelwright emphasize primarily on worker (skill and capability of workforce, real worker participation), manager (management technology competence), customer (competing through quality), and technology (rebuild manufacturing engineering, incremental progress), Schonberger's 16 principles can be described in a more concise way as customer focused, employee driven, and data (fact) based. Customer is viewed as the core of the principles (principles 1,2,7), supplier is brought into the picture (principle 5), how to reward and get employee involved is detailed (principles 4, 8, 9, 11). Design (principle 5), operations (principle 6, 7), performance measurement and reward systems (principle 9, 13), marketing (principle 16) which were ignored by Hayes and Wheelwright are key aspects perceived by Schonberger. In some aspect, they even disagree: while Hayes and Wheelwright suggest proprietary equipment is the key to lasting capability, Schonberger proposes improving present equipment and seeking simple, readily available equipment.

Giffi, Roth and Seal (1990) have taken a similar approach to Schonberger's. They described world class manufacturing in terms of principles in the following way: quality and customer dimension is the core of the principles, the other dimensions such as management approach, manufacturing strategy, manufacturing capabilities, performance measurement, human assets, organization and technology aspects all interact with quality and customer dimension. Giffi et al. were the first to add manufacturing strategy into the framework. They also provided some insight about trade-off vs. synergy about manufacturing capabilities. They argued that achieving multiple capabilities (quality, dependability, cost and flexibility) simultaneously is one of the key success factors for manufacturing excellence. On the other hand, they stressed that quality is current measure of success. They predict that time-based competitive capabilities (such as dependable delivery time, delivery speed, and flexibility) will be the key success factor for the future. They also emphasized that it does not mean quality will no longer be important, but superior quality will be assumed. This line of thinking echoes Ferdows and De Meyer (1990)'s cumulative model on building competitive capabilities. Schmenner (1993) also found agreement with Giffi et al. in that world class manufacturing outdated tradeoff theory.

2.4. Relationship between Practices and Performance

The relationship between practices and performance has been attracting a lot of attention in manufacturing strategy literature. There are two main reasons why the practice-performance relationship has been the focus of attention for some time. First, the wide-spread use of benchmarking (copying the best practices) to achieve competitive advantage implicitly assumes a strong relationship between manufacturing practices and performance. Second, unrelenting pressure on firms from stakeholders to increase asset productivity has been forcing companies to carefully evaluate and justify investments in manufacturing practices. Despite this topic's practical significance and importance, there has not been a great deal of literature that has examined the relationship between practice and performance comprehensively.

Manufacturing practices typically include shop floor practices (e.g. application of Total Quality Management), human resource management practices, supply chain management practices, to name a few. The definition of manufacturing performance typically varies based on the objective of the individual study.

Studies in the literature have mostly focused on the relationship between a subset of practice with a subset of performance.

For example, Flynn et al. (1995, a) investigated the relationship between quality management practices to quality performance. Flynn et al. (1995, b) confirmed that the use of unique JIT practices was positively related to JIT performance, given use of common infrastructure practices. Flynn et al. (1995, b) also verified that the use of common infrastructure practices was positively related to JIT performance, and the use of unique

TQM practices was positively related to JIT performance, given use of unique JIT and common infrastructure practices.

The relationship between some specific practices and composite manufacturing performance also provoked researcher's great interest. Young (1992) has proposed direct relationship between performance and some aspects of practice. These aspects include rate of adoption of JIT, high quality delivery, the rate of adoption of a secondary control system etc. Yet these relationships remain to be examined empirically. Sakakibara et al. (1997) studied the impact of JIT and its infrastructure on manufacturing performance and suggested that JIT practices have value only when they are used to build infrastructure.

Voss et al. (1995) and Collins et al. (1996) have asserted that the adoption of best practices leads to high performance. Both authors found this relationship to hold at the aggregate level through an examination of scatter plots of data relating to a performance index versus an aggregate index of manufacturing practices. These two studies represent the first two studies to systematically examine the relationship between manufacturing practices and performance and they have defined a new area for research within the rubric of manufacturing strategy. Beaumont et al. (1997) found that the use of AMT which includes direct technologies (NC and laser cutting), indirect technologies (CAD and MRP), and philosophies (JIT and TQM) in general is not associated with manufacturing or business success, which is an apparent contradiction in light of the conclusions reached by Voss et al., and Collins et al. However, the authors also found that specific technologies are associated with some aspects of performance.

The review of literature in the relationship between practice and performance reveals that an empirical testing between the relationship of a comprehensive set of manufacturing practices and a comprehensive set of manufacturing performance was lacking. The link between specific manufacturing practices and specific manufacturing performance was not well understood. The relationship between quality and cost is a good example. Increasingly, quality is now recognized as a major contributor to cost reduction. Thus, in a cost competitive environment, quality programs may be the most appropriate response rather than cost reduction programs. These specific relationships are of great interest to operations managers. Decisions on adoption of specific practices are usually made after manufacturing strategies have been made. Managers are especially interested in deciding which practices have an effect on their manufacturing goals.

2.5. Summary of Literature Review

The review of literature in the area of world class manufacturing, relationship between practices and performance, taxonomy of manufacturing strategy, and competitive performance revealed several issues.

First, literature in world class manufacturing has been going into two directions: practice-based and performance-based. Despite recognizing that "best practices" lead to superior performance, there was no systematic approach to study this relationship in the context of world class manufacturing.

Second, measurement issue in world class manufacturing, taxonomy of manufacturing strategy, and competitive performance needs to be solved. Empirical studies in these fields will help advance theory in these areas.

Third, the knowledge bases of taxonomy, relationship between practice and performance, competitive performance and world class manufacturing are intertwined. It is not surprising that the advance of one field will help to solve the questions in another field. The trade-off theory vs. cumulative model is one example. It originated as a debate in the area of competitive performance. The experiences coming from world class manufacturing offered a great deal of explanation in this debate.

There is increasing number of research pieces that utilized the methodology and knowledge from multiple areas in strategy literature. It can be argued that taxonomy of manufacturing strategy, relationship between practices and performance, and competitive performance are all relevant topics within world class manufacturing. An effort to apply the techniques and theory from these areas to the context of world class manufacturing will lead to the advance of knowledge base and a better understanding of strategy in world class manufacturing and manufacturing in general. A framework that integrates knowledge bases from multiple areas will be presented in chapter 3.

CHAPTER 3

CONCEPTUAL FRAMEWORK

Chapter 2 identified the limitations and gaps in several research streams that are related to world class manufacturing. The gaps and limitations in literature helped identifying research questions in this dissertation. The review of literature, in return, also offered the potential solutions to these questions. Chapter 3 will develop a conceptual framework based on literature review, propose research hypotheses and provide rationale for research hypotheses.

3.1. Conceptual Framework

This dissertation aims to provide a definition of world class manufacturing and an empirical investigation of the relationship between manufacturing practices and performance.

The relationship between practices and performance has been assumed by practice-based definition of WCM and many other research pieces in manufacturing strategy. However, it has not been studied in a systematic way. To study the relationship between practices and performance, the first and foremost task is to establish measurement models for practice and performance.

In order to do so, efforts were made to synthesize the dimensions of practice and performance from the most classical literature on WCM. Nine practice constructs were identified based on Hayes and Wheelwright (1984), Schonberger (1990, 1996), Giffi, Roth and Seal (1990).

The practice profile is listed in Table 3.1. The descriptions on these dimensions from previous researchers are also listed. A symbol (a), (b), or (c) for each practice construct indicates the literature where the description comes from. (a) indicates it comes from Hayes and Wheelwright (1984), (b) indicates it comes from Schonberger (1990, 1996), (c) indicates it comes from Giffi, Roth and Seal (1990).

Table 3.1 Practice Profile with Literature Support

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1. Quality Management

(a) Competing though quality

(b) Principle 3: Dedicate to continual, rapid improvement in quality, response time, flexibility, and value.

Principle 10: Continually reduce variation and mishaps.

Principle 11: Frontline teams record and own process data at the workplace.

(c) Define quality in terms of the customers' needs. Make customer closeness the number one priority.

View quality from a global perspective. Achieving quality of product should be no more and no less important than achieving quality of process and service.

2. Customer Orientation

(a) Principle 1. Team up with customers; organize by families of customers or products (what customers buy/use).

Principle 2: Capture and apply customer, competitive, and best practice information

Principle 7: Operate close to customer's rule of use or demand.

(b) Integrate the concept of customer closeness into the organization so that everyone in the organization has a customer, and everyone's goal is to provide quality product and service to his or her customer.

(c) Define quality in terms of the customers' needs. Make customer closeness the number one priority.

3. Labor Force Management

(a) Workforce skills and capabilities

Workforce participation

(b) Principle 4: Frontline employees involved in change and strategic planning -- to achieve unified purpose.

Principle 11: Frontline teams record and own process data at the workplace

Principle 8: Continually enhance human resources through cross-training, job and career-path rotation and improvements in health, safety and security.

(c) Invest in people; develop a pattern for updating workforce skills and capabilities consistent with the evolution of technology within the organization.

Empower teams of workers to carry out the mission of the organization. Seek ways to liberate the teams from traditional organizational controls, and reward and motivate, based upon ability to achieve meaningful goals.

Eliminate the terms supervisors and supervision. Develop leaders who can create and execute the strategic vision through the teams.

Evaluate the success of your human assets on the basis of their ability to learn, adopt to change, and improve performance within their area of responsibility.

Develop accelerated and integrative learning programs.

4. Operations Flow

(a) Not mentioned

(b) Principle 5: Cut to the few best components, operations, and suppliers

Principle 6: Cut flow time, distance, start-up, and changeover times all along the chain of customers.

Principle 7: Operate close to customers' rate of use or demand

(c) Make dependability and consistency in quality, delivery, and service to your customers the goal of all operations.

Develop manufacturing operations that are flexible and able to respond rapidly to changes in products and markets. Value leanness of operation above all other manufacturing performance indicators.

Restructure engineering operations to reduce waste and inefficiency and improve quality. Develop engineering capabilities characterized by adherence to concurrent development techniques that integrate customer quality requirements.

Consider the environmental impact of all products and processes, making environmental considerations an integral component of the design and production processes.

5. Operations Capability

(a) Incremental improvement approach

(b) Principle 3: Dedicate to continual, rapid improvement in quality, response time, flexibility and value

Principle 5: Cut to the few best components, operations and suppliers

Principle 10: Continually reduce variations and mishaps

(c) Develop manufacturing operations that are flexible and able to respond rapidly to changes in products and markets.

Develop measurement systems that encourage continual learning.

6. Strategy Formulation and Measurement

(a) not mentioned

(b) Principle 9: Expand the variety of rewards, recognition, pay and celebration -- to match the expanded variety of employee contributions.

(c) Establish a clearly defined strategic intent; define success in terms of winning for the long term.

Establish a strategy consistent with the potential for developing needed manufacturing capabilities. Base the strategy on a realistic assessment of capabilities and priorities, but always look to push beyond the present.

Develop a global perspective on competition, responding to international competition with at least the same intensity as to domestic challenges.

Make the strategy more than a formal statement of policy. Make it a blueprint for action, a pattern of decision to be executed over time. Deal with structural elements, infrastructural issues, and integration elements.

Put the strategy in writing. Manufacturers that have written strategies have been more forceful in the change process than those that have not written strategy.

Develop the strategy through a participative approach and freely share it with all employees in the organization.

Develop a strategy that is flexible and adaptive over time as the competitive environment changes. Review the strategy on a scheduled, periodic basis to ensure congruence with current and future goals and capabilities. Make modifications and enhancements as required.

Implement the strategy to effect change as a gradual process of small continuous steps over time. Allow your strategic intentions to govern the size of your steps.

Focus on the competitive variables the customer requires. Allow customer success to drive financial success.

Promote and measure knowledge and skill development. Develop measurement systems that encourage continual learning.

Increase the vitality of the entire business by focusing attention on integrated business management. Measure the effectiveness of the boundary management that occurs.

Tailor the performance measurement system to the company's strategic action programs. Manufacturing strategy is defined explicitly in terms of performance measurement. As strategy changes, so too should the critical measures of success.

7. Technology

(a) Management technical competence, Rebuilding manufacturing engineering

(a) Principle 14: Improve present equipment and human work before considering new equipment and automation

(b) Principle 15: Seek simple, flexible, movable, low-cost, readily available equipment and work facilities -- in multiples, one for each production / customer family. Develop an investment for the continual enhancement of technology throughout the organization, based on a clearly defined vision of future competitive requirements. Identify the competitive advantage of the knowledge base that advanced technology can create; simultaneously implement new technology and develop the new knowledge base.

Carefully plan technological upgrades to be consistent with infrastructural upgrades, Benefits can be achieved only when the infrastructure is capable of integrating and exploiting the technology advantage offered.

8. Supplier Relationship

(a) Not mentioned

(b) Principle 5: Cut to the few best components, operations, and suppliers.

(c) Not mentioned

9. New Product Development

(a) Not mentioned

(b) Principle 1: Team up with customers; organize by families of customers or products.
Principle 2: Capture and apply customer, competitive, and best practice information
Principle 3: Dedicate to continual, rapid improvement in quality, response time, flexibility and value.
Principle 5: Cut to the few best components, operations and suppliers.

(c) Not mentioned

It is shown from Table 3.1 that the first seven practice dimensions in this practice profile received greater attention from literature. The last two dimensions: supplier relationship and new product development are relatively new and received less attention. These two dimensions, however, are perceived to impact the manufacturing capability by many recent researchers. Their impact on performance is somewhat less determined. They are added into practice profile due to the consideration that the three classic works on WCM practices are somewhat less recent and may not be complete in including all the dimensions that emerged in recent practices. It is the goal of this dissertation to either confirm or disconfirm the relationship between these practices with performance.

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The performance profile measures will take the most conventional constructs: cost, quality, delivery and flexibility. The detailed breakdown for each construct is selected and modified from Garvin's decomposed strategic priorities. Table 3.2 lists all the items in performance profile.

Table 3.2 Performance Profile

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1. Cost

(1) initial purchase cost

(2) manufacturing overhead cost

(3) maintenance cost

2. Quality

(1) Product overall quality performance

(2) Product feature

(3) Product reliability

(4) Product conformance

(5) product durability

(6) Product serviceability (speed, courtesy and competence of repair)

(7) Customer satisfaction

(8) Impact of brand name

3. Delivery

(1) Delivery accuracy (correct items were delivered)

(2) Delivery availability (the probability that items will be in stock at the time of order)

(3) Delivery dependability (delivered on the agreed upon date)

(4) Delivery speed (short elapsed time between order placement and product reaches the customer)

(5) Delivery quality (condition of product after shipment)

4. Flexibility

(1) Ability to customize products

(2) Lead time to introduce new products

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(3) Ability to adjust production volumes

(4) Number of engineering change orders per year

(5) Number of new products introduced each year

(6) Ability to respond to changes in delivery requirements

(7) Ability to produce a range of products

In achieving the two objectives of this dissertation, not only the methods and theories from world class manufacturing literature are studied, but also theories and methodologies from related areas. For example, efficiency analysis is one method that has been used for performance analysis and identifying "best practice" units in various domains such as health care systems (Sherman 1984, Gerdtham, Rehnberg, and Tambour 1999), retail stores (Thomas et al. 1998), banks (Sherman and Gold 1985, Thomas and Barr 1998), education systems (Bessent and Bessent 1980, McMillan and Datta 1998), and manufacturing (Banker et al. 1984, Byrnes et al. 1988 and Vargas et al. 1996).

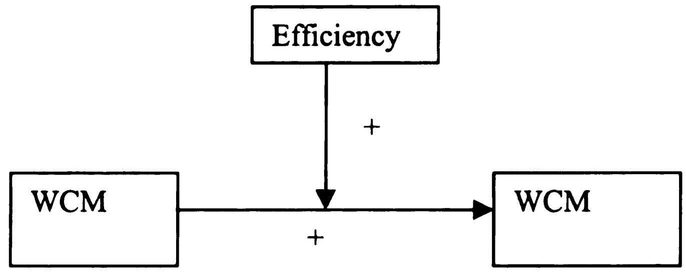
In efficiency analysis, more specifically, data envelopment analysis (DEA), no functional forms linking outputs and inputs have to be assumed. Efficiency can be defined as the weighted sum of unit i's outputs over weighted sum of unit i's inputs. A separate linear programming problem is solved for each unit. The objective for each unit is to maximize the weighted sum of that unit's output versus its inputs. Those units that achieve an efficiency of 1 are those units that can produce the most amount of outputs with the least amount of inputs compared with their peers.

Data envelopment analysis, due to its non-parametric property, requires no prior knowledge or theory relating to the relationship between inputs and outputs, therefore, this method is not biased toward any existing theory. It has also been used extensively as a popular tool to identify the "best practices" production function. In this study, an identification of best performing manufacturing plants can be very well fulfilled by applying this type of analysis.

