A study of operations management constructs and their relationships

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Abstract *This paper describes an exploratory research effort to analyze and classify emerging operations management practices in US manufacturing. Using a survey of senior materials and operations management professionals in the United States, this study investigates manufacturers' supplier assessment practices, new product design and development practices, just-in-time practices, and quality practices. This study also identifies practices that share common variance-covariance characteristics and to what extent the observed practices are linked to their underlying factors by means of exploratory factor analysis. Finally, bivariate correlation analysis is used to examine the relationships of the factors.*

Introduction

In the 1950s and 1960s, US manufacturers practiced mass production to improve productivity, while little attention was paid to product and process flexibility. New product design and development was slow and relied exclusively on in-house technology and capacity. Sharing technology and expertise through strategic buyer-supplier partnerships was essentially unheard of. Bottleneck operations were cushioned with inventory to maintain balanced material flows, resulting in large investments in work in process (WIP) inventory. In the 1970s, manufacturing resource planning was developed, and the importance of effective materials management was recognized as manufacturers became aware of the impact of WIP on manufacturing costs, quality, new product design and development, and delivery lead times.

Intense global competition in the 1980s provided an incentive for manufacturing firms to offer low cost, high quality, and reliable products with greater design flexibility. Manufacturers utilized just-in-time (JIT) and total quality management (TQM) strategies to improve quality and manufacturing efficiency. In a JIT production environment with little inventory to cushion scheduling and/or production problems, savvy manufacturers realized the potential benefits of strategic and cooperative buyer-supplier relationships. The concept of strategic buyer-supplier partnerships and alliances emerged as firms experimented with JIT and mass customization.

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As competition intensified further in the 1990s, the challenges associated with improving quality, manufacturing efficiency, and new product design and development also increased. Manufacturers began purchasing from a limited number of certified suppliers whose quality was trusted (Inman and Hubler, 1992), and involved suppliers in product design and development. Assessments of supplier efficiency were broadened to include different aspects of suppliers' products and processes, including technology, delivery, cost, and quality considerations.

While many researchers have studied these operations strategies and practices (Tan *et al.*, 1998), the common variance-covariance characteristics of these observed practices that define individual constructs and their relationships have not been analyzed. Studying these constructs and their relationships could prove beneficial to both researchers and practitioners seeking to model or implement various operations management practices.

This paper describes an empirical investigation of manufacturers' supplier assessment practices, new product design and development practices, JIT practices, and quality practices. The compilation of practices was based on a review of the relevant literature, and discussions with practicing managers. Due to a limited knowledge of how these practices might be related, exploratory factor analysis was used to determine which practices shared common variance-covariance characteristics and to what extent the observed practices were linked to their underlying constructs. The underlying constructs or factors are useful in explaining complex phenomena. For example, although an individual's intelligence cannot be measured directly, it can be expressed as a linear combination of various measured variables such as test-score, grade point average, verbal, communication, and analytical skills. Finally, bivariate correlation analysis was used to examine the relationships of the constructs.

The following section reviews the literature and describes the research framework. Supplier assessment, new product design and development, JIT, and quality practices are described, and hypotheses are presented. This is followed by a methodology section, which describes variable measurement, sampling methods, and data collection procedures. Demographic information and the results of the survey are then presented and discussed, and conclusions are drawn.

Research constructs

While supplier assessment, new product design and development, JIT, and TQM share the common goal of continuous improvement to reduce waste and enhance competitive position, specific activities and practices to execute each strategy vary. In order to articulate relevant practices under each strategy, we reviewed the relevant literature to identify common practices and/or activities. To further refine and analyze a list of important practices under each strategy, we discussed our initial list of practices with several practicing managers to ensure that the practices were relevant and expected in a manufacturing firm that practiced such a strategy.

Supplier assessment practices

At the turn of the twenty-first century, many manufacturers are exploiting supplier strength and technology to support new product design and development efforts (Morgan and Monczka, 1995). Suppliers may also participate earlier in the product design process to render more cost-effective design choices, develop alternative conceptual solutions, select the best components and technologies, and help in design assessment (Burt and Soukup, 1985; Monczka *et al.*, 1994). Conversely, there is also an increasing interest in supplier development by buying firms to increase suppliers' technical, quality, delivery, and cost capabilities (Krause, 1997). Hahn *et al.* (1990) proposed an organizational decision process model associated with a supplier development program to link purchasing strategy with a firm's overall corporate competitive strategy. Subsequently, Watts and Hahn (1993) discovered that formal supplier assessment is crucial to the supplier development process. Firms thus find themselves expanding the need to effectively manage internal competencies to include external members of the value chain, and supplier assessment becomes an important tool in monitoring supplier performance.

Supplier certification is a form of supplier assessment. It focuses on purchased raw materials and components, with a few exceptions on service suppliers (Jancsurak, 1992; Schneider *et al.*, 1995). Supplier certification is inevitable for a JIT manufacturer who operates with no excess inventory and the need to deliver to the point of use (Burgess, 1987; Maass, 1988). Grieco (1989) in an early work on supplier certification proposed a five-phase supplier certification process. Eventually, supplier certification was extended to include the logistics function, as in the work of Gibson *et al.* (1995) who described the utilization of supplier certification to certify carriers. Inman and Hubler (1992) carried the concept of supplier certification further by suggesting that supplier products and processes should be certified.

Many firms have reduced their supply bases so that they can more effectively assess and manage relationships with strategic suppliers (Tully, 1995). Many firms find themselves expanding the need to effectively manage internal competencies to include members of the supply chain. If approached collaboratively, supplier assessment allows the suppliers to demonstrate management quality through good practice and compliance, and encourage investment in the best available technology. An effective assessment program sets and communicates expected standards and goals for all suppliers. Supplier assessment can be accomplished by means of a detailed questionnaire or complete audit of a supplier's operations (Lamming and Hampson, 1996).

