An Empirical Analysis of Quality Management in Japanese Manufacturing Companies

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Abstract

This paper focuses on quality management committed by every people in Japanese manufacturing companies, with its relationship to other main areas of production management. After presenting a simple analytical framework, we establish four hypotheses to be tested; 1) there are major differences in practices for quality improvement among industries; 2) world class manufactures have more sophisticated quality management system than randomly sampled manufacturers; 3) excellent quality management supports and/or is supported by some operations management practices in the areas of organization, human resource management, just-in-time production, information systems/information technology, technology development and manufacturing strategy; and 4) excellent quality management should improve competitive performance of the companies. Then, we suggest twelve measurement scales and a summarized super-scale characterizing quality management practices in high performance manufacturing companies, and show that most of the scales are reliable and valid for forty-six Japanese manufacturing companies. Using these scales we empirically examine inter-industry and inter-class differences in quality management and its relationship with other operations management practices and competitive performance to evaluate the requirements for and the role of quality management. There are no major differences in quality management practices among three industries we investigated, i.e. machinery, electrical & electronics, and automobile, although two-factor analysis of variance detects moderately significant differences in practices of *maintenance* and *process control*. On the other hand, world-class manufacturers have more sophisticated quality management system than randomly sampled manufacturing plants besides of *customer involvement*. A series of canonical correlation analyses demonstrate that quality management is strongly influenced by certain organizational characteristics, human resource management, information systems, and manufacturing strategy, and that it plays an important role in determining the competitive performance of the manufacturing companies, partly through the impacts upon just-in-time production, information systems, and technology development. Quality management depends on *commitment*, *coordination of decision making*, *task-related training for employees*, *small group problem solving*, *multi-functional employees*, *distinctive competence*, and *anticipation of new technology* among others. On the other hand, *maintenance* activities support just-in-time production and production information systems, while *top management leadership for quality*, *process control*, and *supplier quality involvement* provide bases for technology development by manufacturing departments. In summary hypotheses except the first one concerning inter-industrial differences are strongly supported for the data set of the Japanese manufacturing plants.

Keywords: Quality Management; Production/Operations Management; Empirical Research

1. Introduction

Quality management represents company-wide activities to improve the quality level of products through customer orientation, continuous quality improvement, employees' involvement, etc. so as to establish and sustain a competitive advantage. From a perspective of competitive strategy, quality is often seen as a source of differentiation. Quality improvement is an important issue influencing long-term viability of any business enterprise, especially manufacturing companies producing physical goods. Based on the empirical findings, Nakane [8], Hall [5] and others proposed the hierarchical model of manufacturing objectives. They found that most manufacturing companies had improved their capabilities in a predetermined sequence from quality, delivery, through flexibility and cost. DeMeyer *et al.* [1] surveyed 574 manufacturing companies in North America, Europe and Japan and found that Japanese companies

focused on resolving the tradeoff between flexibility and cost, while American companies emphasized quality improvement

In order to improve the quality of products, a large number of Japanese manufacturing companies have been trying to intermittently develop new tools and techniques such as various charts, suggestion systems and so on. Quality management activities in Japan have been characterized as company-wide participation, emphasis on employees training, quality circles, quality diagnoses, statistical methods and national-wide campaign. People from all levels of management and workers are involved in the company-wide quality management or total quality management. This concept intends to not only control quality levels of products by applying statistical methods and other analytical techniques, but also manage all kinds of work properly centered on quality. Schonberger [9] found that some of the world class manufacturing companies regarded quality as a competitive weapon and devoted themselves to zero defects program by all means. Womack, Jones and Roos [11] argued that quality circles, continuous improvement, autonomation, and the five why's are prerequisites for lean production.

The objective of this paper is to empirically analyze what requirements should be satisfied for comparatively effective quality management, and whether it can support strategic decisions, systems and practices in operations function and finally contribute to the improvement in competitive positions, based on the relevant measurement scales and data collected from Japanese manufacturing plants through extensive questionnaires. Using data from US manufacturing plants, Flynn, Sakakibara and Schroeder [2] and Flynn, Schroeder and Sakakibara [4] constructed measurement scales for core practices and infrastructure practices concerning total quality management, and analyzed their relationships with quality performance, just-in-time production performance and practices.