Efficient manufacturing plants will be the ones that can best utilize inputs and produce outputs. This criterion will be considered as a pre-condition for world class manufacturing.

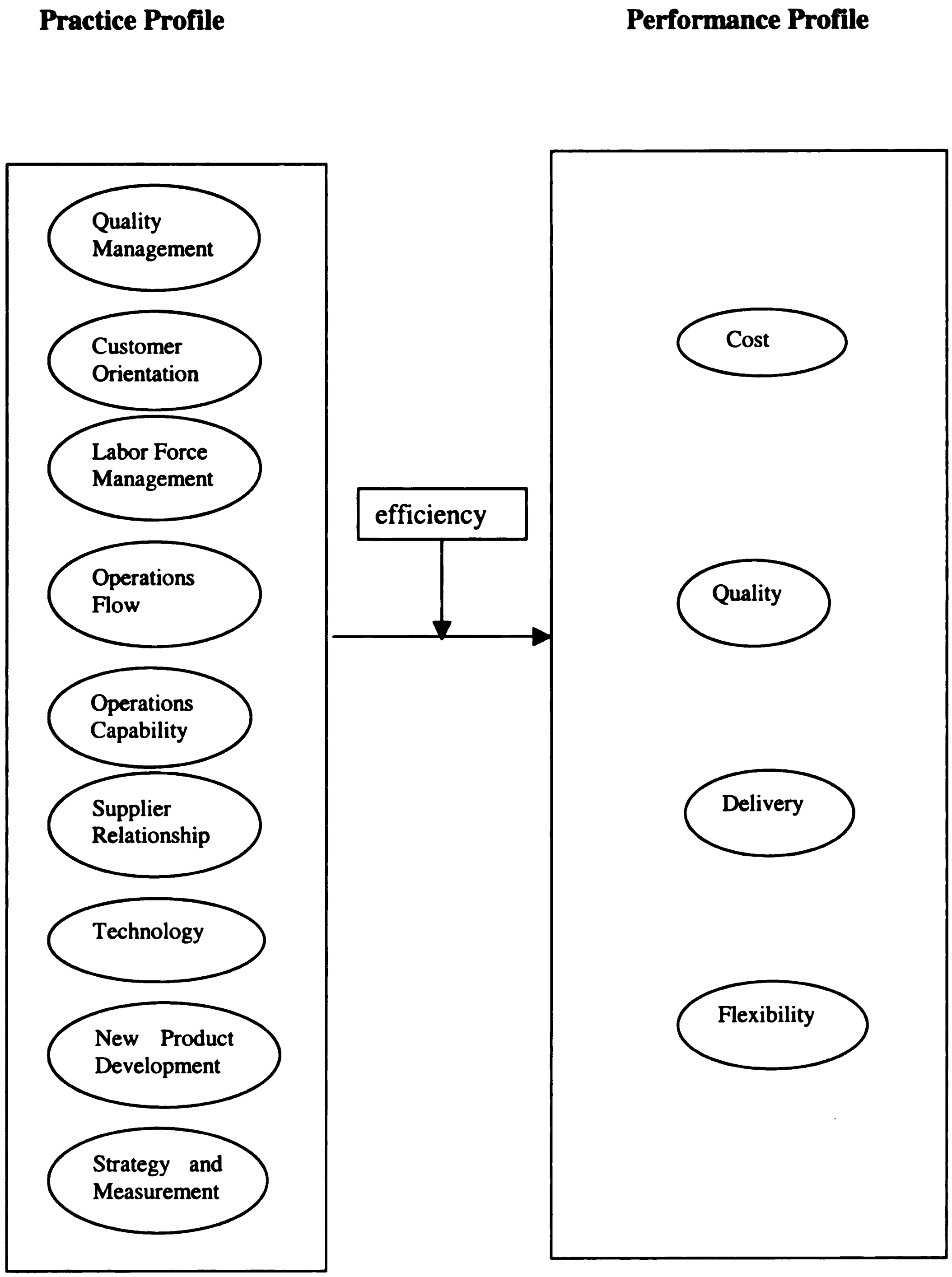
The second objective of this dissertation is to systematically study the relationship between the so-called "WCM practices" and performance. The positive relationship between "WCM practices" and performance has been assumed in WCM literature, but has never been empirically tested and verified. In this dissertation, not only will the relationship between WCM practices and performance be studied, but also the relationship will be used to verify the validity of efficiency analysis. Efficiency analysis is a quite new technique in operations management although it has been used extensively in other fields. One way to verify the validity of efficiency is to cross check efficiency with the strength of the relationship between practices and performance. Efficient plants are best performing plants that can best utilize tangible inputs to produce tangible outputs. It can be argued that efficient plants can also utilize manufacturing practices better than non-efficient plants. That is, the strength of the relationship between practices and performance are stronger for efficient plant than for non-efficient plants.

Figure 3.1 Efficiency as a Moderator between WCM Practices and Performance



The purpose of this dissertation is to examine the relationship between practice and performance from a broad perspective. It is hypothesized, that adopting these practices will lead to superior performance, similar to arguments of the "best practice" literature and practice-based definition of WCM. Figure 3.2 depicts the framework in this dissertation. In this figure, practice profile and performance profile are the two vital components. However, this framework differs from prior knowledge in that the relationship between practice and performance is moderated by efficiency.

Figure 3.2 Conceptual Framework for World Class Manufacturing



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3.2. Hypotheses Development

To test the moderating effect of efficiency on the relationship between practices and performance, hypothesis 1 is constructed with nine separate sub-hypothesis each for testing for one practice dimension.

Hypothesis 1a: Efficiency is a positive moderator between Quality Management dimension and performance.

Hypothesis 1b: Efficiency is a positive moderator between Customer Orientation dimension and performance.

Hypothesis 1c: Efficiency is a positive moderator between Labor Force Management dimension and performance.

Hypothesis 1d: Efficiency is a positive moderator between Operations Flow dimension and performance.

Hypothesis 1e: Efficiency is a positive moderator between Operations Capacity dimension and performance.

Hypothesis 1f: Efficiency is a positive moderator between Supplier Relationship Dimension and performance.

Hypothesis 1g: Efficiency is a positive moderator between Technology dimension and performance.

Hypothesis 1h: Efficiency is a positive moderator between New Product Development and performance.

Hypothesis 1i: Efficiency is a positive moderator between Strategy and Measurement dimension and performance.

Literature from taxonomy of manufacturing strategy suggested that there are multiple strategy types even with the best manufacturing plants. By applying the same logic, it is reasonable to assume that there is more than one strategic group in efficient manufacturing plants. Competitive priorities are generally viewed as the linkage between market/consumer and manufacturing strategy (Porter 1980, New 1992, Todd 1995). Since market is generally segmented by different groups of customers disregarding the specific product or industry, efficient manufacturing plants have adopted different strategies that best serve the diverse market.

This leads to hypothesis 2 which is constructed to test whether there are more than one strategy type within efficient manufacturing plants.

Hypothesis 2: There is more than one strategic group within the efficient manufacturing plants.

The nine practice dimensions in the conceptual framework are summarized based on literature of practice-based definition of world class manufacturing. One of the weaknesses in such definition is that it does not address the priority in selecting these practices. A plant planning to benchmark the best performing plant, however, would very much want to find out, on which practices it should place its efforts since resources are limited. This dissertation tries to overcome this limitation by investigating how the priorities differ across the practice dimensions among different strategic groups.

Hypothesis 3 is framed in line with prior expectation that these priorities differ across different strategic groups. Nine sub-hypothesis are constructed one for each practice dimension.

Hypothesis 3a: Different strategic groups within efficient manufacturing plants place different priorities on Quality Management dimension.

Hypothesis 3b: Different strategic groups within efficient manufacturing plants have different priorities on Customer Orientation dimension

Hypothesis 3c: Different strategic groups within efficient manufacturing plants have different priorities on Labor Force Management dimension.

Hypothesis 3d: Different strategic groups within efficient manufacturing plants have different priorities on Operations Flow dimension

Hypothesis 3e: Different strategic groups within efficient manufacturing plant have different priorities on Operations Capability dimension.

Hypothesis 3f: Different strategic groups within efficient manufacturing plants have different priorities on Supplier Relationship dimension.

Hypothesis 3g: Different strategic groups within efficient manufacturing plants have different priorities on Technology dimension.

Hypothesis 3h: Different strategic groups within efficient manufacturing plants have different priorities on New Product Development dimension.

Hypothesis 3i: Different strategic groups within efficient manufacturing plants have different priorities on Strategy and Measurement dimension.

This chapter presented a conceptual framework that integrated theory and methodology from several different areas. This framework resolves around and facilities a better understanding of world class manufacturing. Individual hypotheses were development to test this framework and achieve the objectives of this dissertation.

Chapter 4 describes research design, sampling frame, and the methodology that will be used to test hypotheses and the conceptual framework.

CHAPTER 4

RESEARCH DESIGN

4.1. Research Design

As stated in chapter 1, there are two major objectives that this dissertation intends to achieve by following five procedures. In this chapter, five stages of statistical testing are designed one for each procedure.

The first stage of this dissertation is to establish a set of measures for WCM practices. Previous studies (Hayes and Wheelwright 1984, Schonberger (1990, 1996), Giffi, Roth and Seal (1990)) are descriptive in nature. None of them provided concrete measurement items, not to mention validation of the measures. The second stage is to provide efficient analysis and select efficient plants in data sample. The third stage is to investigate the moderating effect of efficiency on the relationship between manufacturing practices and performance. The fourth stage is to provide an empirical taxonomy on efficient manufacturing plants in data sample. The fifth stage is to test whether strategic groups emphasize different set of practices if there is more than one strategic group in efficient manufacturing plants.

For the above purposes of this dissertation, a large scale empirical testing will be useful because standardized measures, which are a necessity for making comparisons, can be used across a broad population in order to make generalizable conclusions (Fowler 1988). A survey will be used since very few published empirical studies have undertaken broader scale investigations to empirically test hypotheses associated with WCM.

DeVellis (1991) recommended a sequence of action when building scales:

First, clarify and specify what is sought to be measured, and generate an item pool. Next, choose the format of measurement, have initial item pool reviewed by experts, and consider inclusion of validation items. Then administer items to a development sample, evaluate the items. Lastly, optimize scale length.

Scale development procedure in this dissertation will follow the above guidelines.

4.1.1. Scale Validation

Except for control variables, all practices and performance item measures will be measured on a 7 point Likert scale. The respondents are asked to compare their plants with industry average, with 1 indicating "much less" (than industry average), 4 indicating "about the same" (as industry average) and 7 indicating "to a much greater extent" (than industry average). The Likert scale has been preferred over other scales for several reasons. Alternative methods do not offer specific response categories. For example, in semantic differential scaling method, there are no interval points along the two extremes. The respondents' position on the continuum between the two extreme is subject to mis-interpretation by both respondents and researchers. In contrast, there are plenty of supports in literature for the assumption of numeric, equal intervals in a Likert scale, for the purpose of multivariate data analysis (DeVellis 1991, Nuunally 1978, Kerlinger 1973). Therefore, Likert scale has been commonly used in operations strategy literature due to its established performance.

Initial face validation for the items was achieved through discussions with practitioners and academics. A Q-sort of the scales was undertaken through a blind administration of the item measures to a group of 3 practitioners and 3 academics. The subjects were requested to examine the item measure and relate them to their respective underlying constructs. Those items with a majority of incorrect linkages to underlying constructs were dropped from the list of measures.

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

4.1.2. Unit of Analysis and Sample Selection

The unit of analysis in this dissertation was individual plant due to the consideration that plant is the level of implementation for most manufacturing practices programs, and has been used in numerous other empirical studies related to competitive priorities (Schonberger 1983, Griffin 1988, Ebrahimpour and Withers 1992, Ahire, Golhar, and Waller 1996). Therefore, the use of plant as the unit of analysis is strongly supported by previous research.

It is noted that information gathered from multiple respondents at a single site is desired in reducing the potential for bias from a single respondent (Klassen 1995). However, the cost and time associated with obtaining multiple responses from a large number of plants would be prohibitive in this research. Response rate will very likely be significantly reduced with such a strategy. Miller and Roth (1994) suggested that greater attention to informant selection can help to overcome the common method variance problem. Therefore, only single respondents will be targeted for this dissertation. Plant manager is considered the level of management that is most suited to complete this questionnaire, is therefore selected as the respondent in this research.

4.1.3. Data Collection

The data was collected by utilizing Internet Technology: web technology and database. The respondents were not required to mail the questionnaire back. Instead, a copy of the questionnaire was posted on the Internet. The respondents were given a survey ID when they received the invitation letter and they were required to go to the specified web site to fill out the questionnaire. When the respondent first visited the web site, he/she was asked to provide the survey ID (in order to keep track of respondents and send follow up notice to the non-respondents) and select login name and password. With login name and password, they were not required to fill out the questionnaire in one session. They were able to save the answers by submitting the questionnaire. Upon submitting the questionnaire, the respondent was notified how many questions he/she has already filled out. When the respondent logged on using login name and password next time, only the unanswered questions were presented to him/her. This design prevents the respondents from modifying their answers once submitted and helps the respondents keep track of unanswered questions. If the respondent wanted to keep a copy of what he/she answered for the questions, he/she could select the option of "view survey" and print out his/her own answers for each survey question.

This technique had several advantages over the traditional mail based surveys (Dillman 2000). The primary reason for adopting this technique was cost consideration. By utilizing the web survey technique, the printing cost was totally avoided. The cost of mailing was significantly reduced due to a smaller package. Time is also a big issue that favors the decision to go on web survey. With the Internet communications, the responses were able to reach the researcher in a few seconds rather than weeks via mail. With database performing data storing and retrieving functionality, there was no need to manually enter data into the spreadsheet from responses as needed by the traditional mail survey. Not only was time and cost for data entry reduced, but there was increased accuracy. The specific design of this web survey, which allowed respondent to return to the web site and fill out in another session, added a lot of flexibility. First, fatigue with filling out a long survey was somewhat lessened, therefore, response rate may have increased. Second, by constantly informing the respondents of the number of questions they have completed, the chances of unintentional missing field were reduced. Integrity checking was added in database design to prevent the respondent entering obviously invalid responses. For example, when asked for sales, we would expect the responses to be in the format of numbers instead of letters. If letters were received, an error message was sent to the respondent and the respondent was prompted to reenter the field. By adding error checking into the database, a higher level of data integrity that is not possible with the mail based survey was achieved.

Despite so many advantages with this new technique, it is not perfect. The biggest concern the researchers are faced with web based survey is that the response rate may be affected by managers' inexperience with Internet Technology. The senior managers, the target of this research, are often in their fifties or sixties. These managers are generally less familiar with the Internet than younger generations. They may feel uncomfortable or reluctant to read and answer questions on the computer and using the mouse clicks. They may prefer reading and filling out questionnaires old-fashioned way.

Although the questionnaires were to be filled out on the Internet, the managers were contacted by mail because it was believed the mailing material would generate more awareness than email. The mailing procedure employed a three-step process similar to that recommended by Dillman (1979, 2000). Each letter was mailed directly to the plant manager. The first invitation letter was sent out together with the web address where the survey is hosted. A reminder postcard with the web-address of the questionnaire was sent out to those plants not yet responding two week following the first mailing. Finally, four weeks after the first mailing, another reminder postcard was sent to the non-respondents.

4.2. Methodology

To follow the five procedures of data analysis in this dissertation, there will be five different research methodology one for each procedure. This section details how these five procedures will be implemented, and how to test for validity of each procedure.

4.2.1. Establish Measurement Models

During the first stage of data analysis, the WCM practices and performance measurement models was tested using confirmatory factor analysis. Confirmatory factor analysis overcomes some inherent limitations associated with exploratory factor analysis (Ahire, Golhar and Waller 1996). Exploratory factor analysis often falters when faced with interpretability issues (Mulaik 1972). Lack of a-priori knowledge about construct covariation dynamics may lead to the result that the interpretations of the factors may be nothing more than tautological transformations of the names of the original variables. Confirmatory factor analysis, on the other hand, builds factor constraints based on the number of factors, the nature of their mutual relationships and the strength of those relationships. Confirmatory factor analysis has gained increasing popularity over exploratory factor analysis in the fields of marketing and organizational behavior due to its conceptual strengths (Venkatraman 1989, Bollen 1989).