While the literature did not list any specific supplier assessment practices, it revealed that supplier assessment focused on evaluation of supplier products and processes. For the purpose of this study, 15 supplier assessment practices were postulated (Appendix, Part 1), and reviewed by practicing managers to ensure that these practices were likely to be used among the survey respondents. We collected data on supplier assessment practices and used factor-analytic techniques to explore how the observed practices related to a construct. In other words, we attempted to determine which sets of observed supplier assessment practices shared common variance-covariance characteristics that defined an individual construct. Our first hypothesis proposed that the set of 15 supplier assessment practices are interrelated and could be reduced to a smaller set of constructs based on their common variance-covariance characteristics.

New product design and development practices

Designing new products and getting them to market quickly is a critical task for many manufacturers. The literature shows that buying firms are developing cooperative and mutually beneficial relationships with suppliers, and view suppliers as virtual extensions of their firm (Copacino, 1996; Mason, 1996). Superior supplier capability often leads to exceptional quality, cost-effective design choices, innovation in process and material technology, and rapid integration of the latest technological breakthroughs in new product design and development (Monczka *et al.*, 1994; Prahalad and Hamel, 1990; Ragatz *et al.*, 1997).

However, involving suppliers in new product design and development to take advantage of technical expertise and to reduce development time, is inherently a complex task. Collaborative new product design and development requires frequent communication and trust among partners, flexible corporate systems and management style, a fit with existing business, and the choice of good partners (Littler *et al.*, 1995). Firms must be willing to share proprietary information, and new product design and development teams must focus on reducing the product development cycle time and costs, while improving product quality. The extent of cooperation depends on the technical complexity, strategic importance, and scope of the project (Ragatz *et al.*, 1997). Interestingly, research has shown that the US manufacturers tended to involve suppliers more extensively in new product design and development than their European counterparts (Birou and Fawcett, 1994).

Many companies have begun using modular design, concurrent engineering, simplification, standardization, value engineering, and quality enhancement tools like the house of quality to reduce new product design and development time (Chase *et al.*, 1998; Heizer and Render, 1999). Modular design offers flexibility to both production and marketing by making product development, production, and subsequent changes easier. Instead of using a serial approach that proceeds from one phase to another, concurrent engineering emphasizes cross-functional integration and concurrent development of a product and its associated processes. Value engineering helps to eliminate unnecessary costs and simplifies products and processes to achieve equivalent or better performance at a lower cost while maintaining all functional requirements. Quality function deployment uses inter-functional teams from marketing, design engineering, and manufacturing to incorporate customers' requirements into the design specification of a product. Simplification and standardization enable manufacturers to reduce the number of variations in materials and components and aid in cost reduction.

Although the literature did not exclusively provide a common set of new product design and development practices, ten practices were identified (Appendix, part 2) based on Chase *et al.* (1998) and Heizer and Render (1999). These practices included modular design, early supplier involvement, simplification, and standardization of parts. Our second hypothesis proposed that these practices could be grouped into a set of constructs based on their common variance-covariance characteristics (i.e. these practices were interrelated).

JIT practices

Schonberger (1982), a pioneer in JIT research in the US, cited many shop floor practices, such as setup time reduction, small lot sizes, mixed model production, multifunction workers, preventive maintenance, and JIT delivery by suppliers as important practices in a JIT system. In a later study, Schonberger (1986) included employee involvement and quality as important practices. Subsequently, Celley *et al.* (1987), Crawford *et al.* (1988), and Im and Lee (1989) conducted empirical research on US JIT practices. Voss and Robinson (1987) studied JIT practices in the United Kingdom, whereas Inman and Mehra (1990) compared JIT practices between large and small firms. Humphreys *et al.* (1998) indicated that the purchasing function plays a key role in the successful implementation of the JIT systems.

Through a survey of 33 US firms, Im and Lee (1989) discovered that JIT practices were used in almost all aspects of the organization, particularly in the production planning and control system, including inventory control, purchasing, capacity planning, and distribution planning. Voss and Robinson's (1987) study of UK firms also supported this finding. Sakakibara *et al.* (1997) contended that conceptual literature on JIT practices was extensive, but the empirical literature was limited. In general, empirical JIT studies supported the conceptual studies and research also indicated that the JIT adopters achieved improved performance (Celley *et al.*, 1987; Gilbert, 1990; Im and Lee, 1989; White, 1993).

Recently, White *et al.* (1999) showed that implementation of JIT practices differed between the US small and large manufacturers. The JIT practices used in the study included quality circles, total quality control, focused factory, preventive maintenance, reduced setup times, group technology, uniform workload, cross-trained workers, kanbans, and JIT purchasing. Although the results showed that large firms were more advanced in the implementation of JIT systems than the small firms, three of the ten JIT practices (reduced setup times, cross-trained workers, and kanbans) affected the performance of both the small and large firms equally.

Sakakibara *et al.* (1997) identified six key JIT practices (setup time reduction, scheduling flexibility, maintenance, equipment layout, kanbans, and JIT supplier relationships) through a series of plant visits, and concluded that these practices were related to quality management and product design. While the literature indicates that not all organizations implemented the same JIT practices (Gilbert, 1990; Im and Lee, 1989), and specific JIT practices adopted were based on the organizational characteristics (Harber *et al.*, 1990; Sohal *et al.*, 1989), effective JIT implementation requires employee involvement (Germain and Droge, 1997; Mclachlin, 1997).

Based on the above discussion, it was clear that the JIT literature provided specific practices for enhancing firm performance. For this study, eight JIT practices were identified from the literature (Appendix, part 3). These practices included reducing the lot size, setup time, supplier base, and inventory, as well as using preventive maintenance. Our third hypothesis proposed that the set of eight practices could be grouped into a set of constructs based on their common variance-covariance characteristics (i.e. these practices were interrelated).

Quality practices

In recent years, intense global competition has forced many firms to examine how they manage quality as they seek to enhance their competitiveness (Malhorta *et al.*, 1994; Symons and Jacobs, 1985). While quality management efforts at some companies have resulted in improved competitiveness (Hendricks and Singhal, 1996), similar results in many firms have remained elusive (Grant *et al.*, 1994; Hiam, 1993). The failure of many quality programs to yield the anticipated outcomes stems in part from uncertainty in how the programs should be implemented (Greene, 1993), although the literature on quality management is replete with approaches for managing quality (Ahire *et al.*, 1995). Much of the quality literature has been descriptive in nature (Flynn *et al.*, 1995b), and there is a lack of well-defined linkages between practices and outcomes. Thus, many companies practice quality initiatives in a piecemeal manner or without thoroughly understanding their impact on the organization (Cole, 1993; Schaffer and Thomson, 1992). However, recent research has attempted to establish a theory of quality management and to empirically identify relationships between quality management practices and performance.

Saraph *et al.* (1989) proposed and empirically validated eight quality practices derived from the writings of quality pioneers and demonstrated that actual quality practices along with ideal quality management are dependent on the organizational quality context. The quality practices were the role of top management leadership, the role of the quality department, training, product design, supplier quality management, process management, quality data and reporting, and employee relations. Anderson *et al.* (1994, 1995) developed a quality management theory and identified six constructs underlying the Deming quality management philosophy. Flynn *et al.* (1995a) derived eight quality practices (process flow management, the product design process, statistical quality control, customer relationships, supplier relationships, work attitudes, workforce management, and top management support) from the empirical studies of actual quality practices in the US and Japan. Ahire *et al.* (1996) identified 11 quality management constructs and showed that the constructs correlated positively with product quality. Black and Porter (1996) used the Malcolm Baldrige National Quality Award framework to examine the quality practices, and identified several quality management practices not embodied in the framework.

These studies identified various quality practices and focused on quality management at a strategic level. Little attention was paid to whether these practices shared common variance-covariance characteristics that defined an individual construct. From this body of literature, 13 quality practices that involved attempts to design, build, and/or inspect quality into the product were identified (Appendix, part 4). Our fourth hypothesis proposed that a set of constructs or factors could be identified from the set of 13 quality practices based on their common variance-covariance characteristics (i.e. these practices were interrelated).

Construct relationships

In addition to suggesting that quality practices can improve JIT performance and conversely, that JIT practices will improve quality performance, Flynn *et al.* (1995a) concluded that quality and JIT practices interacted. Our literature review also indicated a difficulty in precisely differentiating the practices comprising supplier assessment, new product design and development, JIT, and quality management because of the extensive overlap or commonalities between the approaches. Thus, our fifth hypothesis proposed that the constructs identified from the four sets of practices were related.

Survey methodology

A survey instrument was designed based on the constructs described above. The survey was pre-tested for content validity by a number of practicing business and non-profit managers. The revised survey instrument was sent to 1,500 senior supply and materials managers of the manufacturing firms identified from the Institute of Supply Management (ISM, formerly known as the National Association of Purchasing Management) membership list.

Respondents were asked to indicate the importance of their firm's supplier assessment, new product design and development, JIT, and quality practices using a five-point Likert scale (as described in the Appendix). Other questions, including demographics information, were also presented in the questionnaire. Two mailings and a follow-up reminder yielded a response rate of 7 percent (101 useable returned surveys). Approximately 2 percent of the surveys were returned unusable due to incorrect addresses or change of employment. The low response rate was most likely due to the respondents' survey fatigue (ISM respondents have been targeted with many surveys in the recent past by different researchers and thus were reluctant to reply). Several respondent comments alluding to this were also received. The lower than expected response rate potentially affected our ability to generalize the survey results.

Non-response bias

The responses were divided into early and late waves of returned surveys to test for non-response bias of the survey data (Armstrong and Overton, 1977; Lambert and Harrington, 1990). The last wave of surveys received were considered to be the representative of non-respondents. Specifically, 30 of the survey items used for this analysis were randomly selected, split into two groups based on early and late survey return times, and then *t*-tests were performed on the responses of the two groups. The groups represented the first 74 and last 27 responses of the 101 responses received. The *t*-tests yielded no statistically significant differences among the 30 survey items tested. These results suggested that non-response bias was not a concern for this study.

A profile of the respondents

The respondent profile information is shown in Table I. Almost 60 percent of the respondents were final product manufacturers, whereas 24.2 percent were component manufacturers. Other firm types (10.1 percent) included turnkey and contract manufacturers. The companies represented by the respondents varied in size, employing between 15 and 80,000 employees (including part-time and temporary employees). Approximately 20 percent of the companies employed fewer than 150 employees while 11 percent employed more than 5,000 employees. Most of the respondents (67.3 percent) engaged in international operations, and a few respondents (4.1 percent) operated primarily in local markets within the USA. Annual gross sales of the companies ranged from $4 million to $18 billion, with an average of $745 million. About half of the respondents reported annual gross sales of less than $70 million.

Additionally, a number of interesting supplier management characteristics were found among the respondents. Over the most recent three-year period, 51.2 percent of the respondents reported an increase in outsourcing activities in primary materials, components, subassemblies, and services, whereas 35.2

Table I.
Respondents' profile

Respondents' business function	*Percent*	*Respondents' business operations*	*Percent*
Raw material manufacturer	6.1	Local business	4.1
Component manufacturer	24.2	Regional business	28.6
Final product manufacturer	59.6	Global business	67.3
Others	10.1		
	100 percent		100 percent
Number of employees (1998) [a]	#	*Annual gross sales (1998)*	$
Mean	2,874	Mean	$745 m
Median	400	Median	$70 m
Minimum	15	Minimum	$4 m
Maximum	80,000	Maximum	$18 b
Percent change in outsourcing activity	*Percent decrease*	*No change*	*Percent increase*
Primary materials, components, subassemblies and services	8.8	40.0	51.2
MRO supplies	1.4	63.4	35.2
Percent change in supplier base			
Primary materials, components, subassemblies and services	41.9	29.1	29.0
MRO supplies	31.3	45.8	22.9
Percent change in the			
Number of strategic alliance programs	0.0	28.8	69.2
Acceptable process capability index (C_{pk})	*Mean/median*	*Lowest*	*Highest*
Critical materials and parts	1.37/1.33	1.00	2.00
Non-critical materials and parts	1.14/1.00	1.00	1.33
Others			*Percent*
Percent of respondents with ISO 9000 series certification[b]			58.5
Percent of respondents with ISO 14000 certification			3.2
Percent of respondents that use specific written quality plans/policies			84.7