In this research, separate measurement models for WCM practices and performance using CFA based on literature were constructed and tested. Data were first analyzed for univariate and multivariate normality by examining Mardia's coefficient in EQS. Reliability can be assessed using Cronbach's alpha or composite alpha. Convergent validity was evaluated by the standardized factor loading for constructs, using a cut-off value of 0.40 (Hair, Anderson, Tatham, Black 1994). Discriminant validity can be assessed by two methods. First, all inter-factor correlations for all the constructs needed to be significant different from 1 (Challagalla and Shervani, 1996). Second, the average variance extracted for each construct was computed and verified to ensure that it was greater than the squared correlation between that construct and any other construct in the model (Fornell and Larcker 1981).

After eliminating items that load on multiple constructs or have low item-to-construct loadings, fit indices were used to assess if the measurement model is a good fit in the data.

Absolute fit concerns the degree to which the covariance implied by the fixed and free parameters specified in the model match the observed covariance from which the free parameters in the model were estimated. Four of the most basic measures of absolute fit are the likelihood Chi-square (χ^2), the goodness-of-fit index (GFI), the root mean square residual (RMR) and root mean squared error of approximation (RMSEA). Chi-square can be used to assess the discrepancy between a hypothesized model and data. χ^2 test become more sensitive as the number of indicators rise. Bentler and Bonnet (1980) and Bentler 1990 indicated that t statistics may not be χ^2 distributed in small sample. Small samples usually have a much greater tolerance towards specification errors than large samples. Specifically, the χ^2 statistics will almost always be significant in large samples (Hartwick and Barki, 1994). GFI is a goodness-of-fit measure, which is not adjusted for model parsimony. The recommended level for an acceptable GFI is .90 or higher. . The root mean square residual (RMR) indicates the average residual correlation, usually deemed acceptable with a value of .080 or lower. Root mean squared error of approximation (RMSEA) assesses model discrepancy per degree of freedom. Values of the RMSEA less than or equal to .080 represent a reasonable fit (Hair et al. 1994).

Incremental fit measures assess the incremental fit of the model compared to a null model, usually the one that specifies no covariances among variables. The recommended value for both an acceptable IFI (incremental fit index) and an acceptable CFI (comparative fit index) is .90 or higher. CFI is relatively unaffected by sample size (Bentler 1990) and was recommended by Bentler (1990) as the index of choice. Bentler-Bonnet Non Normed Fit Index (NNFI) is also an incremental fit index has no substantial association with sample size (Marsh et al. 1988).

Parsimonious fit measures provide a basis for comparison between models of differing complexity and objectives. One applicable measure for evaluating a single model is the normed χ^2 measure, which is χ^2 divided by the degree of freedom. The normed χ^2 with a value below 2 is considered acceptable (Bentler 1990).

Individual estimates of free parameters are evaluated according to their difference from zero. The ratio of each estimate to its standard error is distributed as a z statistic. Z value must exceed 1.96 to achieve a significance level of $p < .05$. For significance level of $p < .10$, z value must be greater than or equal to 1.645.

Reliability is a measure of the internal consistency of the construct indicators, depicting the degree to which they "indicate" the common latent (unobserved) construct. Cronbach's alpha with a value equal to or higher than .70 indicates a good reliability for a latent construct.

4.2.2. Identify Efficient Manufacturing Plants

During the second stage of data analysis, data envelopment analysis (DEA) was performed to identify efficient manufacturing plants. Data Envelopment Analysis (DEA) was developed in 1978 by Charnes, Cooper and Rhodes. Since then, it has become a popular tool for performance evaluation. Applications of DEA have been used to evaluate the efficiency of vendors (Weber and Desai 1996, Weber, Current, and Desai 1998), manufacturing firms (Banker, Charnes, and Cooper 1984, Byrnes, Fare, Grosskopf, and Lovell 1988, Vargas, Whybark and Xiao 1996), health care systems (Sherman 1984; Gerdtham, Rehnberg, and Tambour 1999), retail stores (Thomas, Barr, Cron, and Slocum 1998), banks (Sherman and Gold 1985, Thomas and Barr 1998), education systems (Bessent and Bessent 1980, McMillan and Datta 1998) to name a few.

DEA is a linear programming based technique for estimating the relative efficiency of organizational units where the presence of multiple inputs and outputs makes the comparison difficult. In DEA, relative efficiency for each decision making unit (DMU) is the ratio between weighted sum of outputs and weighted sum of inputs.

Each DMU is allowed to adopt a set of weights which maximize this unit's efficiency in comparison to the other units.

DEA was chosen as the tool to analyze the efficiency of manufacturing plants and derive the best plants for several reasons. First, DEA is a non-parametric technique. That is, it does not require any assumptions regarding the function form for the relationship between the inputs and outputs. In this study, the production function of the plants may vary from one plant to another. WCM plants are expected to have a different production function from non-WCM plants. Second, DEA focuses on determining "best-practice" production function by identifying the Decision Making Units (DMUs) on the efficient frontier rather than on central tendency properties of frontiers. In contrast to parametric approaches whose object is to optimize a single regression plane through the data, DEA optimizes on each individual unit. That is, instead of focusing on "average" production function as in regression, DEA focuses on "best practices" production function. The comparison between DEA and regression production functions is shown in Figure 4.1. WCM plants, in this study, are defined as those plants that utilize the "best-practices" production function so that they produce the most amounts of the outputs with the least amounts of the inputs. These characteristics of DEA make it an ideal tool to determine which plants in the sample are WCM plants.

There are four basic DEA models: CCR ratio model (Charnes, et al. 1978), BCC model (Banker, Charnes, and Cooper 1984), Multiplicative model (Charnes, et al. 1982; Charnes, et al. 1983), and Additive model (Charnes, et al. 1985, 1990). The choice for these basic models is the envelopment surface. The CCR model yields a piecewise linear, constant returns-to-scale envelopment surface, the BBC and Additive models result in a piecewise linear, variable return-to-scale envelopment surface, while the Multiplicative model yields piecewise log-linear envelopment surface. Figure 4.2. depicts a CCR model with constant return-to-scale envelopment surface. Figure 4.3. illustrates a BCC model with variable return-to-scale envelopment surface.

Figure 4.1 Comparison between DEA and Regression

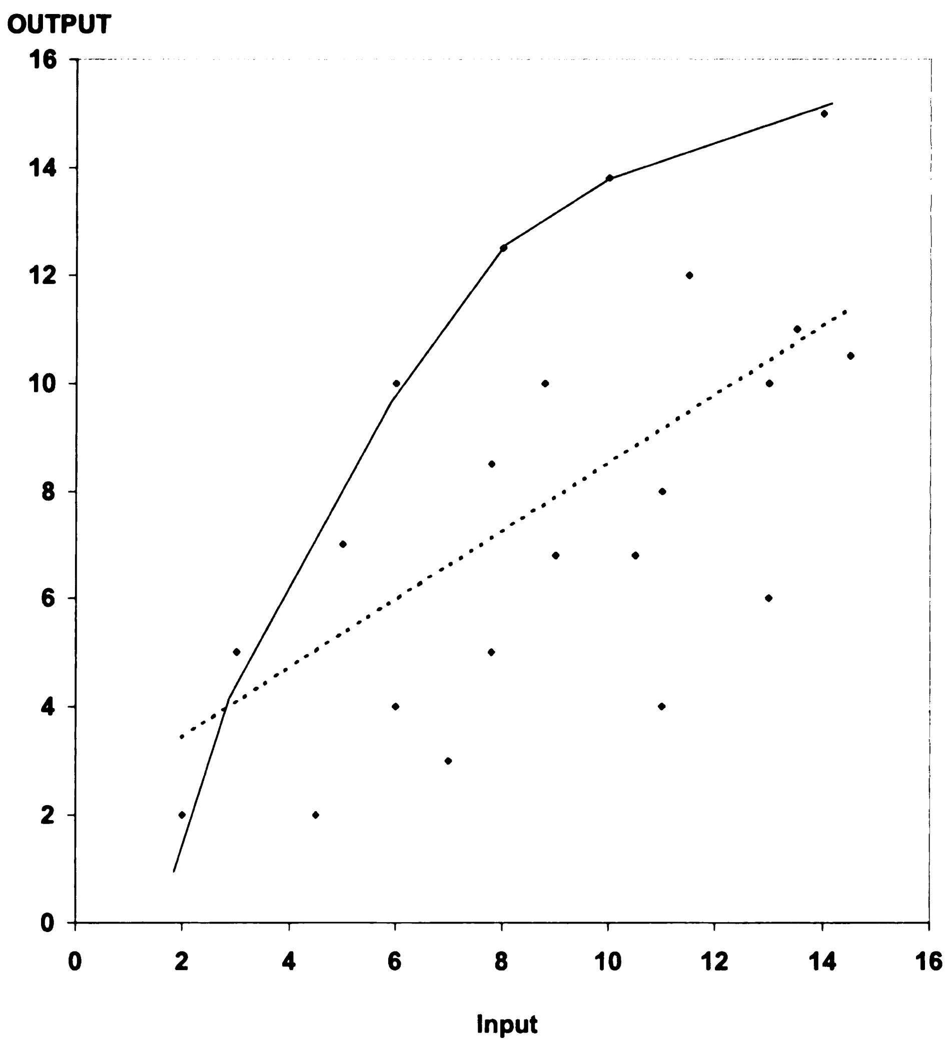


Figure 4.2 Envelopment Surface for BCC Model

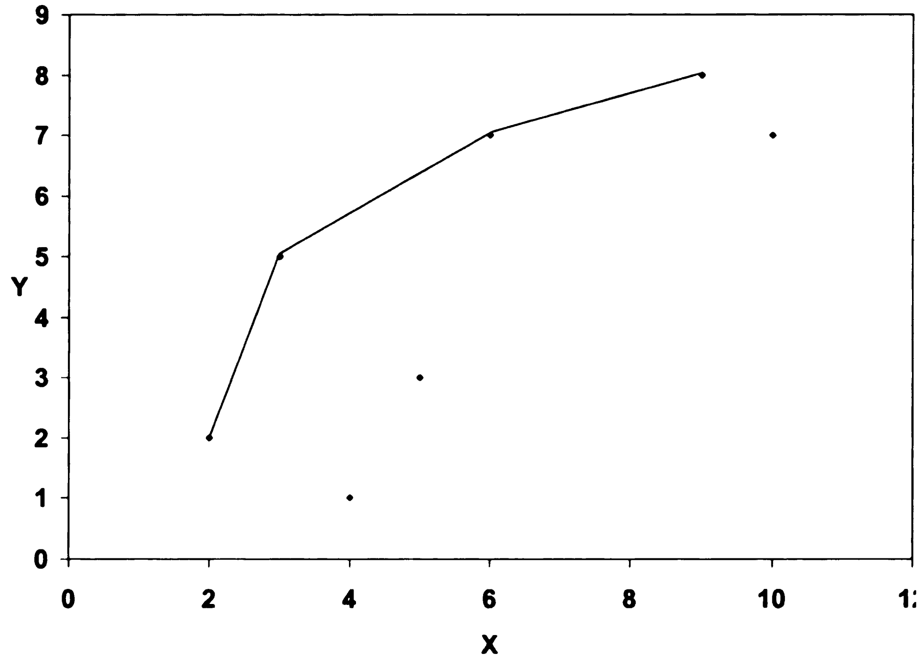
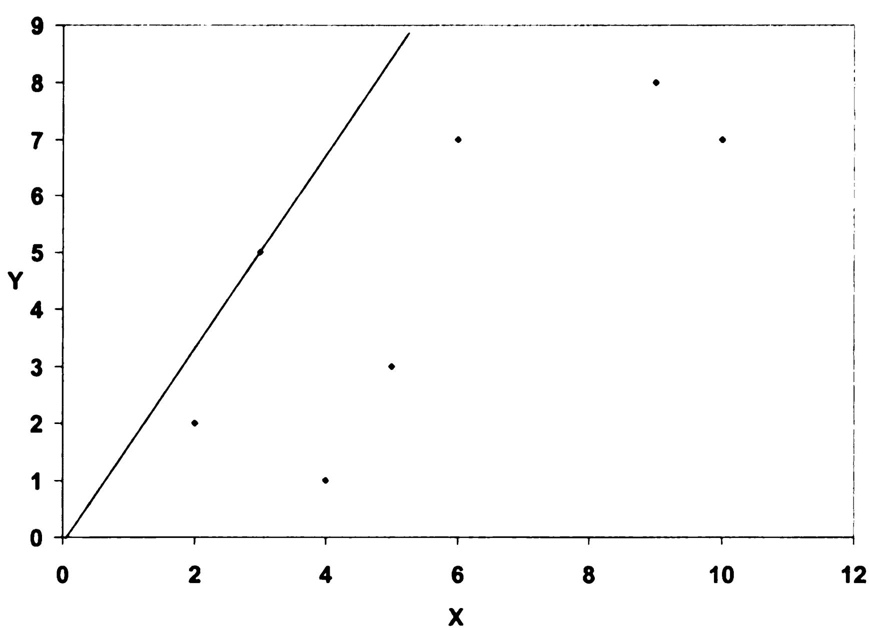


Figure 4.3 Envelopment Surface for CCR Model



Depending on the projection path to the envelopment surface for the inefficient DMUs, the BCC and the CCR models could have either input orientation or output orientation (therefore BCC and CCR are called orienting models whereas ADD and Multiplicative are called nonorienting models). In an input orientation, the projection path focuses on maximal movement toward the frontier via proportional reduction of inputs, whereas in an output orientation the projection path focuses on maximal movement through proportional increase of outputs.

In this dissertation, the basic assumption of constant returns to scale is chosen.

Inputs to manufacturing plants are identified as number of factory worker, number of non-factory worker, total raw material purchase, investment in equipment, and investment in Information Technology. Outputs are annual change in profitability, annual change in market share and total sales.

Efficiency of a unit i is defined as:

$$\text{Efficiency of unit } i = \frac{\text{Weighted sum of unit } i\text{'s outputs}}{\text{Weighted sum of unit } i\text{'s inputs}} = \frac{\sum_{j=1}^{no} O_{ij} w_j}{\sum_{j=1}^{ni} I_{ij} v_j}$$

Where O_{ij} is the value of unit i on output j, I_{ij} is the value of unit i on input j, w_j is a nonnegative weight assigned to output j, v_j is a nonnegative weight assigned to input j, n_o is the number of output variables, n_i is the number of input variables. The problem in DEA is to determine optimal values for weights w_j and v_j.

A separate linear programming problem is solved for each unit in a DEA problem. The objective for each unit is the same: to maximize the weighted sum of that unit's outputs. For an arbitrary unit i, the objective is:

$$\text{Max: } \sum_{j=1}^{no} O_{ij} w_j$$

Since it is impossible for any unit to be more than 100% efficient, for each unit, it is required that the weighted sum of the unit's outputs is less than or equal to the weighted sum of its inputs.

$$\sum_{j=1}^{no} O_{ij} w_j \leq \sum_{j=1}^{ni} I_{ij} v_j, \text{ for k = 1 to the number of units}$$

$$\sum_{j=1}^{ni} I_{ij} v_j = 1$$

To prevent unbounded solutions, it is required that the sum of the weighted inputs for the unit under investigation (unit i) is equal to one.

The weights for inputs and outputs must be constrained to be nonnegative.

$w_j \geq 0$, for j = 1 to n_o, $v_j \geq 0$, for j = 1 to n_i

After this linear programming problem is solved for each unit, all the units (manufacturing plants) will have an efficiency score which is less than or equal to one. The efficient units are those that have an efficiency score of one.

4.2.3. Investigate Moderating Effect of Efficiency

Moderating effect can often be modeled as an interaction term between independent variable and moderator in multivariate analysis. Since correlation between the practice dimensions is expected, it would be wise to construct nine models to test each sub-hypothesis of hypothesis 1 separately. In these nine models, the four performance variables (cost, quality, delivery, and flexibility) are the dependent variables. We could either construct nine multivariate models having all four dependent variables in the same model or thirty-six univariate models having one dependent variable in each model. Multivariate analysis is chosen since it can reduce family type I error rate relative to multiple univariate analysis (Huitema, 1980). There are two multivariate techniques that could be used to test a model with multiple independent variables and multiple dependent variables: multivariate analysis of covariance (MANCOVA) and cononical correlation analysis. Analysis of covariance is a statistical technique that combines regression and analysis of variance (Wildt and Ahtola, 1978). Cononical correlation, however, is similar to factor analysis in a way that both are variable reduction techniques that construct uncorrelated linear combinations. Cononical correlation is a means of parsimoniously describing the number and nature of mutually independent relationships between independent variables and dependent variables (Stevens 1996). Since the objective is not to find out a parsimonious representation of independent and dependent variables, rather, the purpose is to investigate interaction effect as can be done in regression analysis but with multiple dependent variables, MANCOVA was chosen to be the technique to test alternative hypothesis 1.