[a] Includes part-time and temporary employees; [b] 14.5 percent of the respondents are ISO 9000 certified, 40.0 percent are ISO 9001 certified, 50.9 percent are ISO 9002 certified, 1.8 percent are ISO 9003 certified, and none are ISO 9004 certified. The total percent exceeded 100 percent because some respondents obtained multiple certifications.

percent reported an increase in outsourcing of maintenance, repair, and operating (MRO) supplies. The respondents also indicated a trend toward decreasing their supplier base, particularly for primary materials (41.9 percent). Additionally, almost 70 percent of the respondents indicated an increase in the number of strategic alliances over the same three-year period, suggesting that they were concentrating their purchases on fewer suppliers, and taking advantage of buyer-supplier partnership programs. This is consistent with the recent literature in supply chain management (Tan *et al.*, 1998; Tully, 1995). The respondents also reported a higher acceptable process capability index (C_{pk}) for critical materials and parts ($C_{pk} = 1.37$) than non-critical materials and parts ($C_{pk} = 1.14$). A large portion (58.5 percent) of the respondents were ISO 9000 certified, whereas only 3.2 percent were ISO 14000 certified. Finally, almost 85 percent of the respondents used specific written quality plans suggesting the widespread adoption of quality policies and procedures.

Statistical analyses

Reliability analysis

Table II presents the reliability analysis information. Prior to analyzing the test item scales, the reliability of the scales for supplier assessment practices, new product design and development practices, JIT practices, and quality practices was evaluated using Cronbach's α (Cronbach, 1951). The survey items, suppliers need to maintain a formal program for safety and hygiene (Appendix I, part 1, question a), and suppliers need to comply with all requirements of your firm (Appendix, part I, question k), were eliminated from the supplier assessment practices because they correlated weakly with the other questions. Thus, supplier assessment was reduced to 13 items. Similarly, inspection (Appendix, part 4, question a) and statistical process control (Appendix, part 4, question d) were eliminated, reducing quality practices to 11 items. The final Cronbach's α was greater than 0.85 for each set of practices (Table II) suggesting that the scales were sufficiently reliable (Nunnally, 1988).

Scale items	Cronbach's α	Standardized item α
Supplier assessment[a]	0.9379	0.9403
New product design and development practices	0.8901	0.8918
JIT principles	0.8512	0.8518
Quality practices[b]	0.9033	0.9043

Notes: [a] Suppliers need to maintain a formal program for safety and hygiene (Appendix, part 1, question a) and suppliers need to comply with all requirements of your firm (Appendix, part I, question k) were eliminated because they correlated weakly with other supplier assessment questions; [b] Inspection (Appendix, part 4, question a) and statistical process control (Appendix, part 4, question d) were eliminated because they correlated weakly with other quality practices.

Table II. Reliability analysis

The supplier assessment practices

Table III shows the mean importance responses for the 13 supplier assessment practices. Based on mean scores, Ensuring purchased product and materials conform to specifications was the highest ranked supplier assessment practice. Investigating causes of non-conformance and taking corrective actions was also ranked highly by the respondents. Surprisingly, having a comprehensive internal quality audit system *in place* did not rank highly among the assessment practices. Additionally, the need to maintain a facility-wide, documented preventive maintenance program was ranked at the bottom of supplier assessment practices.

As shown in Table IV, the mean importance responses to questions on new product design and development practices ranged from 3.95 to 3.14. Quick product development and introduction time was ranked the highest, suggesting that time-based competition was an important competitive strategy. Savvy manufacturers who manage to introduce new products ahead of the competition can charge a price premium in the early product introduction stage due to limited competition. These results also indicated that manufacturers were taking advantage of suppliers' knowledge and technology by involving them early in the new product design and development process. The managerial implication is that firms should focus on key suppliers to establish mutually beneficial relationships, instead of

Supplier assessment practices	Mean	Standard deviation
Suppliers need to:		
(i) Ensure that their purchased products and materials conform to their specifications	4.58	0.64
(m) Investigate causes of non-conformance and take corrective actions	4.56	0.67
(g) Ensure that the quality policy is understood, implemented, and maintained	4.42	0.74
(j) Establish and document their quality system	4.36	0.83
(e) Maintain adequate gauging and testing devices for inspection and testing	4.33	0.94
(b) Maintain adequate records of all inspections and tests performed	4.28	0.96
(f) Ensure that crucial processes are carried out under controlled conditions	4.16	1.01
(c) Maintain procedures to control and verify the design of the product	4.13	0.90
(h) Ensure that statistical techniques/process controls are used on a daily basis	4.03	1.09
(n) Verify whether quality activities comply with planned quality system	4.02	0.81
(o) Provide their personnel with written inspection and testing instructions	4.00	1.06
(l) Have a comprehensive internal quality audit system in place	3.93	0.98
(d) Maintain a facility-wide, documented preventive maintenance program	3.51	1.08

Table III.
Mean importance of supplier assessment practices

relying on price competition among a large number of suppliers to drive down unit price.