There are generally two situations where analysis of covariance is recommended. In observational studies, the dependent variable, in addition to being influenced by the treatment level, may be subject to the influence of a quantitative independent variable. Analysis of covariance under this condition provides a method to adjust for the difference between treatment levels caused by the quantitative independent variable (Cochran, 1957, Elashoff, 1969). In other situations, the researcher is interested in the relationship between quantitative independent and dependent variables, but is also concerned about the possible effects of some qualitative variable upon this relationship and the interaction between the categorical and the continuous independent variable (i.e. covariate) (Wildt and Ahtola, 1978).

This study falls into the second category. Since there are always two types of independent variables involved in MANCOVA: categorical and continuous variables, the efficiency is transformed into a categorical variable eff_mem by following coding:

eff_mem = 1 if efficiency<1.00,

eff_mem = 2 if efficiency=1.00.

The model to test H1a can be constructed in analysis of covariance as follows:

$$\text{Cost} + \text{Quality} + \text{Delivery} + \text{Flexibility} = \bar{b}_0 + \bar{b}_1 * P1 + \bar{b}_2 * \text{eff\_mem} + \bar{b}_3 * P1 * \text{eff\_mem}$$

where $\bar{b}_0$, $\bar{b}_1$, $\bar{b}_2$, $\bar{b}_3$ are nonscalar.

Testing hypothesis 1a is equivalent to testing that $\bar{b}_3$ is positive and significant.

Since factor scores are generally considered non-transferable (Hair et al. 1994), summated scales of the performance variables (cost, quality, delivery and flexibility) are established from their measurement items to represent the corresponding constructs.

To assess whether there is positive and significant interaction between efficiency and practices, two indices are of interest. Wilk's Λ is the multivariate index that measures the relationship between the interaction and the set of dependent variables (Stevens, 1996). The sign and significance of regression coefficients B indicates how interaction and each individual dependent variable are related. Similar to steps of assessing overall F test and parameter estimate in regression, F value of Wilk's Λ is always examined first to ensure that there is at least one dependent variable significantly associated with interaction. If Wilk's Λ is not significant, then none of the regression coefficients for interaction need to be examined.

4.2.4. Taxonomy of Efficient Manufacturing Plants

The fourth stage of this study is to test whether there is more than one strategic group contained in efficient manufacturing plants. Cluster analysis is the most commonly adopted approach for this purpose.

Depending on how the clustering procedures are carried out, clustering algorithms can be classified into two general categories: hierarchical and nonhierarchical. Hierarchical procedures can be further divide into agglomerative methods and divisive methods. In the agglomerative methods, each observation begins as a cluster. The two closest clusters are combined into a new cluster in the subsequent steps. Divisive method works in reverse direction. All the observations start out as one large cluster. The observations that are most dissimilar are split off in succeeding steps. Nonhierarchical techniques are often referred to as K-means clustering. The algorithm of K-means clustering can be described as following:

1. Select k samples (μ_1, μ_2, ... μ_k) from n original samples as the initial cluster centers for k clusters.
2. Classify n samples according to nearest $\mu_{i.}$.
3. Recompute $\mu_{i.}$
4. Repeat 2 and 3 until there is no change in $\mu_{i.}$

Hierarchical procedures are fast comparing to nonhierarchical procedures. However, they can be misleading because undesirable early combinations of the observations persist throughout the analysis. Nonhierarchical procedures have gained increased popularity since they are less influenced by the outliers in the data, choice of cluster variates and the distance measures applied. The nonhierarchical clustering results, however, are very sensitive to the selection of initial cluster centers. There is no standard procedure to determine the proper number of clusters in the data by nonhierarchical procedures.

A combination of hierarchical and nonhierarchical procedures was applied in this dissertation to overcome the weakness of either procedure as suggested by Hair et al. (1994). First, the data was analyzed by hierarchical technique to establish the number of clusters, profile cluster centers and identify outliers. The cluster centers generated by hierarchical technique were then chosen as the initial cluster centers for K-means clustering. The number of clusters generated by the hierarchical clustering procedure was taken as the K for K-means clustering. K-means clustering algorithm therefore performs a fine-tuning of the results by allowing the switching of cluster membership.

4.2.5. Compare Strategic Groups within Efficient Manufacturing Plants

If hypothesis 2 is supported, that is, there are multiple strategic groups in efficient manufacturing plants, it would be interesting to see whether strategic groups perform differently on various practice dimensions. The fifth stage of data analysis involved testing hypotheses 3 which exams how strategic groups perform differently on practice dimensions.

Sample data was divided into groups as suggested by cluster analysis. For hypotheses 3, nine groups of ANOVA tests each with the one practice dimension as its dependent variable and clusters as independent variables were performed. A significant test result indicated that clusters perform differently in terms of that practice dimension. Upon recognizing the significant test result, ANOVA does not reveal specifically the difference between which two clusters on that practice dimension leads to the significant test result of ANOVA. Multiple range test was applied for that purpose.

This chapter presented the research design of the dissertation. Sampling frame, scale selection, and research methodologies are discussed and justified. Chapter 5 will present the results of data analysis by applying procedures discussed in this chapter.

CHAPTER 5

DATA ANALYSIS

This chapter begins with a brief discussion of the pros and cons of web based survey. Response profile is presented next to examine if there is response bias. Details of the five date analysis procedures carrying out research design in chapter 4 are presented. The hypothesized relationships are examined based on the results of the data analysis procedures.

5.1. The Pros and Cons of Web Based Survey

A three-wave mailing, with one invitation letter and two reminder postcards and some follow up phone calls employed many techniques proposed by Dillman (1978, 2000), and resulted in the return of 224 surveys. During data collection period, the researcher did realize the advantages and disadvantages of web based survey. Comparing to traditional paper based survey, the cost saving of web survey is obvious. The huge savings are on the printing cost of survey and mailing cost. As discussed in the previous chapter, the turnaround time of survey is reduced. The web survey also reduced the labor involved and potential errors in data entering and helped collecting some extra information very easily. For example, by adding a simple log field for each participant in the database, the researcher is able to get the information on the how many times a participant logged on to the web site, how many questions a participant answered when he/she leaves the web site by running a simple query. This information helps identify respondents from each wave, will be useful in testing for non-response bias. The database also provides information on completion status and contact information of participants who logged onto the web site but did not complete the survey. With this information, the researcher was able to easily identify the problems if the participants did not finish the survey and make follow up contacts with participants to encourage them finish the survey and even relax some of the requirements based on the participants' inputs.

At the same time, the researcher did realize that there were some disadvantages with web based survey that have been overlooked. The biggest problem the researcher faced with was the inexperience and impatience with the web technology of the senior managers. The researcher received a lot of phone calls and emails for logging problems. Some participants requested to review the survey before they decided to participate. Under these circumstances, the researcher often chose to email the html copy of survey to the participants and offered them the option to fax the responses back. The front end of the database was implemented by cold fusion. The researcher believed that some of the logging problem was associated with the instability of cold fusion server. The business school that hosts the web survey sometimes shut the server down for backup and maintenance. During this time period, the web pages were not available. This problem, however, can be relatively easily mended by hosting the survey on a proprietary and more stable web server. As stated in previous section, the respondent was asked to establish an account and password so that they can come back to work on the surveys. The researcher found that this design had both its benefits and drawbacks. The benefits were obvious. The respondents were usually not able to answer all the questions in one session. For example, they had to ask the financial people on financial indices and sales people on sales information to get that part of questions answered. Therefore, it was very common that a participant would take between two weeks and one month to finish the survey. The drawbacks included that sometimes the managers would forget the password and felt frustrated with logging problem and finally gave up. The web survey also tends to be less reminding than paper based survey in the cases that the participants did not complete the survey at once and had to come back to finish.

With all these pros and cons of web based survey, the researcher believes that with more experience in designing such a survey, this technique will become more and more favored by researchers with similar requirements and will eventually become the norm in the field.

5.2. Respondent Profile

105 respondents first logged onto the web site before the second mailing was out and 58 of them completed 90% or more of the survey at that time. 82 respondents logged onto web site and 79 surveys were completed between second mailing and third mailing. After the third mailing and follow up phone calls, 68 respondents came onto the web site, 87 more surveys were completed. It should be noticed that due to the time it took the managers to complete the survey, it was often the case that they logged onto the web site in an earlier time frame than they completed the survey. Therefore, it was not surprising to see that more surveys were completed in the second or third wave but more respondents actually logged onto the web site in the first or second wave. In total there were 255 plants that logged onto the web site. 224 of the 255 responses were more than 90% complete and deemed as useful responses. The 31 responses that are not considered valid responses were either completely empty, (in which case the respondent decided not to participate after reviewing the survey) or half-completed. After making email or phone

contacts with those respondents, most of them cited reason as either they were private firms so that they could not answer some of the questions or they did not have the time to complete such a long survey.

Some descriptive characteristics of the participants from the three waves were listed in table 5.1, table 5.2 and table 5.3.

Table 5.1 Group 1 respondents (n=58)

	mean	Standard Deviation
Number of factory workers	581	213
Number of non-factory workers	331	201
Plant international sales (in Million $)	56.7	36.9
Plant domestic sales (in Million $)	149.3	101
Number of products	70	160
Percentage of continuos flow	31.6	22.5
Percentage of assembly line	25.7	28.3
Percentage of job production	8.0	10.2
Percentage of batch production	34.7	32.3

Table 5.2 Group 2 respondents (n=79)

	mean	Standard Deviation
Number of factory workers	492	310
Number of non-factory workers	389	314
Plant international sales (in Million $)	66.3	103
Plant domestic sales (in Million $)	128	92.7
Number of products	54	90
Percentage of continuos flow	16.9	20.4
Percentage of assembly line	29.1	28.0
Percentage of job production	13.7	22.9
Percentage of batch production	40.3	30.0

Table 5.3 Group 3 respondents (n=87)

	mean	Standard Deviation
Number of factory workers	680	435
Number of non-factory workers	527	449
Plant international sales (in Million $)	78.8	103
Plant domestic sales (in Million $)	190	374
Number of products	44	80
Percentage of continuos flow	15.1	25.9
Percentage of assembly line	45.8	38.8
Percentage of job production	30.0	37.0
Percentage of batch production	42.3	35.8

5.3. Confirmatory Factor Analysis

Confirmatory Factor Analysis (CFA) was used to evaluate the measurement models for World Class Manufacturing Practices and Performances. Based on theory and past research, CFA is a more rigorous method for assessing unidimensionality of multiple-item constructs rather than coefficient alpha in exploratory factor analysis (Gerbing and Anderson 1988; Calatone, Schmidt, and Song 1996).

There are several software programs that are widely adopted by operations researchers to perform structural equation modeling. LISREL (Linear Structural RELations) is a flexible model for cross-sectional, experimental, and longitudinal studies. EQS places less stringent assumptions on the multivariate normality of the data (Bentler 1989, 1992). In this dissertation, EQS was used to execute structural equation modeling including CFA and path models.

The estimation of parameters in the model was determined by maximum likelihood (ML) estimation (Bollen 1989; Bentler 1992a; Joreskog and Sorbom 1993). ML function is the most widely used fitting function for structural equation modeling to date. ML estimation reproduces the covariance matrix of observed variables by using a fitting function.

While evaluating the measurement model, the following criteria are considered important: unidimensionality, univariate and multivariate normality, reliability, convergent validity, and discriminant validity (Peter1981, Venkatraman 1989, Klassen 1995).

The evaluation of the measurement models was conducted as follows:

1) Initial runs based on the categorization of items into constructs as the survey suggested was carried out.
2) LM suggestions as to adding parameters was examined. CFA model was justified based on LM suggestions and theoretical backgrounds. The model was rerun and model fit was re-evaluated.
3) Step 2 was repeated until satisfactory global fit indication was found.

The data were examined for univariate and multivariate normality. Reliability of the constructs, convergent validity, and discriminant validity were evaluated.

Common method bias was examined by employing the error covariance matrix and LM test results.

5.3.1. CFA for WCM Practices

Table 5.4 lists all the factors and variables in CFA model for WCM practices .

Table 5.4 Factors and Variables in WCM Practices CFA Model

F1: **Quality Management Programs**

V1: Everyone has responsibility to improve quality

V4: Processes on the shop floor are under statistical quality control.

V11: Total Quality Management philosophy is promoted

F2: **Customer Orientation**

V13: We maintain close contacts with our customers.

V14: Results of customer satisfaction surveys are communicated throughout organization.

V19: We have a formal "customer satisfaction" program in place.

F3: **Labor Force Management**

V23: Team members are encouraged to exchange opinions/ideas.

V25: Our employees have strong problem solving abilities.

V35: Labor scheduling / job assignments is handled by empowered team

F4: **Operations Flow**

V38: The shop floor is laid out to optimize processing sequence and flow.

V42: We use lean manufacturing production methods.

V43: We offer JIT delivery to customers.

F5: **Operations Capability**

V45: We dedicate to continual improvement in quality.

V46: We dedicate to continual improvement in response time.

V47: We dedicate to continual improvement in flexibility.

V48: We dedicate to continual improvement in cost.

F6: **Supplier Relationship**

V56: We establish long-term contracts with suppliers.

V57: We have reduced the number of suppliers for each part family.

V58: We frequently source multiple part families from a single supplier.

Table 5.4. Factors and Variables in WCM Practices CFA Model

F7: **Technology Management**

V78: We plan technological upgrades to be consistent with infrastructural upgrades

V79: Computer-aided-design (CAD) technology practice is applied

V81: Flexible manufacturing systems (FMS) technology practice is applied

F8: **New Product Development**

V91: Customer requirements are clearly specified early in conceptual design.

V92: We use design-for-manufacture and assembly (DFMA) methods.

V97: Product designers and manufacturing staff have equal status in NPD projects.

F9: **Strategy Formulation and Measurement**

V101: We have clearly defined strategic manufacturing goals and objectives.

V102: Our firm's strategy leverages existing capabilities.

V103: Corporate strategy at our firm drives manufacturing decisions.

V105: Manufacturing strategy is frequently reviewed and revised.

V106: Manufacturing strategy is well aligned with corporate strategy.

5.3.1.1. Univariate and Multivariate Normality

Multivariate normality is one of the critical assumptions of structural equation modeling. Violation of this assumption could lead to downwardly biased standard errors that would result in an inflated number of statistically significant parameters (Muthen and Kaplan 1985; Byrne 1994). Since normal theory test statistic may not reflect an adequate evaluation of the model if the assumption of multivariate normality is violated, the statistical hypothesis testing can be seriously invalidated under such situation (Browne 1982, 1984; Hu, Bentler, and Kano 1992).

The univariate statistics for the items that represent WCM practices constructs are displayed in table 5.5. The multivariate kurtosis for WCM practices constructs are represented in table 5.6. Values for skewness ranged from -1.2778 to 0.2579. Values for kurtosis ranged from -1.0764 to 1.5572. Since all of the univariate skewness < 2.0, and all of the univariate kurtosis < 7.0, no indications of departures from normality existed (Cho and Bentler 1995).

The normalized estimate of Mardia's coefficient is very small (0.8176) which indicates no violation of multivariate normality existed (Mardia 1970; Byrne 1994).

Table 5.5 Univariate Statistics: WCM Practices CFA

VARIABLE	V1	V4	V11	V13	V14
MEAN	5.4107	4.1607	5.1964	5.6607	4.8036
SKEWNESS (G1)	-0.2960	-0.4455	-0.4544	-0.7401	-0.8269
KURTOSIS (G2)	-0.8652	0.1065	-0.4955	0.1269	0.3895
STANDARD DEV	1.1641	1.6596	1.3315	1.1870	1.5781

VARIABLE	V19	V23	V25	V35	V38
MEAN	4.5179	5.1607	4.3929	3.4821	4.9643
SKEWNESS (G1)	-0.2466	-0.3072	-0.0379	-0.1601	-0.3802
KURTOSIS (G2)	-1.0746	-0.6237	0.0122	-0.7753	-0.5826
STANDARD DEV	1.7358	1.2388	1.2374	1.9034	1.4295

Table 5.5. Univariate Statistics: WCM practices CFA

VARIABLE	V42	V43	V45	V46	V47
MEAN	5.0179	4.7500	5.3571	5.3571	5.2500
SKEWNESS (G1)	-1.2778	-0.6358	-0.5326	-1.1443	-1.0788
KURTOSIS (G2)	1.0706	-0.0382	-0.4991	1.5572	1.0666
STANDARD DEV	1.7203	1.6321	1.2482	1.2043	1.2881

VARIABLE	V48	V56	V57	V58	V78
MEAN	5.5714	4.8929	5.0536	4.8214	4.1429
SKEWNESS (G1)	-0.5930	-0.5548	-0.5433	-0.4929	-0.9611
KURTOSIS (G2)	-0.2180	-0.0493	0.2494	0.1543	1.3489
STANDARD DEV	1.2107	1.4006	1.3843	1.5631	1.5321

VARIABLE	V79	V81	V91	V92	V97
MEAN	5.1964	3.7500	4.5893	4.0893	3.3929
SKEWNESS (G1)	-0.7206	-0.5111	-0.5145	-0.5623	-0.2579
KURTOSIS (G2)	0.8015	-0.2650	0.0758	-0.5014	-0.9855
STANDARD DEV	1.2905	1.8678	1.6047	1.9890	2.0283

VARIABLE	V101	V102	V103	V105	V106
MEAN	5.0893	4.8929	4.6071	4.5714	4.7679
SKEWNESS (G1)	-0.6712	-0.5618	-0.2660	-0.3269	-0.3329
KURTOSIS (G2)	0.9517	-0.1489	-0.8069	-0.3088	-0.6995
STANDARD DEV	1.2460	1.2228	1.3747	1.3507	1.5502

Table 5.6 Multivariate Kurtosis for WCM Practices

MARDIA'S COEFFICIENT (G2,P) =	4.7873
NORMALIZED ESTIMATE =	0.8176
ELLIPTICAL THEORY KURTOSIS ESTIMATES	
MARDIA-BASED KAPPA =	0.0050
MEAN SCALED UNIVARIATE KURTOSIS =	-0.0114
MARDIA-BASED KAPPA IS USED IN COMPUTATION. KAPPA=	0.0050

5.3.1.2. Goodness of Fit Indices

A summary of selected fit indices for the EQS analysis is presented in Table 5. 7.