The mean importance responses to the eight JIT practices ranged from 4.22 to 3.34 (Table V). While the literature stressed that the primary goal of JIT was to reduce inventory to expose hidden problems (Chase *et al.*, 1998; Heizer and Render, 1999), the respondents indicated that their primary reason for reducing inventory was to free up capital investment. Indeed, the need to expose manufacturing and scheduling problems was rated much less important than the need to free up capital investment. The primary job responsibility of the respondents could be the best explanation for this controversial finding because an important role for supply and materials managers is to ensure materials are available when needed. Thus, a critical performance measure is inventory turnover. It may also be that given the recent economic slowdown, many firms have become more cost-conscious, making reductions in inventory investment a critical priority.

Mean importance responses to the 11 quality practices ranged from 4.26 to 3.18 (Table VI). Designing quality into the product ranked at the top, which is consistent with the existing quality literature. The finding emphasized the importance of the ability to manufacture the product correctly, instead of relying on corrective actions to rectify errors. The respondents also rated top

New product design and development practices	Mean	Standard deviation
(g) Quick product development and introduction time	3.95	1.03
(b) Early supplier involvement	3.78	1.04
(c) The use of concurrent engineering	3.77	0.93
(e) Standardization of component parts	3.76	1.07
(d) Simplification of component parts	3.55	1.13
(f) The use of value analysis/value engineering	3.45	1.12
(h) The use of quality function deployment (house of quality)	3.26	1.20
(a) Modular design of parts	3.14	1.30

Table IV. Mean importance of new product design and development practices

JIT principles	Mean	Standard deviation
(g) Reducing inventory, which in turn frees up capital investment	4.22	0.81
(b) Reducing setup time	3.82	1.13
(c) Reducing supplier base	3.73	1.00
(d) Preventive maintenance	3.72	0.90
(h) Reducing inventory to expose manufacturing and scheduling problems	3.62	0.99
(f) Increasing delivery frequencies	3.61	0.90
(a) Reducing lot size	3.52	1.09
(e) Buying from JIT suppliers	3.34	1.08

Table V. Mean importance of JIT principles

Quality practices	Mean	Standard deviation
(f) Designing quality into the product	4.26	0.97
(k) Top management communication of quality goals to the organization	4.06	1.04
(h) Process improvement (modification of process)	4.05	1.03
(i) Employee training in quality management and control	3.99	1.10
(j) Empowerment of shop operators to correct quality problems	3.94	1.03
(l) Emphasis on quality instead of price in the supplier selection process	3.86	1.02
(m) Considering manufacturability and assembly in the product design stage	3.68	1.18
(e) Using standard component parts	3.67	1.07
(b) Using benchmark data	3.57	1.12
(c) Simplifying the product	3.46	1.16
(g) Modular design of component parts	3.18	1.21

Table VI.
Mean importance of quality practices

management communication of quality goals to the organization, and process improvement highly with respect to quality practices, which was not surprising. Benchmarking, product simplification, and modular design were viewed as the least important quality practices.

Factor analysis

To test the first four hypotheses, exploratory factor analysis was used to explore the common variance-covariance characteristics of the four sets of practices. The goal was to identify a smaller set of factors to represent the relationships among the variables parsimoniously (i.e. to explain the observed correlation with fewer factors). In this research, principal component analysis with eigenvalues greater than one was used to extract factors, and varimax rotation was used to facilitate the interpretation of the factor matrix. The Bartlett Test of Sphericity (to test the null hypothesis that the correlation matrix is an identity matrix) and the Kaiser-Meyer-Olkin measure of the sampling adequacy (where a small value of KMO indicates factor analysis is inappropriate) were used to validate the use of factor analysis.

The 13 supplier assessment practices were reduced to two underlying factors, as shown in Table VII. We named the first construct supplier operations assessment because it contained six supplier assessment practices addressing various operating characteristics of suppliers. This factor accounted for 34.83 percent of the variance in the data. The results suggested that the need for suppliers to maintain procedures, gauging devices, testing records, to ensure that crucial processes were carried out under controlled conditions, and that purchased materials conformed to specifications, thus measured the operations aspect of supplier performance. These practices can be used in a linear combination to measure supplier operations performance.

Factors	Percent of variance[a]	Empirical indicators/scale items	Factor loadings
Supplier operations assessment	34.83	(b) Maintain adequate records of all inspections and tests performed	0.840
		(f) Ensure that crucial processes are carried out under controlled conditions	0.835
		(e) Maintain adequate gauging and testing devices for inspection and testing	0.816
		(c) Maintain procedures to control and verify the design of the product	0.774
		(h) Ensure that statistical techniques/process controls are used on a daily basis	0.632
		(i) Ensure that their purchased product and materials conform to specifications	0.535
Supplier quality assessment	31.61	(n) Verify whether quality activities comply with planned quality system	0.876
		(l) Have a comprehensive internal quality audit system in place	0.813
		(d) Maintain a facility-wide, documented preventive maintenance program	0.659
		(o) Provide their personnel with written inspection and testing instructions	0.649
		(g) Ensure that the quality policy is understood, implemented and maintained	0.622
		(j) Establish and document their quality system	0.602
		(m) Investigate causes of non-conformance and take corrective actions	0.556

Note: [a]Based on rotation sums of squared loadings. Total variance explained = 66.44 percent; Kaiser-Meyer-Olkin measure of sampling adequacy = 0.907; Bartlett test of sphericity = 891.494, Significance = 0.000; Factor loadings = Correlation between latent variable and empirical indicator; $(\text{Factor loadings})^2$ = percent of variance in the empirical indicator explained by the latent variable.

Table VII. Factor analysis – supplier assessment

The second factor, supplier quality assessment, included seven practices relating to the evaluation of supplier quality issues. These two factors accounted for a total of 66.44 percent of the total variance in the data. All factor loadings (the correlation between latent variable and empirical indicator) were higher than 0.50 and the KMO measure was 0.907. This indicated that a model with two factors was considered adequate to represent the supplier assessment data (Nunnally, 1988). The results supported our first hypothesis that the supplier assessment practices shared common variance-covariance characteristics that defined an individual construct. Therefore, the supplier assessment practices were interrelated, and a set of two constructs (i.e. supplier operations assessment and supplier quality assessment) was identified based on their common variance-covariance characteristics.