Table 5.7 Goodness-of-Fit Indices for WCM Practices Measurement Model

n	224	
χ^2	989.500	
Degree of Freedom (df)	368	
p value	.001	
χ^2/df	2.69	
BENTLER-BONETT NORMED FIT INDEX	0.923	
BENTLER-BONETT NONNORMED FIT INDEX	0.912	
COMPARATIVE FIT INDEX (CFI)	0.941	
BOLLEN (IFI) FIT INDEX	0.935	
STANDARDIZED RMR	0.057	
ROOT MEAN SQ. ERROR OF APP.(RMSEA)	0.044	
90% CONFIDENCE INTERVAL OF RMSEA (	0.025,	0.058)

The fit indices in Table 5.7 (χ^2 , normed χ^2, CFI, NFI, NNFI, IFI, RMR, RMSEA) indicate a strong global fit obtained in the CFA model. The normed χ^2 is below 3, CFI, NFI, NNFI and IFI are greater than cutoff value .90, RMR and RMSEA are below cutoff value .080.

5.3.1.3. Reliability and Convergent Validity

Table 5.8 listed the measurement equations with standard errors, standardized solution and cronbach's α for all the practices constructs.

Cronbach's α is a widely used measure for scale reliability. Typically, these coeffiecients should be 0.70 or higher for narrow constructs, and 0.55 or higher for moderately broad constructs such as those defined here (Van de Ven and Ferry 1979). Cronbach's α ranges between .684 to .913 for the nine practice constructs, which represents a reasonable scale reliability.

Convergent validity was indicated by the strong and significant item loadings. In the standard solutions for the measurement equations, all the loadings were higher than .50 except two items at .486 and .434. All the factor loadings were significant at .05.

Table 5.8 Measurement Equations with Standard Errors, Standardized Solution and Cronbach's alpha for WCM Practice CFA Model

Cronbach's α	Measurement Equation	Standard Error	t value
.731	**Quality Management Programs (F1)**		
	V1= 1.000 F1 + 1.000 E1	Path fixed at 1.0	
	V4 =.838*F1 + 1.000 E2	.115	7.309
	V 11 =1.224*F1 + 1.000 E3	.080	15.247
	Standardized Solution		
	V1 = .827 F1 + .563 E1		
	V4 = .486*F1 + .874 E2		
	V11 = .884*F1 + .467 E3		
.773	**Customer Orientation (F2)**		
	V13 = 1.000 F2 + 1.000 E4		
	V14 = 1.615*F2 + 1.000 E5	.182	8.850
	V19 =1.729*F2 + 1.000 E6	.197	8.773
	Standardized Solution		
	V13 = .653 F2 + .758 E4		
	V14 = .793*F2 + .609 E5		
	V19 = .772*F2 + .636 E6		
.774	**Labor Force Management (F3)**		
	V23 = 1.000 F3 + 1.000 E7		
	V25 = .972*F3 + 1.000 E8	.056	17.398
	V35 = .933*F3 + 1.000 E9	.108	8.629
	Standardized Solution		
	V23 = .889 F3 + .458 E7		
	V25 = .864*F3 + .503 E8		
	V35 = .540*F3 + .842 E9		
.685	**Operations Flow (F4)**		
	V38 = 1.000 F4 + 1.000 E10		
	V42 = 1.126*F4 + 1.000 E11	.103	10.937
	V43 = .750*F4 + 1.000 E12	.101	7.406
	Standardized Solution		
	V38 = .774 F4 + .634 E10		
	V42 = .724*F4 + .690 E11		
	V43 = .508*F4 + .861 E12		
.902	**Operations Capability (F5)**		
	V45 = 1.000*F5 + 1.000 E13		
	V46 = 1.122 F5 + 1.000 E14	.065	17.210
	V47 = 1.109*F5 + 1.000 E15	.072	15.408
	V48 = .914*F5 + 1.000 E16	.071	12.803
	Standardized Solution		
	V45 = .807*F5 + .590 E13		
	V46 = .939 F5 + .345 E14		
	V47 = .867*F5 + .497 E15		
	V48 = .761*F5 + .649 E16		

.884	**Supplier Relationship (F6)** V56 = 1.000 F6 + 1.000 E17 V57 = .951*F6 + 1.000 E18 V58 = 1.106*F6 + 1.000 E19 Standardized Solution V56 = .863 F6 + .505 E17 V57 = .830*F6 + .557 E18 V58 = .855*F6 + .518 E19	 .064 .072	 14.778 15.323
.684	**Technology Management (F7)** V78 = 1.163*F7 + 1.000 E21 V79 = 1.176*F7 + 1.000 E22 V81 = 1.000 F7 + 1.000 E20 Standardized Solution V78 = .616*F7 + .787 E21 V79 = .740*F7 + .672 E22 V81 = .434*F7 + .901 E20	 .216 .205	 5.393 5.734
.753	**New Product Development (F8)** V91 = 1.000 F8 + 1.000 E23 V92 = 1.062*F8 + 1.000 E24 V97 = .896*F8 + 1.000 E25 Standardized Solution V91 = .841 F8 + .541 E23 V92 = .720*F8 + .693 E24 V97 = .596*F8 + .803 E25	 .095 .100	 11.230 8.971
.913	**Strategy Formulation and Measurement (F9)** V101= 1.000 F9 + 1.000 E26 V102= .895*F9 + 1.000 E27 V103= .950*F9 + 1.000 E28 V105= 1.027*F9 + 1.000 E29 V106= 1.240*F9 + 1.000 E30 Standardized Solution V101= .876 F9 + .482 E26 V102= .799*F9 + .602 E27 V103= .754*F9 + .657 E28 V105= .830*F9 + .557 E29 V106= .873*F9 + .487 E30	 .059 .069 .063 .070	 15.135 13.771 16.201 17.788

5.3.1.4. Discriminant Validity and Nomological validity

Table 5.9. listed the variances for each factor, all inter-factor covariance, all inter-factor squared correlation and their squared error and t value.

The inter-factor correlations are significantly different from 1.00, indicating discriminant validity. The average variance extracted for each factor is greater than the squared correlation between that factor and any other factor in the CFA, providing a more rigorous confirmation of discriminant validity.

All the inter-factor correlations are statistically significant and positive, which confirmed nomological validity.

Table 5.9 Variances for Each Factor and Inter-Factor Covariances for WCM Practices CFA

Factor	Avg. Variance Extracted	Inter-factor squared correlation	Inter-factor covariance	Standard error	t value
F1	.926				
		F1-F2: .291	F1-F2: .402	.076	5.299
		F1-F3: .685	F1-F3: .877	.109	8.014
		F1-F4: .579	F1-F4: .810	.155	7.065
		F1-F5: .498	F1-F5: .714	.098	7.291
		F1-F6: .254	F1-F6: .586	.103	5.707
		F1-F7: .336	F1-F7: .453	.103	4.406
		F1-F8: .161	F1-F8: .521	.114	4.580
		F1-F9: .238	F1-F9: .512	.090	5.666
F2	.600				
		F1-F2: .291	F1-F2: .402		
		F2-F3: .282	F2-F3: .453	.084	5.364
		F2-F4: .188	F2-F4: .371	.086	4.329
		F2-F5: .233	F2-F5: .377	.075	5.034
		F2-F6: .086	F2-F6: .275	.081	3.402
		F2-F7: .124	F2-F7: .221	.070	3.144
		F2-F8: .128	F2-F8:.374	.097	3.855
		F2-F9: .081	F2-F9:.240	.071	3.369
F3	1.212				
		F1-F3: .685	F1-F3: .877		
		F2-F3: .282	F2-F3: .453		
		F3-F4: .710	F3-F4: 1.026	.132	
		F3-F5: .618	F3-F5: .872	.111	
		F3-F6: .193	F3-F6: .586	.111	
		F3-F7: .054	F3-F7: .208	.085	
		F3-F8: .016	F3-F8: .188	.120	
		F3-F9: .147	F3-F9:.460	.097	

F4	1.223				
		F1-F4: .579	F1-F4: .810		
		F2-F4: .188	F2-F4: .371		
		F3-F4: .710	F3-F4: 1.026		
		F4-F5: .667	F4-F5: .910	.123	7.418
		F4-F6: .281	F4-F6: .709	.126	5.625
		F4-F7: .093	F4-F7: .274	.097	2.832
		F4-F8: .224	F4-F8: .707	.142	4.958
		F4-F9: .399	F4-F9: .762	.117	6.494
F5	1.015				
		F1-F5: .498	F1-F5: .714		
		F2-F5: .233	F2-F5: .377		
		F3-F5: .618	F3-F5: .872		
		F4-F5: .667	F4-F5: .910		
		F5-F6: .270	F5-F6: .633	.106	5.965
		F5-F7: .162	F5-F7: .329	.089	3.698
		F5-F8: .076	F5-F8: .375	.110	3.400
		F5-F9: .325	F5-F9: .627	.097	6.467
F6	1.461				
		F1-F6: .254	F1-F6: .586		
		F2-F6: .086	F2-F6: .275		
		F3-F6: .193	F3-F6: .586		
		F4-F6: .281	F4-F6: .709		
		F5-F6: .270	F5-F6: .633		
		F6-F7: 318	F6-F7: .553	.126	4.401
		F6-F8: .184	F6-F8: .699	.142	4.932
		F6-F9: .283	F6-F9: .702	.114	6.171
F7	.659				
		F1-F7: .336	F1-F7: .453		
		F2-F7: .124	F2-F7: .221		
		F3-F7: .054	F3-F7: .208		
		F4-F7: .093	F4-F7: .274		
		F5-F7: .162	F5-F7: .329		
		F6-F7: .318	F6-F7: .553		
		F7-F8: .520	F7-F8: .790	.165	4.785
		F7-F9: .169	F7-F9: .364	.097	3.762
F8	1.821				
		F1-F8: .161	F1-F8: .521		
		F2-F8: .128	F2-F8:.374		
		F3-F8: .016	F3-F8: .188		
		F4-F8: .224	F4-F8: .707		
		F5-F8: .076	F5-F8: .375		
		F6-F8: .184	F6-F8: .699		
		F7-F8: .520	F7-F8: .790		
		F8-F9: .482	F8-F9: 1.022	.142	7.218

F9	1.191	F1-F9: .238 F2-F9: .081 F3-F9: .147 F4-F9: .399 F5-F9: .325 F6-F9: .283 F7-F9: .169 F8-F9: .482	F1-F9: .512 F2-F9:.240 F3-F9:.460 F4-F9: .762 F5-F9: .627 F6-F9: .702 F7-F9: .364 F8-F9: 1.022		

5.3.1.5. Common Method Bias

Only single respondent from each plant completed the survey due to cost and time constraints. The potential drawback with single informant is that it may yield common method bias (Hughes, Price, and Marrs 1986). In order to test for common method bias, the model was rerun to allow the errors to covary, that is, the zero-correlation constraints for the relevant off-diagonal elements in the Θ_δ matrix were released. The LM test provided by EQS indicated that there was only a small drop in χ^2 to the already well-fitting model with Θ_δ matrix released. The LM test result is displayed in table 5.10. The absence of significant model improvement was an indication of the absence of common method bias.

Table 5.10 Multivariate LM Test with theta lambda Matrix Released

Cumulative Multivariate Statistics

Step	Parameter	chi-square	D.F.	Probability
1	E13, E1	32.115	1	0.000
2	E4, E6	47.229	2	0.000
3	E17, E18	58.844	3	0.001
4	E17, E19	67.513	4	0.003

5.3.2. CFA for WCM Performance

Table 5.11 lists all the factors and variables in CFA model for WCM performance.

Table 5.11 Factors and Variables in WCM Performances CFA Model

---

F1: **<u>Cost Performance</u>**

V113: manufacturing overhead cost

V114: maintenance cost

F2: **<u>Quality Performance</u>**

V115: Product overall quality performance

V116: Product feature

V117: Product reliability

V119: product durability

F3: **<u>Delivery Performance</u>**

V124: Delivery availability (the probability that items will be in stock at the time of order)

V125: Delivery dependability (delivered on the agreed upon date)

V126: Delivery speed (short elapsed time between order placement and product reaches the customer)

F4: **<u>Flexibility Performance</u>**

V130: Ability to adjust production volumes

V133: Ability to respond to changes in delivery requirements

5.3.2.1. Univariate and Multivariate Normality

The univariate statistics for the items that represent WCM performance constructs are displayed in table 5.12. The multivariate kurtosis for WCM performance constructs are represented in table 5.13. Values for skewness ranged from -1.7272 to 0.0209. Values for kurtosis ranged from -0.5275 to 4.2619. Since all of the univariate skewness < 2.0, and all of the univariate kurtosis < 7.0, no indications of departures from normality existed (Cho and Bentler 1995).

The normalized estimate of Mardia's coefficient is small (26.8875), which indicates no violation of multivariate normality existed (Mardia 1970; Byrne 1994).

Table 5.12 Univariate Statistics: WCM Performance CFA

VARIABLE	S10CV113	S10CV114	S10QV115	S10QV116	S10QV117
MEAN	4.1250	3.3571	5.4821	5.0714	5.4643
SKEWNESS (G1)	-0.5887	-0.9690	-0.3210	-1.1870	-1.1459
KURTOSIS (G2)	1.2662	0.0992	-0.5236	4.2200	2.7362
STANDARD DEV	1.4308	1.4724	1.0544	1.1807	1.3522

VARIABLE	S10QV119	S10DV124	S10DV125	S10DV126	S10FV130
MEAN	5.4286	4.5714	5.0536	4.7143	4.9107
SKEWNESS (G1)	-1.7272	-1.0841	-0.7515	-0.8188	-0.2886
KURTOSIS (G2)	4.2619	0.7751	-0.9527	0.8879	-0.2638
STANDARD DEV	1.4654	1.9395	1.4600	1.7121	1.3825

VARIABLE	S10FV133
MEAN	5.0357
SKEWNESS (G1)	0.0209
KURTOSIS (G2)	-0.5275
STANDARD DEV	1.0540

Table 5.13 Multivariate Kurtosis for WCM Performance

MARDIA'S COEFFICIENT (G2,P) = 60.7630

NORMALIZED ESTIMATE = 26.8875

ELLIPTICAL THEORY KURTOSIS ESTIMATES

MARDIA-BASED KAPPA = 0.4249
MEAN SCALED UNIVARIATE KURTOSIS = 0.4207
MARDIA-BASED KAPPA IS USED IN COMPUTATION. KAPPA= 0.4249

5.3.2.2. Goodness of Fit Indices

A summary of selected fit indices for the EQS analysis is presented in Table 5. 14

Table 5.14 Goodness-of-Fit Indices for WCM Performance Measurement Model

n	224
χ^2	75.620
Degree of Freedom (df)	38
p value	.002
χ^2/df	1.99
BENTLER-BONETT NORMED FIT INDEX	0.941
BENTLER-BONETT NONNORMED FIT INDEX	0.950
COMPARATIVE FIT INDEX (CFI)	0.944
BOLLEN (IFI) FIT INDEX	0.922
STANDARDIZED RMR	0.070
ROOT MEAN SQ. ERROR OF APP.(RMSEA)	0.068
90% CONFIDENCE INTERVAL OF RMSEA	(0.062 0.074)

The fit indices in Table 5.12 (χ^2 , normed χ^2, CFI, NFI, NNFI, IFI, RMR, RMSEA) indicate a strong global fit obtained in the CFA model. The normed χ^2 is below 2, CFI, NFI, NNFI and IFI are greater than cutoff value .90, RMR and RMSEA are below cutoff value .080.