The set of eight new product design and development practices grouped into a single underlying factor presented in Table VIII, with all factor loadings above 0.61. The KMO measure was above 0.80, and the factor accounted for more than 57 percent of the variance in the data, indicating that it was sufficient to represent the data. We named this factor simultaneous product design and development concepts due to its emphasis on reduced product development time. The results supported our second hypothesis that new product design and development practices shared common variance-covariance characteristics that defined an individual construct. Therefore, these practices were interrelated, and a single latent variable was identified based on the common variance-covariance characteristics of the practices. Thus, we can infer that simplification, standardization, early supplier involvement, and the use of value analysis and concurrent engineering are considered relevant practices for enhancing new product design and development. The results supported our third hypothesis that the set of new product design and development practices could be reduced to a smaller set of constructs.

The set of eight JIT practices was reduced to two underlying factors. This information is presented in Table IX. The first construct, operations-based JIT concepts comprises five JIT practices addressing the operations characteristics of JIT principles. Operations-based JIT concepts involved reducing setup time, lot sizes, and the supply base, buying from JIT suppliers, and performing preventive maintenance. This factor accounted for 37.05 percent of the variance in the data. The second factor, inventory-based JIT concepts included the remaining three practices relating to the management of JIT inventory. These two factors accounted for 62.78 percent of the total variance in the data. Factor loadings were higher than 0.65, and the KMO measure was 0.802, indicating

Factors	Percent of variance[a]	Empirical indicators/scale items	Factor loadings
Simultaneous product design and development concepts	57.26	(d) Simplification of component parts	0.860
		(f) The use of value analysis/value engineering	0.793
		(b) Early supplier involvement	0.769
		(e) Standardization of component parts	0.768
		(c) The use of concurrent engineering	0.766
		(a) Modular design of parts	0.743
		(h) The use of quality function deployment (house of quality)	0.715
		(g) Quick product development and introduction time	0.617

Note: [a] Based on rotation sums of squared loadings. Total variance explained = 57.26 percent; Kaiser-Meyer-Olkin measure of sampling adequacy = 0.838; Bartlett test of Sphericity = 391.439, Significance = 0.000

Table VIII.
Factor analysis – new product design and development practices

Factors	Percent of variance[a]	Empirical indicators/scale items	Factor loadings
Operations-based JIT concepts	37.05	(b) Reducing setup time	0.854
		(e) Buying from JIT suppliers	0.728
		(a) Reducing lot size	0.724
		(d) Preventive maintenance	0.667
		(c) Reducing supplier base	0.661
Inventory-based JIT concepts	25.73	(g) Reducing inventory, which in turn frees up capital investment	0.857
		(h) Reducing inventory to expose manufacturing/scheduling problems	0.781
		(f) Increasing delivery frequencies	0.656

Note: [a] Based on rotation sums of squared loadings. Total variance explained = 62.78 percent; Kaiser-Meyer-Olkin measure of sampling adequacy = 0.802; Bartlett test of Sphericity = 293.887, Significance = 0.000

Table IX. Factor analysis – JIT principles

that the use of factor analysis and a model with two factors was considered adequate to represent the data.

The results supported our third hypothesis that the JIT practices shared common variance-covariance characteristics that defined an individual construct. Therefore, the JIT practices were interrelated, and a set of two constructs was identified based on their common variance-covariance characteristics. Based on this finding, one could argue that the construct known as operations-based JIT concepts could be expressed as a linear combination of reducing setup time, lot size and supplier base, buying from JIT suppliers, and performing preventive maintenance. Similarly, inventory-based JIT concepts could be represented as a linear combination of reducing inventory and increasing delivery frequencies.

The set of quality practices was reduced to two underlying factors, and appears in Table X. The first factor, process focused quality initiatives contained five quality practices that addressed the processes of the respondents. This factor accounted for 32.29 percent of the total variance in the data. The second factor, product focused quality initiatives included six practices related to the quality of respondents' products. These two factors accounted for a total of 62.63 percent of the total variance in the data. All factor loadings were higher than 0.50, and the KMO measure was 0.902, indicating that the use of factor analysis, and a model with two factors was considered adequate to represent the data.

The results supported our fourth hypothesis that the quality practices shared common variance-covariance characteristics and thus were interrelated. A set of two constructs was identified based on their common variance-covariance characteristics. Top management communication of

Factors	Percent of variance[a]	Empirical indicators/scale items	Factor loadings
Process-focused quality initiatives	32.29	(k) Top management communication of quality goals to the organization	0.835
		(j) Empowerment of shop operators to correct quality problems	0.827
		(i) Employee training in quality management and control	0.767
		(l) Emphasis on quality instead of price in the supplier selection process	0.761
		(h) Process improvement (modification of process)	0.545
Product-focused quality initiatives	30.34	(e) Using standard component parts	0.816
		(g) Modular design of component parts	0.733
		(c) Simplifying the product	0.699
		(m) Considering manufacturability and assembly in product design stage	0.617
		(b) Using benchmark data	0.574
		(f) Designing quality into the product	0.566

Note: [a]Based on rotation sums of squared loadings. Total variance explained = 62.63 percent; Kaiser-Meyer-Olkin measure of sampling adequacy = 0.902; Bartlett test of Sphericity = 528.469, Significance = 0.000

Table X.
Factor analysis – quality practices

quality goals, empowerment, employee training, emphasis on quality, and process improvement could be expressed as a linear combination of the construct process focused quality initiatives. Similarly, the use of standard component parts, modular design, simplification, manufacturability, benchmarking, and designing quality into the product could be used to represent the product focused quality initiatives of a manufacturing organization.