5.3.2.3. Reliability and Convergent Validity

Table 5.15 listed the measurement equations with standard errors, standard solutions and cronbach's α for the performance constructs. All the Cronbach's α ranges between .723 to .843 for the nine practice constructs, which represents a reasonable scale reliability.

Convergent validity was indicated by the strong and significant item loadings. In the standard solutions for the measurement equations, all the loadings were higher than .566 and significant at .05.

5.3.2.4. Discriminant Validity and Nomological validity

Table 5.16 listed the variances for each factor, all inter-factor covariance, all inter-factor squared correlation and their squared error and t value.

The inter-factor correlations are significant different from 1.00, indicating discriminant validity. The average variance extracted for each factor is greater than the squared correlation between that factor and any other factor in the CFA, providing a confirmation of discriminant validity.

All the inter-factor correlations are statistically significant and positive, which confirmed nomological validity.

Table 5.15 Measurement Equations with Standard Errors, Standardized Solution and Cronbach's alpha for WCM Performance CFA Model

Cronbach's α	Measurement Equation	Standard Error	t value
.723	**Cost Performance(F1)**		
	V113= 1.431*F1 + 1.000 E1	.068	21.119
	V114 =.834*F1 + 1.000 E2	.090	9.228
	Standardized Solution		
	V113 = 1.000*F1 + .000E1		
	V114 = .566*F1 + .824 E2		
.843	**Quality Performance(F2)**		
	V115= .623*F2 + 1.000 E3	.066	9.499
	V116 =.955*F2 + 1.000 E4	.067	14.261
	V117 = 1.322*F2 + 1.000E5	.069	19.138
	V119 = 1.038*F2 + 1.000E6	.087	11.904
	Standardized Solution		
	V115= .591*F2 + .807 E3		
	V116 =.809*F2 + .588 E4		
	V117 = .978*F2 + .211E5		
	V119 = .708*F2 + .706E6		
.823	**Delivery Performance(F3)**		
	V124 = 1.539*F3 + 1.000E7	.113	13.603
	V125 = 1.016*F3 + 1.000E8	.090	11.352
	V126 = 1.518*F3 + 1.000E9	.095	15.982
	Standardized Solution		
	V124 = .794*F3 + .608E7		
	V125 = .696*F3 + .718E8		
	V126 = .886*F3 + .463E9		
.817	**Flexibility Performance(F4)**		
	V130 = .990*F4 + 1.000 E10	.080	12.403
	V133 = 1.054*F4 + 1.000 E11	.050	21.119
	Standardized Solution		
	V130 = .716*F4 + .698 E10		
	V133 = 1.000*F4 + .000 E11		

Table 5.16 Variances for Each Factor, Inter-Factor Covariances and Squared Correlation for WCM Performance CFA

Factor	Avg. Variance Extracted	Inter-factor squared correlation	Inter-factor covariance	Standard error	t value
F1	1.000				
		F1-F2: .140	F1-F2: .374	.059	6.319
		F1-F3: .012	F1-F3: .109	.017	1.529
		F1-F4: .083	F1-F4: .288	.061	4.698
F2	1.000				
		F1-F2: .140	F1-F2: .374		
		F2-F3: .191	F2-F3: .437	.061	7.153
		F2-F4: .000	F2-F4: .000	.068	.004
F3	1.000				
		F1-F3: .012	F1-F3: .109		
		F2-F3: .191	F2-F3: .437		
		F3-F4: .437	F3-F4: .661	.043	15.248
F4	1.000				
		F1-F4:	F1-F4:		
		F2-F4:	F2-F4:		
		F3-F4:	F3-F4:		

5.3.2.5. Common Method Bias

The LM test provided by EQS indicated that there was only a small drop in χ^2 to the already well-fitting model with Θ_δ matrix released. The LM test result is displayed in table 5.17. The absence of significant model improvement was an indication of the absence of common method bias.

Table 5.17 Multivariate LM Test with theta lambda Matrix Released for WCM Performance CFA Model

Cumulative Multivariate Statistics

Step	Parameter	chi-square	D.F.	Probability
1	E10, E1 1	5.432	1	0.000
2	E9, E4	7.021	2	0.000
3	E1, E3	8.311	3	0.001

5.4. Data Envelopment Analysis

Table 5.18 listed the input and output dimensions for the DEA model

Table 5.18 Input and Output Dimensions for DEA Model

Inputs

1) Number of factory employees at your plant
2) Number of non-factory employees at your plant
3) Total raw material purchase in your plant last year
4) Investment in equipment in your plant over the last 3 years
5) Investment in Information Technology over the last 3 years.

Outputs

1) Average annual change in profitability over the last two years (in %)
2) Average annual change in market share over the last two years (in %)
3) Total sales (international + domestic) for your plant last year (in $)

Labor, expenses and equipment investment are the most commonly used input variables in DEA analysis (Sherman and Gold 1985, Parkan 1987, Epstein and Henderson, 1989, Oral and Yolalan 1990, Vassiloglou and Giokas 1990, Giokas 1991, Sherman and Ladino 1995, Vargas et. al. 1996, Athanssopoulos 1997, Schefczyk and Gerpott, 1998, Kantor and Maital 1999, Golany and Storbeck 1999). With the emergence of e-commence and the widespread applications of Information Technology in all functional areas, manufacturing sections are also learning that competitive advantages can be gained by Information Technology. E-business has had a great impact on inventory management, forecasting and aggregate planning etc (Krajewski and Ritzman 1999). Various authors have showed that operations systems can be improved by Information Technology. For example, Frohlich and Dixon (1999) showed that successful

AMT implementation must be accompanied by information systems adaptation, while Kathuria et al. (1999) developed an intelligent decision support system that can allow a firm to align its competitive priorities with the appropriate process structure and information technology applications. Investment in Information Technology is therefore added to the input list since operations managers have recognized the importance of IT and are investing in IT to improve manufacturing performance.

Selection of output variables varies by the industry of the sample. For example, studies in banking industry performance often adopt number of transactions as output measurement in DEA (Sherman and Gold 1985, Parkan 1987, Oral and Yolalan 1990, Vassiloglou and Giokas 1990, Giokas 1991, Sherman and Ladino 1995). In manufacturing industry, Sales is most often employed as the output variable (Vargas et al. 1996, Schefcayk and Gerpott, 1998). Profitability and market share are gaining increasing attention from operations manager as performance measures (Garvin 1989). The way these variables are structured (as average annual change in the last two years rather than absolute values) in this dissertation is due to both measurement considerations and theoretical foundation. The data collection results from this dissertation indicate that there are more missing values for the actual measures than relative improvement measures. It seems to suggest that managers are more reluctant to give out actual numbers of profitability and market share rather than the relative improvement in these areas. The annual change measures, however, may be more pertinent as performance measures in this dissertation since absolute value of market share and profitability are determined by a lot more factors such as company history and strategy that are beyond the control of a manufacturing unit. However, the annual change measures better reflect the recent performance of the manufacturing unit.

In this dissertation, Warwick Windows DEA software was used to carry out DEA. The models are solved in two phases. In the first phase, the following model is solved:

Max: q

s.t. $\sum_j \lambda_j x_{ij} + s_i^- = (1 - w_i q) x_{ij_0}$ $\quad i = 1 \ldots m$

$\sum_j \lambda_j \, y_{rj} - s_r^+ = (1 + w_r q) y_{rj_0}$ $\quad r = 1 \ldots s$

$\lambda_j \geq 0; \quad j = 1 \ldots n, \qquad q > 0$

where x_{ij} and y_{rj} are the ith input and rth output level at DMU_j,

w_i and w_r are user-specified priorities.

j_0 is the DMU being assessed.

In phase-2 the constraints of the above model are used after setting q to its optimal phase 1 value. Then the following objective function is optimized over the constraints:

Max: $\sum_i F_i^- s_j^- + \sum_r F_r^+ s_r^+$

Where F_i^- and F_r^+ are user-specified priorities.

Since DEA requires that any of the input and output to be non-null, those plants that did not answer all of the questions are not included in this DEA model. Questions about investment and sales were the questions that were most often left unanswered by the managers. After deleting plants with incomplete responses, sample size dropped to 178.

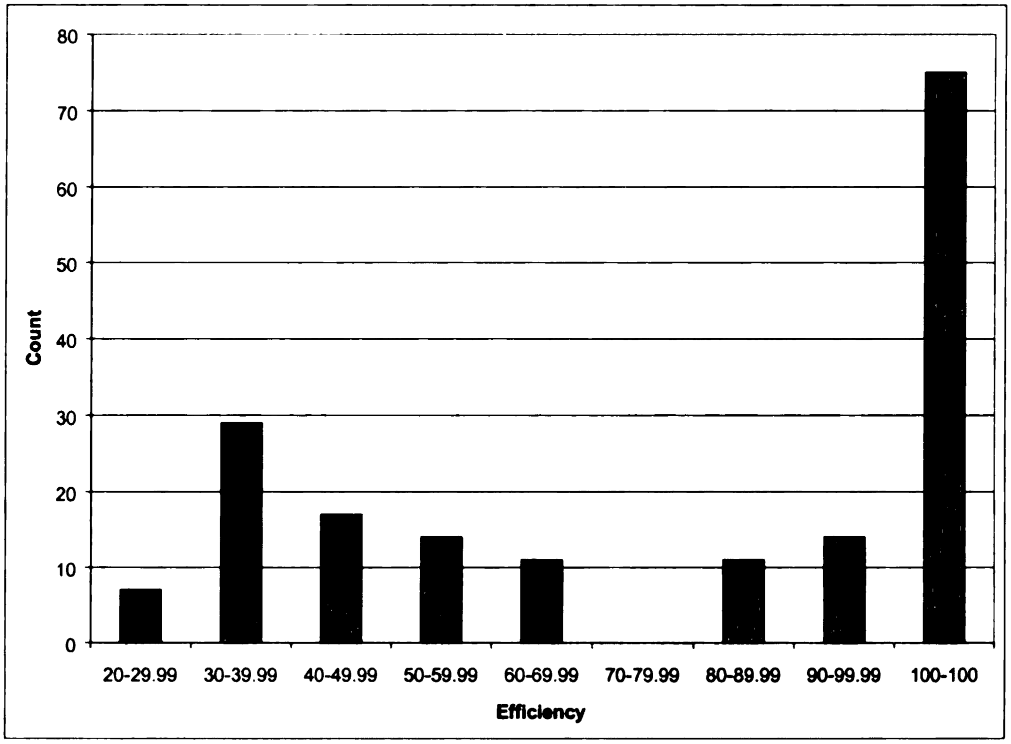
These 178 data sets were entered into the DEA model as 178 DMUs, with input and output fields specified. The efficiency score for each unit was given by DEA.

The efficiency ranged between 23.11% and 100%. The distribution of efficiency scores of the 178 units is summarized in Table 5.19. Figure 5.1 plotted the distribution against individual units.

Table 5.19 Distribution of Efficiency Scores

Range	count	Percentage
20-29.99	7	3.93%
30-39.99	29	16.29%
40-49.99	17	9.55%
50-59.99	14	7.87%
60-69.99	11	6.18%
70-79.99	0	0.00%
80-89.99	11	6.18%
90-99.99	14	7.97%
100-100	75	42.13%
Total	178	100.00%

Figure 5.1 Distribution of Efficiency Score



From both Table 5.19 and Figure 5.1, we can see that the efficiency score is heavily skewed to the right with 42.13% of sample data achieving a efficiency score of 100. The 75 plants in the sample with efficiency score of 100 were identified as efficient plants.

In DEA, relative efficiency for each decision making unit (DMU) is the ratio between weighted sum of outputs and weighted sum of inputs. The efficient DMUs identified by DEA are those that can produce the most amount of outputs with the least amount of inputs relative to the rest of DMUs in data sample. Therefore, it is crucial that the participating plants in this research, if not superior to industry average, are at least representative of industry average.

To validate the representativeness of data sample, a comparison on general performance metrics between respondents of the questionnaire and a random sample within the same SIC range from public database was made. Since unit of analysis is plant in this research, while the general performance metrics publicly available are in firm's level, it is important that the metrics compared are not affected by the size of unit of analysis. Two metrics that can be obtained from both sources and are relatively irrelevant to the size of unit of analysis are ROA and percentage change in sales from last year to this year.

A random sample of 30 firms within the same SIC range as respondents of the questionnaire was drawn from a public database. ROA and sales of this year and last year of these 30 firms were available in this public database. The percentage change in sales from last year to this year was calculated for these 30 firms. A random sample of 30 plants was selected from respondents of the questionnaire. ROA and percentage change in sales between respondents and random sample were compared by applying two t tests. The mean of percentage change for the 30 random selected firms was 5.26% while the mean for the 30 respondents was 12.37%. With a p-value of .176, it was concluded that percentage change in sales are not significantly different between respondents and random sample. The mean of ROA for the 30 firms in public database was 8.48% while the mean of ROA for the 30 respondents was 32.67%. The p-value for this t test was less than 0.01, which means that the respondents have a significantly higher ROA than the random sample.

The above analysis shows that the respondents of the questionnaire in this dissertation are performing equally well or better than a random sample in the same industry. Therefore, it would be safe to conclude that the efficient DMUs identified from these respondents are not biased in an undesirable way.

5.5. MANCOVA tests

There are two choices as to how to represent the practice factors: using factor score or summated scale. Hair et al. (1994) argued that factor scores are unique to a particular data set and should be replicated or transferred to another study. Summated scales are preferred to factor scores when replicability or transferability is desired. Therefore, for each practice construct, a summated scale is constructed from its measurement items.

A close examination of the content of efficiency and practice constructs reveals that efficiency and practice could be focusing on different aspects of plant performance. While efficiency is measuring plant's performance in pure economic sense (i.e. technical efficiency), practices focus more on what plant does on shop floor and strategy formulation (i.e. allocative efficiency) etc.

5.5.1. Test of Hypotheses 1

Wilk's Λ for the interaction terms in the nine MANCOVA models are listed in Table 5.20.

Table 5.20 shows that there is significant interaction between six out of nine WCM practices and efficiency. The results indicate that three of the nine hypotheses are not supported. The three hypotheses are H1f, H1g and H1h.

In order to assess the other six hypotheses, regression coefficients need to be examined for these six practices. Table 5.21 lists the regression coefficients for interaction terms of the six models remaining to be tested.

Table 5.20 Wilk's lambda for Nine MANCOVA Models Testing Hypothesis 1

Practice	Wilk's Λ	F	Sig.
P1: Quality Management Programs	.761	13.443	.000
P2: Customer Orientation	.822	9.283	.000
P3: Labor Force Management	.806	10.304	.000
P4: Operations Flow	.824	9.109	.000
P5: Operations Capability	.900	4.746	.001
P6: Supplier Relationship	.958	1.869	.118
P7: Technology	.969	1.376	.244
P8: New Product Development	.983	.747	.561
P9: Strategy and Measurement	.818	9.531	.000

Table 5.21 Regression Coefficients for Interaction Terms in MANCOVA

P1: Quality Management Programs

Dependent variable	B	Std. Error	t	Sig.
Cost	**.622**	**.179**	**3.468**	**.001**
Quality	.005	.152	.033	.974
Delivery	**.322**	**.181**	**1.784**	**.076**
Flexibility	**.648**	**.140**	**4.614**	**.000**

P2: Customer Orientation

Dependent variable	B	Std. Error	t	Sig.
Cost	-.522	.154	-3.392	.001
Quality	**.279**	**.131**	**2.132**	**.034**
Delivery	.125	.159	.786	.433
Flexibility	**.470**	**.129**	**3.630**	**.000**

P3: Labor Force Management

Dependent variable	B	Std. Error	t	Sig.
Cost	**.331**	**.150**	**2.205**	**.029**
Quality	.183	.128	1.433	.154
Delivery	**.460**	**.142**	**3.245**	**.001**
Flexibility	**.552**	**.106**	**5.209**	**.000**

Table 5.21 Regression Coefficients for Interaction Terms in MANCOVA

P4: Operations Flow

Dependent variable	B	Std. Error	t	Sig.
Cost	.145	.139	1.040	.300
Quality	-.011	.119	-.095	.925
Delivery	**.469**	**.122**	**3.832**	**.000**
Flexibility	**.511**	**.098**	**5.223**	**.000**

P5: Operations Capability

Dependent variable	B	Std. Error	t	Sig.
Cost	-.279	.160	-1.747	.082
Quality	-.118	.137	-.861	.390
Delivery	.224	.151	1.488	.139
Flexibility	**.526**	**.125**	**4.199**	**.000**

P9: Strategy and Measurement

Dependent variable	B	Std. Error	t	Sig.
Cost	-.059	.188	-.312	.755
Quality	-.303	.153	-1.983	.049
Delivery	**.697**	**.185**	**3.766**	**.000**
Flexibility	**.712**	**.137**	**5.190**	**.000**

5.5.2. Hypothesis 1 Test Result and Analysis

The results from Table 5.20 and Table 5.21 provide us with an assessment of the nine sub-hypothesis of hypothesis 1. The result and its implication are discussed in this section.

H1a

The interaction between Quality Management Programs (QMP) and efficiency is significant on performance (p= .000). The interactions between QMP and three of the four performance variables are positively significant. These three performance variables and their regression coefficients are: cost (.622), delivery (.322), and flexibility (.648). Efficiency as a positive and significant moderator of the relationship between QMP and performance is supported. That is, H1a is supported.

H1b

The interaction between Customer Orientation (CO) and efficiency is significant on performance (p= .000). The interactions between CO and two of the four performance variables are positively significant. These two performance variables and their regression coefficients are: quality (.279), and flexibility (.470). Efficiency as a positive and significant moderator of the relationship between CO and performance is supported. That is, H1b is supported.

H1c

The interaction between Labor Force Management (LFM) and efficiency is significant on performance (p= .000). The interactions between LFM and three of the four performance variables are positively significant. These three performance variables and their regression coefficients are: cost (.331), delivery (.460), and flexibility (.552).

Efficiency as a positive and significant moderator of the relationship between LFM and performance is supported. That is, H1c is supported.

H1d

The interaction between Operations Flow (OF) and efficiency is significant on performance (p= .000). The interactions between OF and two of the four performance variables are positively significant. These two performance variables and their regression coefficients are: delivery (.469), and flexibility (.511). Efficiency as a positive and significant moderator of the relationship between OF and performance is supported. That is, H1d is supported.

H1e

The interaction between Operations Capability (OC) and efficiency is significant on performance (p= .001). The interaction between OC and one of the four performance variables is positively significant. This performance variable and its regression coefficients are: flexibility (.526). Efficiency as a positive and significant moderator of the relationship between OC and performance is supported. That is, H1e is supported.

H1f

The interaction between Supplier Relationship (SR) and efficiency is not significant on performance (p= .118). Efficiency as a positive and significant moderator of the relationship between SR and performance is not supported. That is, H1f is not supported.

H1g

The interaction between Technology and efficiency is not significant on performance (p= .244). Efficiency as a positive and significant moderator of the relationship between Technology and performance is not supported. That is, H1g is not supported.

H1h

The interaction between New Product Development (NPD) and efficiency is not significant on performance (p= .561). Efficiency as a positive and significant moderator of the relationship between NPD and performance is not supported. That is, H1h is not supported.

H1i

The interaction between Strategy and Measurement (SM) and efficiency is significant on performance (p= .000). The interaction between SM and two of the four performance variables are positively significant. These two performance variables and their regression coefficients are: delivery (.697), and flexibility (.712). Efficiency as a positive and significant moderator of the relationship between SM and performance is supported. That is, H1i is supported.

The further implications and significance of the MANCOVA testing of hypothesis 1 and the ensuing results are discussed in chapter 6.

5.6. Cluster Analysis

Cluster analysis was performed on the 75 WCM plants to test hypothesis 2 that there is more than one strategic group in WCM plants. The four performance constructs -- cost, quality, delivery and flexibility which manifested the plant's strategic orientation were chosen as cluster variate -- the set of variables representing the characteristics used to compare objects in the cluster analysis.

5.6.1. Hierarchical Procedure

Since most statistical packages use agglomerative methods versus divisive methods and agglomerative method act as divisive method in reverse, agglomerative method was applied for hierarchical clustering procedure. There are five popular agglomerative procedures depending on how the distance between clusters is defined: 1) Single linkage, 2) complete linkage, 3) average linkage, 4) Ward's method, and 5) centroid linkage. In single linkage, the distance between two clusters is defined as the minimum distance between two individual observations each from one cluster while in complete linkage, it is defined as the maximum distance between two individual observations each from one cluster. The distance is defined as average distance from all individuals in one cluster to all individuals in another in average linkage and distance between their centroid in centroid method. In the Ward's method, the distance between two clusters is the sum of squares between the two clusters summed over all variables. Ward's method is most popular since it tends to produce clusters with approximately the same number of observations.

The optimal number of clusters can be determined by examining agglomeration coefficient. The agglomeration coefficient increases as the number of cluster decreases.

The optimal number of clusters would be the one that has highest percentage increase in agglomeration coefficient to the lower number of clusters (Aldenderfer and Blashfield 1984).

Hierarchical clustering is run using SPSS by applying Ward's method as cluster method and squared Euclidean distance as distance measure. Five outliers are identified. Therefore the sample size for clustering analysis dropped from 75 to 70. Agglomeration schedule is examined to determine what is the best number of clusters. As can been seen from Table 5.22, agglomeration coefficient has increased most significantly when number of clusters decreased from three to two. Therefore, three is considered the best number of clusters based on the agglomeration coefficient.

Three is also the most favored number of clusters in strategy literature. Porter (1980) classified strategy into three groups (cost, segmentation and focus) conceptually. Miller and Roth (1994) empirically classified American manufacturers also into three groups. The three groups by Miller and Roth's taxonomy are caretakers, marketers, and innovators.

Based on both empirical evidence and theoretical considerations, three was chosen as the number of strategic groups in our study. The three cluster centers resulted from Ward's method are listed in Table 5.23. The four performance variables in each cluster center are ranked by their magnitude to provide us an idea how each strategic group in WCM place their priority among the four performance variables.

Table 5.22 Agglomeration Coefficients from Ward's Method

Number of Clusters	Agglomeration Coefficient	Percentage Increase in Agglomeration Coefficient to lower number of clusters
10	23.91	38.77
9	33.18	28.18
8	42.53	23.87
7	52.68	24.05
6	65.35	22.2
5	79.86	23.99
4	99.02	22.85
3	**121.65**	**58.27**
2	192.53	33.49
1	256.94	

Table 5.23 The Cluster Centers from Ward's Method

	Cluster 1 (n=24)	Cluster 2 (n=29)	Cluster 3 (n=17)
Cost Mean (rank)	2.58 (4)	4.72 (4)	4.47 (2)
Quality Mean (rank)	5.30 (1)	5.90 (3)	5.03 (1)
Delivery Mean (rank)	5.05 (2)	6.36 (1)	3.22 (4)
Flexibility Mean (rank)	4.33 (3)	5.95 (2)	4.00 (3)

5.6.2. K-means Clustering

The three cluster centers computed from Ward's method are selected as the initial cluster centers for K-means clustering. The distances between cluster centers are listed in Table 5.24.

After specifying the number of clusters as three, the K-means clustering procedure was run to fine-tune the clustering result. It turned out that none of the observations switched membership after K-means clustering. This indicated the stability of cluster solution. The validity of the cluster solution was further investigated by examining analysis of variance (ANOVA) and discriminant analysis results.

Table 5.24 Distances Between Cluster Centers

Cluster	1	2	3
1		3.04	2.67
2	3.04		3.80
3	2.67	3.80	

5.6.3. Validity and Hypothesis 2 Result

K-means clustering procedures in SPSS also print out the result of ANOVA test using cluster membership as independent variable and cluster variates (i.e. strategic variables) as dependent variables. The ANOVA test further examines whether all of the four strategic variables (i.e. cost, quality, delivery, and flexibility) have significant power in differentiating the three clusters. The results of ANOVA test are shown in Table 5.25 from which we can see that all four strategic variables have significantly differentiated the clusters.

Table 5.25 ANOVA Result for K-means Clustering

	F	sig
Cost	56.12	.000
Quality	12.18	.000
Delivery	118.84	.000
Flexibility	67.38	.000

Discriminant analysis using the original clustering variables as independent variables, the cluster membership as dependent variable can serve another test for validity of cluster solution (Dowling and Midgley 1988). Discriminant analysis assigned 98.6% (69/70) of the plants to their correct clusters, which is another indication of strong validity of cluster solution.

These results demonstrated that even using different procedures for clustering, assignments of plants to clusters were relatively stable and reliable. Clusters were also quite well differentiated by the strategic variables. The degree of reproducibility and stability is strong enough for us to believe that despite the relative small sample size, the cluster solution is adequately robust and empirically and theoretically coherent. The strong results of validity test of cluster analysis leads us to believe that hypothesis 2 is supported. That is, there is more than one strategic group in efficient manufacturing plants.

5.7. ANOVA and Multiple Range Tests

One way ANOVA tests serve two purposes. First, hypotheses 3 that strategic groups within efficient manufacturing plants have different priorities in WCM practices can be tested through ANOVA. Second, these ANOVA tests can also be a good validity test for cluster solution achieved in section 5.6. Since the dependent variables in ANOVA will be WCM practice constructs which are different from clustering variables (strategic variables), the significant result of ANOVA will also validate the clustering solution from section 5.6.

5.7.1. One Way ANOVA Tests

Nine one way ANOVA tests were carried out using WCM practices as dependent variable, clustering membership as independent variable. All of the WCM practices except Supplier Relationship and New Product Development proved to be highly significant ($p < 0.05$). Table 5.26 shows the results of ANOVA tests.

Table 5.26 ANOVA Results

Factors	F	p
F1: Quality Management Programs	52.88	0.000
F2: Customer Orientation	3.59	0.033
F3: Labor Force Management	42.26	0.000
F4: Operations Flow	22.97	0.000
F5: Operations Capability	16.40	0.000
F6: Supplier Relationship	2.28	0.110
F7: Technology	8.19	0.001
F8: New Product Development	0.33	0.717
F9: Strategy and Measurement	9.42	0.000

5.7.2. Multiple Range Tests

ANOVA results from Table 5.28 show that the three WCM strategic groups have different means on seven of the nine WCM practices. In order to examine which pairs of means are different for these seven WCM practices, post hoc tests are required. Tukey multiple comparison tests are performed on these seven WCM practices. Table 5.27 shows the results of Tukey multiple range tests.

Table 5.27 Tukey Multiple Range Test Results on Seven WCM Practices

F1: Quality Management Programs

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	**2**	**1.679**	**.163**	**.000**
2	**3**	**.794**	**.181**	**.000**
3	**1**	**.885**	**.188**	**.000**

F2: Customer Orientation

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	2	.072	.271	.962
2	**3**	**.698**	**.300**	**.059**
3	**1**	**.771**	**.312**	**.042**

F3: Labor Force Management

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	**2**	**1.730**	**.209**	**.000**
2	**3**	**1.620**	**.231**	**.000**
3	1	.110	.240	.890

F4: Operations Flow

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	**2**	**1.523**	**.298**	**.000**
2	**3**	**2.034**	**.330**	**.000**
3	1	.511	.343	.302

F5: Operations Capability

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	2	.170	.283	.821
2	**3**	**1.704**	**.313**	**.000**
3	**1**	**1.534**	**.325**	**.000**

F7: Technology Management

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	**2**	**1.059**	**.262**	**.000**
2	3	.457	.290	.263
3	1	.603	.301	.119

F9: Strategy Formulation and Measurement

Cluster i	Cluster j	Absolute Mean Difference	Std. Error	Sig.
1	**2**	**.628**	**.230**	**.022**
2	**3**	**1.068**	**.255**	**.000**
3	1	.440	.264	.226

The descriptive statistics of nine WCM practices dimensions for the three clusters and ranking of the three clusters on practices based on the results of multiple range tests are shown in Table 5.28.

High, Middle, and Low are used to indicate ranking based on multiple range test results. If two clusters differ on the mean of certain practice, they received different rankings; otherwise they received the same ranking. For example, Tukey tests reveal that Quality Management Programs score differ between any pairs of the clusters, therefore, the three clusters receive ranking as "high", "middle" and "low" separately. For Technology Management, cluster 1 and 2 have different means, however, cluster 3 has the same mean as both cluster 1 and cluster 3. Therefore, cluster 1 and 2 have different rankings ("low" and "high") and cluster 3 receive a ranking "high-low" to differentiate from the case that cluster 3 has different means from cluster 1 and 2. There is no significant difference found for Supplier Relationship and New Product Development. Since all three clusters score generally high on Supplier Relationship (mean>4.5) and generally low on New Product Development (mean<3.9), all three clusters received ranking of "high" on Supplier Relationship and "low" on New Product Development.

Table 5.28 Descriptive Statistics of WCM Practices for the Clusters and Multiple Range Test Results

F1: Quality Management Programs

Cluster	N	Mean	Rank	Std. Error
1	24	3.39	Low	0.14
2	29	5.07	High	0.08
3	17	4.27	Middle	0.16
Total	70	4.3		0.11

F2: Customer Orientation

Cluster	N	Mean	Rank	Std. Error
1	24	4.22	High	0.28
2	29	4.15	High	0.12
3	17	3.45	Low	0.18
Total	70	4		0.12

F3: Labor Force Management

Cluster	N	Mean	Rank	Std. Error
1	24	3.5	Low	0.14
2	29	5.23	High	0.12
3	17	3.61	Low	0.24
Total	70	4.24		0.13

F4: Operations Flow

Cluster	N	Mean	Rank	Std. Error
1	24	4.24	Low	0.2
2	29	5.76	High	0.16
3	17	3.73	Low	0.35
Total	70	4.74		0.17

F5: Operations Capability

Cluster	N	Mean	Rank	Std. Error
1	24	5.42	High	0.11
2	29	5.59	High	0.19
3	17	3.88	Low	0.36
Total	70	5.11		0.15

F6: Supplier Relationship

Cluster	N	Mean	Rank	Std. Error
1	24	4.63	High	0.13
2	29	5.02	High	0.23
3	17	5.33	High	0.28
Total	70	4.96		0.13

F7: Technology Management

Cluster	N	Mean	Rank	Std. Error
1	24	3.46	Low	0.23
2	29	4.52	High	0.18
3	17	4.06	High-low	0.13
Total	70	4.04		0.12

F8: New Product Development

Cluster	N	Mean	Rank	Std. Error
1	24	3.87	Low	0.32
2	29	3.7	Low	0.23
3	17	3.55	Low	0.19
Total	70	3.72		0.15

F9: Strategy Formulation and Measurement

Cluster	N	Mean	Rank	Std. Error
1	24	4.68	Low	0.21
2	29	5.3	High	0.16
3	17	4.24	Low	0.12
Total	70	4.83		0.11

5.7.3. Hypothesis 3 Test Result and Analysis

Hypothesis 3 states that WCM strategic groups have difference scores on nine practice dimensions. The assessment of hypothesis 3 can be made from the result of ANOVA tests which are shown in table 5.26.

<u>H3a</u>

ANOVA result shows that the three strategic groups in WCM have different scores on Quality Management Programs. That is, H3a is supported.

<u>H3b</u>

ANOVA result shows that the three strategic groups in WCM have different scores on Customer Orientation. That is, H3b is supported.

<u>H3c</u>

ANOVA result shows that the three strategic groups in WCM have different scores on Labor Force Management. That is, H3c is supported.

<u>H3d</u>

ANOVA result shows that three strategic groups in WCM have different scores on Operations Flow. That is, H3d is supported.

<u>H3e</u>

ANOVA result shows that three strategic groups in WCM have different scores on Operations Capability. That is, H3e is supported.

<u>H3f</u>

ANOVA result shows that three strategic groups in WCM have the same scores on Supplier Relationship. That is, H3f is not supported.

H3

on

H3

on

H3

on

H3g

ANOVA result shows that three strategic groups in WCM have different scores on Technology. That is, H3g is supported.

H3h

ANOVA result shows that three strategic groups in WCM have the same scores on New Product Development. That is, H3h is not supported.

H3i

ANOVA result shows that three strategic groups in WCM have different scores on Strategy and Measurement. That is, H3i is supported.

The implications from multiple range tests are discussed in chapter 6.

CHAPTER 6

DISCUSSION OF RESULTS

Five statistical procedures were carried out to achieve the two major objectives of this dissertation. In-depth examination of these test results adds more knowledge to literature and provides managerial insights for practitioners. This chapter builds on the findings of previous chapters by discussing the implications from MANCOVA testing interaction between practices and efficiency, cluster analysis, ANOVA and multiple range tests. Contributions are presented in the following section (6.3). Finally, the last section (6.4) discusses limitations of this dissertation and future research possibilities that arise as a result of this study.

6.1. Implications of Hypothesis 1 Test Results

Efficiency was proposed as a performance measurement tool for selecting the "best performing" manufacturing plants due to the consideration that neither practice based definition of WCM or performance based definition of WCM is sufficient. Practice based definition assumes that once a manufacturing plant adopts a set of practices, it will achieve WCM status. Performance based definition assumes that there is only one type of strategy existing in WCM. Selecting most efficient plants relating outputs to inputs in economic sense does not require prior knowledge of how the inputs and outputs are related. Neither does the inclusion or exclusion of a specific practice or performance dimension affect the result.