The managerial implication of the exploratory factor analysis result is that, while it is important to identify and understand the impact of individual practices used to assess supplier performance, new product design and development, JIT, and quality initiatives, it is also critical to understand how these practices are all interrelated. For example, reducing setup time, lot size and supply base, buying from JIT suppliers, and preventive maintenance measured the same dimension and characteristic of JIT. Thus, to perform well in this aspect of JIT, manufacturers must address these practices simultaneously instead of in isolation. In addition, knowledge of the interactions among the practices can be a valuable diagnostic tool in addressing the ineffectiveness of each initiative alone to further enhance competitive success.

Bivariate correlation

Bivariate correlation analysis was used to study the relationships of the latent variables, and to test the fifth hypothesis that these latent variables were related. Table XI shows the correlation coefficients at $\alpha = 1$ and 5 percent. Out of 21 correlations, 11 were statistically significant. The results partially supported our fifth hypothesis that some of the constructs identified from supplier assessment, new product design and development, JIT, and quality practices were related. All the significant coefficients were positively correlated, implying that an increase in one variable was directly related to an increase in the other variable.

Discussion and managerial implications

The first noteworthy managerial implication from Table XI is that all the significant correlation coefficients among the constructs are positively related. It suggests that implementing one construct does not negatively impact another construct. For example, implementing supplier quality assessment did not adversely affect simultaneous product design and development. Indeed, the positive coefficient suggests that the two constructs are interactive and

	Supplier quality assessment	Simultaneous product design and development	Operations-based JIT concepts	Inventory-based JIT concepts	Process focused quality initiatives	Product focused quality initiatives
Supplier operations assessment	0.000	0.161	−0.022	0.151	0.177*	0.025
Supplier quality assessment	–	0.376**	0.348**	0.334**	0.084	0.339**
Simultaneous product design and development	–	–	0.611**	0.275**	0.120	0.788**
Operations-based JIT concepts	–	–	–	0.000	0.258**	0.513**
Inventory-based JIT concepts	–	–	–	–	0.115	0.203*
Process-focused quality initiatives	–	–	–	–	–	0.019

Notes: *Correlation is significant at α = 5 percent (1-tailed); **Correlation is significant at α = 1 percent (one-tailed)

Table XI.
Bivariate correlation

mutually beneficial. That is, firms should consider emphasizing both practices simultaneously. More specifically, in order to enhance a simultaneous new product design and development initiative, firms should concurrently assess supplier's written quality policy, documentation, preventive maintenance program, internal quality audit system, inspection and testing policy, and suppliers' efforts in investigating and correcting causes of non-conformance. This is consistent with prior literature that emphasized strategic suppliers should be viewed as virtual extensions of their firm (Copacino, 1996; Mason, 1996). Superior supplier capability often leads to rapid integration of the latest technological breakthroughs in new product design and development (Monczka *et al.*, 1994; Prahalad and Hamel, 1990; Ragatz *et al.*, 1997). Thus, a strenuous effort in improving new product design and development without understanding and concurrently assessing supplier's quality performance could potentially be a waste of effort and scare resources. Indeed, such an isolated implementation approach could even be counter-productive and detrimental to the firm's competitive advantage.

Another factor relating to supplier assessment practices, supplier operations assessment, was positively correlated with process focused quality initiatives, a factor relating to quality practices. The managerial implication here is that supplier operations assessments will impact an organization's process focused quality initiatives positively, and vice versa. The results suggest that requiring suppliers to maintain adequate testing records and devices or to ensure proper control of crucial processes positively impacts process improvement initiatives and other process focused quality practices. Thus, our findings indicate that the two constructs or initiatives should be implemented concurrently to maximize the benefits of these initiatives to the firm. A thorough knowledge of the relationship between these constructs enables an organization to properly design and implement relevant, and comparable practices to achieve their desired goals. This finding may provide an explanation as to why some quality initiatives resulted in improved competitiveness (Hendricks and Singhal, 1996), while others failed to achieve their desired goals (Grant *et al.*, 1994; Hiam, 1993).

Supplier quality assessment was also positively correlated with three other factors, namely, operations-based JIT concepts, inventory-based JIT concepts, and product focused quality initiatives. The benefits in cooperative and mutually beneficial buyer-supplier relationships, and monitoring supplier quality have been well documented (Ragatz *et al.*, 1997; Tan *et al.*, 1998). Thus, there was no surprise that this factor was also positively correlated with three other factors. It was interesting to note that monitoring supplier quality performance correlated positively with product design and development, JIT practices, and product focused quality initiatives, suggesting that developing an organizational culture with suppliers driven by quality would more than improve the quality of incoming materials. The finding also supported Flynn *et al.*'s (1995a) notion that quality practices could improve JIT performance, and that JIT practices would improve quality performance; thus quality and JIT practices interacted. Therefore, this research further confirmed that quality and JIT initiatives are comparable constructs and should be implemented concurrently.

In addition to supplier quality assessment, simultaneous product design and development was also positively correlated with three other factors. In order to reduce the product development time and improve product design, an organization should consider implementing operations and inventory based JIT concepts and product focused quality initiatives, in addition to using the concepts of simplification, standardization, value analysis/engineering, modular design, and concurrent engineering. The results suggest that in addition to assessing and monitoring supplier performance, firms must also adopt effective JIT initiatives to enhance new product design and development process. While both the JIT concepts were significantly correlated with simultaneous product design and development, the higher correlation coefficient of 0.611 for the operations-based JIT concept suggests that its impact on new product design and development was greater than that of the inventory-based JIT concept. Thus, management should focus on reducing their supplier base, buying from JIT suppliers, reducing lot sizes and setup times, and using preventive maintenance (Table IX) to enhance new product design and development. This is also consistent with the finding of Sakakibara *et al.* (1997) that certain JIT practices were related to new product design.

Operations-based JIT concepts were correlated with both the product and process focused quality initiatives, and thus further confirmed Flynn *et al.*'s (1995a) finding that these two constructs interacted. Inventory-based JIT concepts also interacted with product focused quality initiatives, suggesting that JIT practices, implemented to manage inventory, also enhanced quality. Reducing lot sizes, setup times and the supplier base, buying from JIT suppliers, and engaging in preventive maintenance are all well-documented operations practices for improving quality levels (Celley *et al.*, 1987; Gilbert, 1990; Im and Lee, 1989; Schonberger, 1982; White, 1993). Therefore, the managerial implication here is that manufacturing firms should not ignore JIT practices and concepts while implementing any quality initiative.

An interesting observation in Table XI is that the significant correlation coefficient between the simultaneous product design and development and product focused quality initiatives (0.788) is the highest. This suggests that firms cannot afford to ignore the critical roles of standard component parts, modular design, product simplification, manufacturability, and designing quality into the product (Table X) in their new product design and development efforts.

Factor analysis revealed that the four sets of practices could be categorized into smaller sets of constructs, suggesting that many practices were related and measured the same construct or phenomenon. Therefore, it is important for managers to understand that multiple actions or practices may have to be used concurrently to effectively manage and benefit from any of the supplier assessment, JIT, quality or new product design strategies. For example, reducing setup time, lot size and supplier base, buying from JIT suppliers, and engaging in preventive maintenance are necessary components to effectively measure performance of a JIT strategy.

Conclusions

The importance of establishing an appropriate infrastructure and organizational culture to support supplier assessment practices, new product design and development practices, JIT practices, and quality practices has been extensively documented. This study highlights the fact that many of these practices are interrelated and can be reduced to a smaller set of constructs that can be used to explain a complex phenomenon. This study also highlights how these constructs are correlated, thus enabling practitioners to analyze how their action plans impact other practices.

Organizations use a variety of approaches and practices to remain competitive. Identifying practices that impact performance positively, allows an organization to more effectively manage scarce resources. Moreover, it allows organizations to integrate individual practices into a broad based strategic plan rather than using them in the piecemeal manner cited as being an important reason for many failed strategic efforts.

This research identified a number of important interrelationships among the various strategic practices. For example, monitoring supplier quality performance can help to identify candidates for strategic supplier relationships and be an aid to effective new product design and development, JIT, and product focused quality initiatives. The important outcome here is that firms should consider implementing a supplier quality assessment program prior to implementing JIT concepts or internal quality initiatives. Based on our findings, the quality assessment program should include monitoring suppliers' quality activities, an internal quality audit system, preventive maintenance program, written inspection and testing instructions, and a quality policy (Table VII).

It is hoped that the information presented here will provide some direction to those firms seeking to gather information and justification for implementing JIT, quality, new product design and development, and/or supplier assessment programs. The relationships among the constructs identified in this paper and the make-up of these constructs should provide direction for designing improvement programs as well as a significant incentive for management to consider the strategies simultaneously, and thus provide potential continued future economic success. In addition, the findings from the exploratory factor analysis should provide practicing managers with noteworthy insights on how these practices are related, thus affecting the ability to better plan for the future.

This study has identified and addressed important supplier assessment practices, new product design and development practices, JIT practices, and quality practices of manufacturers. The small response rate and the target respondents used in this research could potentially bias the research findings reported in this research. Future research should include investigating similar questions with respondents from services and other industries and countries, and further developing the interrelationships between these important operations constructs.

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Appendix

1. Supplier assessment practices

On a scale of 5 (very important) to 1 (not important), how important are the following issues in assuring that suppliers' products and services conform to your specifications?

(a) Suppliers need to maintain a formal program for safety and hygiene
(b) Suppliers need to maintain adequate records of all inspections and tests performed
(c) Suppliers need to maintain procedures to control and verify the design of the product
(d) Suppliers need to maintain a facility-wide, documented preventive maintenance program
(e) Suppliers need to maintain adequate gauging and testing devices for inspection and testing
(f) Suppliers need to ensure that crucial processes are carried out under controlled conditions
(g) Suppliers need to ensure that the quality policy is understood, implemented, and maintained
(h) Suppliers need to ensure that statistical techniques/process controls are used on a daily basis
(i) Suppliers need to ensure that their purchased product and materials conform to their specifications
(j) Suppliers need to establish and document their quality system
(k) Suppliers need to comply with all requirements of your firm
(l) Suppliers need to have a comprehensive internal quality audit system in place
(m) Suppliers need to investigate causes of non-conformance and take corrective actions
(n) Suppliers need to verify whether quality activities comply with planned quality system
(o) Suppliers need to provide their personnel with written inspection and testing instructions

2. New product design and development practices

On a scale of 5 (very important) to 1 (not important), how important are the following issues/tools in your firm's new product design and development activities?

(a) Modular design of parts
(b) Early supplier involvement
(c) The use of concurrent engineering
(d) Simplification of component parts
(e) Standardization of component parts

(f) The use of value analysis/value engineering
(g) Quick product development and introduction time
(h) The use of quality function deployment (house of quality)

3. JIT practices

On a scale of 5 (very important) to 1 (not important), how important are the following JIT principles in your operations?

(a) Reducing lot size
(b) Reducing setup time
(c) Reducing supplier base
(d) Preventive maintenance
(e) Buying from JIT suppliers
(f) Increasing delivery frequencies
(g) Reducing inventory, which in turn frees up capital investment
(h) Reducing inventory to expose manufacturing and scheduling problems

4. Quality practices

On a scale of 5 (very important) to 1 (not important), how important are the following quality practices in your firm?

(a) Inspection
(b) Using benchmark data
(c) Simplifying the product
(d) Statistical process control
(e) Using standard component parts
(f) Designing quality into the product
(g) Modular design of component parts
(h) Process improvement (modification of process)
(i) Employee training in quality management and control
(j) Empowerment of shop operators to correct quality problems
(k) Top management communication of quality goals to the organization
(l) Emphasis on quality instead of price in the supplier selection process
(m) Considering manufacturability and assembly in the product design stage