It was discovered from the results of hypothesis 1 that efficiency not only measures the ratio of output to input in the economic sense (capital inputs and sales and productivity improvement outputs), but also positively moderates the ratio of manufacturing performance to manufacturing practices. That is, an economically efficient plant is also the one that has the strongest relationship between manufacturing performance and manufacturing practices.

This finding is interesting since the manufacturing plants are indeed most concerned with how effective manufacturing practices are rather than interested in calculating how many practices they have adopted (as Schonberger's 16 principles do) if in fact these practices do not necessarily improve performance.

The findings of hypothesis 1 also correspond to practice dimensions proposed by most WCM literature. Efficiency was found to have a positive interaction with the most commonly endorsed practice dimensions -- Quality Management Programs, Customer Orientation, Labor Force Management, Operations Flow, Operations Capability, Strategy and Measurement (see Table 3.1.for how literature supports each practice dimension). The interaction between efficiency and three relatively recent practice dimensions (Supplier Relationship, Technology, and New Product Development) was not found to be significant. However, this does not mean that WCM plants are not adopting these practices. For example, ANOVA and multiple range test results show that all three clusters in WCM plants score high in Supplier Relationship dimension. Non-significant interaction indicates that the strength of relationship between Supplier Relationship and performance was not found significantly different between efficient manufacturing plants and less efficient plants.

6.2. Implications of Hypothesis 2 and 3 Test Results

Combining the results from Table 5.23 and Table 5.28, the differences among the three clusters are listed below.

The importance cluster 1 places on performance metrics from high to low follows this sequence: Quality, Delivery, Flexibility and Cost. This sequence is the same as the sequence proposed by sand cone model (Ferdows and De Meyer 1990). Sand cone model proposes that if you follow this sequence, the tradeoffs between various performance metrics will be minimized. However, this cluster is not the best performing cluster in terms of competitive performance as sand cone model may have predicted. The relationship among the performance metrics could be more complicated than that proposed by the sand cone model. It may also be mitigated by the strategy the manufacturing plant adopts. Compared to the other strategic groups that are also efficient, this group aims to provide reliable and durable products and fast and on time delivery without a strong focus on cost reduction. Cluster 1 can be labeled as "Quality and Delivery (QD)" based on its strategy that is manifested by its competitive priorities.

Multiple range test results as shown in table 5.28 indicated that members of this group, aiming to provide high quality with customization, have invested their time and resources highly on three of the nine practice dimensions. These three dimensions are: customer orientation, operations capability and supplier relationship. It is worth noting that this group did not focus their attention around Quality Management Programs as one might expect. A close examination of the measurement items of Quality Management Programs and Customer Orientation reveals that while Customer Orientation Program intends to define quality by customer satisfaction, Quality Management Programs focuses on reducing reject rates. The seemingly paradoxical result that "Quality and Delviery" group does not focus on Quality Management Programs suggests that defining customers' needs is the key to achieving quality competitiveness in industry.

The importance cluster 2 places on performance metrics from high to low follows this sequence: Delivery, Flexibility Quality, and Cost. Cluster 2, compared to the rest of the efficient manufacturing plants, placed high priorities on all the practice dimensions except New Product Development. As a result, cluster 2 performs best on all four dimensions of competitive performance compared to the other two clusters. This cluster meets the criteria of both practice-based and performance-based definitions of WCM. In addition, this cluster meets the pre-condition defined in this dissertation: technical efficiency.

Since this group of manufacturing plants meets multiple criteria of WCM, which are defined either in literature or in this dissertation, it is considered to be the only group that deserves the title of "WCM". Up to now, this dissertation proposed a new definition of WCM. This definition not only integrated the requirements of both practice-based and performance-based definition, but also imposed a new criterion: technical efficiency. A plant has to be efficient in the economic sense. The validity of efficiency is established by its moderating effect on the relationship between practices and performance, which is verified by test results of hypothesis 1.

The four competitive advantages, sequenced by the priority that cluster 3 places on them are Quality, Cost, Flexibility, and Delivery. Cluster 3, among all three clusters that are efficient, is the only one that places cost in such a high priority. This cluster, compared to the other two clusters, focuses on a "Cost/Value (CV)" leadership.

Multiple range tests reveal that CV group focuses highly on three out of nine practice dimensions to achieve its cost/value leadership. These three practice dimensions are Quality Management Programs, Supplier Relationship and Technology. CV also emphasized Quality Management Programs, but not to a great degree. Those practice dimensions that CV group chose not to invest in aggressively are Customer Orientation, Labor Force Management, Operations Flow, Operations Capability, New Product Development, Strategy Formulation and Measurement. The list of practices chosen by CV suggests that CV finds its niche in cost/value leadership by ignoring the long term and expensive programs and focusing only on the quick and most effective cost reduction programs. Technology program has a reputation of being risky, less profitable, and paying off slowly. Therefor managers with only short-term goals may not favor it. However, the adoption of Technology Program by CV group shows that keeping up with current technology does help with keeping cost low and quality high.

The taxonomy analysis of efficient manufacturing plants indicates that these plants, although all technically efficient, have adopted different approaches toward the so-called "WCM practices" due to the differences in their strategies.

It shows that to achieve the "WCM status", a manufacturing plant still needs to adopt almost all the practice programs and performs well on all the performance areas. However, Cost/value leadership (CV) and quality and delivery (QD) groups managed to find their niche by investing in only a small set of practice programs and be efficient. Due to the limited resources, this means a lot to a plant wanting to benchmark and become more efficient. It does not have to benchmark a WCM plant if it does not plan to become one. Instead, based on its own strategy, the plant can selectively choose a small set of practices to engage in for the purpose of achieving leadership in certain performance areas.

6.3. Contributions

This dissertation makes four major contributions to operations strategy literature.

First, this research represents one of the first studies to synthesize and validate the dimensions of WCM practices in literature. Comprehensive measurement models, which may provide a foundation for further empirical testing in this area are proposed and empirically tested.

Second, efficiency as defined in this dissertation is based on the traditional ideas in economics relating outputs to inputs. It overcomes the drawback in some empirical studies that purport to study the relationship between practices and performance but have questionable ways of defining WCM. These studies have problems of tautology since they rely on either practices or performance to define WCM. One can claim that the examination of the relationship between practice and performance in this dissertation is more robust. It reconciles the notion of technical efficiency with the notion of world class.

Third, results of cluster analysis and comparison among the three clusters within efficient manufacturing plants indicate that these manufacturing plants have adopted different strategies to become efficient. What is more important is that these groups have different priorities on WCM practices. This further indicates that the approach of current WCM literature, which does not realize that differences exist in priorities on manufacturing practices within best performing plants due to strategy differences, is inadequate. This research points to the need to further investigate how the strategy differences affect the relationship between practices and performance.

Finally, the research findings suggested that to be termed WCM requires all three criteria: 1) engage in WCM practices, 2) be technically efficient and 3) perform well on all the performance areas.

6.4. Limitations and Future Research Directions

The major limitation of this dissertation is that the sample size is relatively small so that carrying out a research design that yields more information and tests more relationships among the constructs in one model was not be possible.

This dissertation represents one of the first efforts that integrated the dimensions of WCM practices in literature and empirically tested the measurement model for WCM practices. Further efforts in offering and testing measurement models of WCM practices on different data sets will help providing a valid and comprehensive model to facilitate future empirical studies in the area of WCM.

This dissertation is the first study that utilized efficiency analysis, taxonomy analysis to solve the questions arising from the context of world class manufacturing. This study identified three strategic groups within the efficient manufacturing plants and showed that strategic difference affects plants' decision as to which practices they should pay more attention to. Strategy could make a lot of differences in more than resource employment decision. For example, strategy may account for the differences in the slope between performance and practices that this dissertation was unable to study due to the smallness of the sample.

This dissertation successfully identified a group of manufacturing plants that perform well on all performance areas. However, whether the trade-off among the performance areas exist is still unclear. With a bigger sample size, models that test the relationship among the performance dimensions will provide us more insight into this debate.

The recommendation that technical efficiency be used as one of the pre-requisites of WCM is a relatively new idea in operations strategy. The choice of input and output variables will significantly affect the quality of the results. Efficiency analysis has a great potential in performance evaluation in manufacturing strategy due to its simplicity and few assumptions. Yet experience from further studies using this tool will help perfect this process.

APPENDIX A

MEASUREMENT INSTRUMENT

APPENDIX A

MEASUREMENT INSTRUMENT

Michigan State University
World Class Manufacturing / Benchmarking Study

Please refer any questions regarding this study to Cynthia Wang, Michigan State University (517) 353-6381 **<u>All returned surveys will remain confidential.</u>**

First Name	
Last Name	
Title	
Company	
Address	
City	
State	
Zip Code	
Phone number	
Please enter your survey ID on the letter you received from us	
Email address	
Password	**********
Confirm password	**********

Plant Characteristics	
average annual change in **labor productivity** over the last two years (in %)	________ %
average annual change in **sales** over the last two years	_________%
average annual change in **profitability** over the last two years	_________%
average annual change in **market share** over the last two years	_________%
What has been the market share for your primary products over the last two years (In %)?	_________%
What is your primary SIC code?	___________
What is your secondary SIC code?	___________
How many factory employees work at your plant?	___________
How many non-factory employees work at your plant?	___________
What was the total international sales for your plant last year (in $)?	$ __________
What was the domestic sales for your plant last year (in $)?	$___________
What was the total raw material purchase in your plant last year (In $)?	$___________
How much did your plant invest in equipment over the last 3 years (in $)?	$____________
How much did your plant invest in information technology over the last 3 years (in $)?	$____________
ROI	_____________
ROA	_____________
Number of different major products produced at your plant?	_____________

Plant Characteristics	
How would you characterize your major product line?	⦿make to stock Omake to order OEngineer to order OAssemble to order
Percentage of continuous flow (24 hour operation) in your plant	_________%
Percentage of assembly line in your plant	_________%
Percentage of job shop (wide variety of custom products) in your plant	_________%
Percentage of batch (medium sized lots of production) in your plant	________%

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Quality Management Programs	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
Everyone has responsibility to improve quality.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Continuous improvement of quality is expected in all work processes.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Workers are financially rewarded for quality improvement.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Processes on the shop floor are under statistical quality control.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use statistical techniques to reduce variance in processes	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We measure process capability (e.g., Cpk)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use visual control techniques (e.g., charting defects, schedule, etc.).	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
SPC method is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Operators inspect their own work	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Quality Function Deployment is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Total Quality Management philosophy is promoted	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Design of Experiments is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Customer Orientation	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We maintain close contacts with our customers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Results of customer satisfaction surveys are communicated throughout organization.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We actively create opportunities for customer-employee interaction.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing operations are organized around specific customers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Mfg. operations are organized around product families with similar customer needs.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We produce at a rate close to the customer's rate of use.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have a formal "customer satisfaction" program in place.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Labor Force Management	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We actively engage in skill development	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Direct labor technical competency is high	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Employees are cross trained to perform a variety of activities	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Team members are encouraged to exchange opinions/ideas.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Supervisors and teams communicate frequently.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our employees have strong problem solving abilities.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Shop floor employees are rotated among jobs.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Employees are rewarded for learning new skills.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use problem solving ability as a criterion in employee selection	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use knowledge and skill level as a criterion in employee selection	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use ability to work in a team as a criterion in employee selection	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use work values and ethics as a criterion in employee selection	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Production scheduling is handled by empowered teams	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Quality assurance is handled by empowered teams	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Labor Force Management	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
Skills certification and training is handled by empowered team	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Labor scheduling / job assignments is handled by empowered team	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Hiring/firing of team members is handled by empowered team	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Performance reviews are handled by empowered teams	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Operations Flow	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
The shop floor is laid out to optimize processing sequence and flow.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use a pull system in production.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We produce in small lot sizes in this plant.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have a "focused factory" (e.g., product or process focused) production system.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use lean manufacturing production methods.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We offer JIT delivery to customers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our production flow utilizes manufacturing cells.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Operations Capability	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We dedicate to continual improvement in quality.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We dedicate to continual improvement in response time.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We dedicate to continual improvement in flexibility.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We dedicate to continual improvement in cost.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We develop measurement systems that encourage continual learning.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We develop operations that are able to respond rapidly to changes in product and market.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We continually reduce variations and mishaps.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply

Supplier Relationship	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
Our suppliers deliver on a just-in-time basis.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We require daily shipments from suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use 'total cost purchasing' in procurement decisions .	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our suppliers are certified or pre-qualified.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We establish long-term contracts with suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have reduced the number of suppliers for each part family.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We frequently source multiple part families from a single supplier.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We procure complete systems / modules from major suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We require major suppliers to contribute to cost and quality improvement efforts.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We no longer require incoming inspection.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have a high degree of mutual trust with our suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We pursue joint investments with suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We provide financial assistance to suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We provide technological assistance to suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Supplier Relationship	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We provide training in quality issues to supplier personnel.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use buyer-supplier councils.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We share real time production schedule information with suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We share our cost information with our major suppliers.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We require cost information sharing by our suppliers .	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We select suppliers based on design/innovation capabilities.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We select suppliers based on abilities to accommodate volume / mix changes.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Technology Management	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We design and develop proprietary equipment for our own use.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We develop dedicated technologies for specific product families/customer segments.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We improve present equipment before considering new equipment	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We present human work methods before considering new automation	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We seek simple, flexible, low-cost, readily available equipment	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We plan technological upgrades to be consistent with infrastructural upgrades	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Computer-aided-design (CAD) technology practice is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Computer-aided-manufacturing (CAM) technology practice is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Flexible manufacturing systems (FMS) technology practice is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Robotics is used.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Automated storage /retrieval systems tehcnology practice (AS/RS) is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Technology Management	Don't Know	Much less			About the same			To a much greater extent
Computer aided process planning (CAPP) technology practices is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Rapid prototyping (e.g., stereolithography) technology practice is applied	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Advanced MRP II systems is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Enterprise Resource Planning system (ERP) is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product data management (PDM) systems is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
EDI links to customers and suppliers is used	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

New Product Development	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
We emphasize early supplier involvement in product development.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Customer requirements are clearly specified early in conceptual design.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use design-for-manufacture and assembly (DFMA) methods.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing involvement and sign-off are required for new products.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We practice job rotation between design and manufacturing engineering.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have created new ways to coordinate design and manufacturing issues.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our product designers make use of manufacturability guidelines / checklists.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product designers and manufacturing staff have equal status in NPD projects.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Comparing your plant to the standard or average in your industry, indicate the extent to which the following statements apply.

Strategy Formulation and Measurement	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
Performance improvements are gauged against "best practice" companies.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Performance measures are directly related to customer requirements.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We use benchmarking studies as a basis for performance improvement.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
We have clearly defined strategic manufacturing goals and objectives.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our firm's strategy leverages existing capabilities.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Corporate strategy at our firm drives manufacturing decisions.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing strategies and goals are clearly communicated to all employees.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing strategy is frequently reviewed and revised.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing strategy is well aligned with corporate strategy.	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our manufacturing strategy emphasizes shortest delivery lead times	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our manufacturing strategy emphasizes highly customized product	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Strategy Formulation and Measurement	**Don't Know**	**Much less**			**About the same**			**To a much greater extent**
Our manufacturing strategy emphasizes a product with better features than those offered by the competitors	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our manufacturing strategy emphasizes 100% conformance quality	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Our manufacturing strategy emphasizes being the lowest cost producer	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Please rate your performance relative to your principal competition

Manufacturing Performance	**Don't Know**	**Much worse**			**About the same**			**Much better**
initial purchase cost	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
manufacturing overhead cost	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
maintenance cost	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product overall quality performance	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product feature	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product reliability	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product conformance	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
product durability	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Product serviceability (speed, courtesy and competence of repair)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Customer satisfaction	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Impact of brand name	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Delivery accuracy (correct items were delivered)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Delivery availability (the probability that items will be in stock at the time of order)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Delivery dependability (delivered on the agreed upon date)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Delivery speed (short elapsed time between order placement and product reaches the customer)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Delivery quality (condition of product after shipment)	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Manufacturing	**Don't**	**Much**			**About**			**Much**

Performance	**Know**	**worse**			**the same**			**better**
Ability to customize products	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Lead time to introduce new products	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Ability to adjust production volumes	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Number of engineering change orders per year	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Number of new products introduced each year	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Ability to respond to changes in delivery requirements	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Ability to produce a range of products	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Productivity	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Profitability	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
Market share of major product/product line	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O
growth rate in unit sales	O N/A	1 O	2 O	3 O	4 O	5 O	6 O	7 O

Thank you for participating in this World Class Manufacturing / Benchmarking study!

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