Next section deals with our analytical framework and hypotheses to be tested, followed by the presentation of research variables in the third section. After a brief description of data collection methods in the fifth section, we will present results of a series of empirical analyses from measurement analysis through hypothesis testing by appropriate techniques, and conclude this paper.

2. Analytical Framework and Hypotheses

We propose a simple analytical framework with four major building blocks to construct high performance manufacturing companies: (1) infrastructure block; organization and human resource management, (2) system block; quality management, just-in-time production systems and production information systems, (3) strategy block; technology development and manufacturing strategy, and (4) performance block; a variety of competitive performance indexes. Organization and human resource management provides an infrastructure on which manufacturing operation systems are established and operations strategy is formulated. The second block represents core manufacturing operation systems concerning quality, production planning and information, which are closely interrelated with each other. The third block is concerned with more long-term and strategic decisions facing manufacturing companies, and it includes new product and process development, distinctive competence and operations objectives. Manufacturing operation systems and strategic decisions are supposed to be complementary or interdependent. These three blocks are put together to determine the competitive performance of manufacturing companies. The relationships among those factors are depicted in Figure 1.

This paper focuses on total quality management practices committed by not merely every people within a company but also suppliers and customers. In addition we explore the relationship of quality management with other areas included in the framework such as organization, human resource management, just-in-time production, information systems, technology, manufacturing strategy, and competitive performance.

After conducting measurement analysis, we will examine industry effects and class effects (world class manufacturing plants vs. randomly sampled manufacturing plants) upon various quality management practices. Product and process features may have impacts upon the basic policy and concrete practices for quality assurance and continuous improvement. On the other hand, class effects seem to be rather clear. It is regarded as a test for our subjective judgment on world-class manufacturing plants. Hypotheses we tested are as follows:

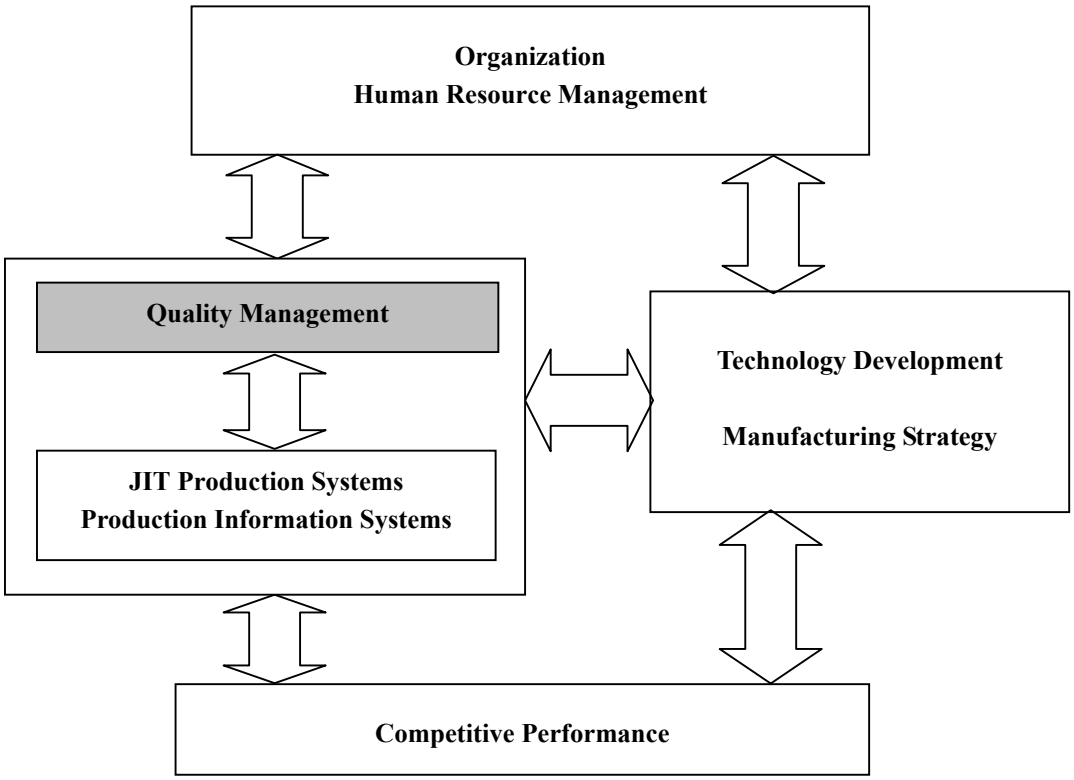

Figure 1 Analytical framework of high performance manufacturing

Hypothesis 1: There are major differences in quality improvement activities among industries. We compare three manufacturing industries: machinery, electrical & electronics, and automobile.

Hypothesis 2: World-class manufactures have more sophisticated quality management system than randomly sampled manufacturers.

More important is the relationship of quality management activities with other manufacturing practices and competitive performance. As shown in Figure 1, quality management activities are supposed to be strongly interrelated with infrastructure, manufacturing operation systems and strategy. It is also hypothesized that quality management is one of the key factors determining competitive performance indexes. Then, hypotheses to be tested are represented as follows:

Hypothesis 3: Excellent quality management supports and/or is supported by operations management practices in the areas of organization, human resource management, just-in-time production, information systems/information technology, technology development and manufacturing strategy.

Hypothesis 4: Excellent quality management should improve competitive performance of the companies.

3. Research Variables

In order to operationalize the analytical framework and the hypotheses in the preceding section, we introduce some research variables below. They are divided into four categories.

3.1 Quality management measurement scales

The first set of variables is concerned with quality management practices by high performance manufacturing companies. We initially constructed the following twelve scales that measured the levels of quality management activities:

(1) *Cleanliness and organization* (CO3S)

This scale is designed to assess whether plant management has taken steps to organize and maintain the work place in order to help employees accomplish their jobs faster and instill a sense of pride in their work place.

(2) *Continuous improvement* (CIMP)

This scale assesses employees' commitment to continuous quality improvement.

(3) *Customer involvement* (CINV)

This scale assesses the level of customer contact/ orientation/ responsiveness.

(4) *Customer satisfaction* (CSTF)

This scale measures what the plant believes to be its customers' satisfaction level.

(5) *Feedback* (FDBK)

This scale is used to assess whether the plant provides shop-floor personnel with information regarding their performance in a timely and useful manner. The scale measures feedback about performance in both chart and verbal form which are useful in facilitating and supporting quality and productivity improvements

(6) *Maintenance* (MTNC)

This scale assesses the level of routine maintenance which the workers perform themselves.

(7) *Process control* (PCTL)

This scale measures the use of statistical process control in production and in office support functions, in designing ways to "fool proof" processes, and self inspection.

(8) *Quality in new products* (QINP)

This scale is designed to assess the influence of quality considerations in design and introduction of new products.

(9) *Rewards for quality* (RWFQ)

This scale indicates whether plant employees feel that quality improvement is rewarded, both for workers and management.

(10) *Supplier quality involvement* (SQIV)

This scale assesses the amount and type of interaction which occurs with vendors regarding quality concerns.

(11) *Top management leadership for quality* (TMLQ)

This scale measures top management commitment and personal involvement in pursuing continuous improvement.

(12) *TQM link with customers* (TLWC)

This scale measures whether the plant has been integrated into customer production in terms of quality.

3.2 Other measurement scales

The second category of variables consists of measurement scales in the areas of organization, human resource management, just-in-time production, production information systems, technology development, and manufacturing strategy. These measurement scales are constructed by several question items measured on a five-point Likert scale. The lists of measurement scales concerning each area can be found in Table 7 through Table 12.

3.3 Super-scales for main areas of production/operations management

In the analysis below, we introduce super-scales in order to summarize the measurement scales in the following areas of production and operations management: *Organization* (OG), *Human resource management* (HR), *Just-in-time production* (JIT), *Quality management* (QM), *Information systems* (IS), *Technology development* (TD), and *Manufacturing strategy* (MS).

3.4 Competitive performance indexes

The fourth category of variables is concerned with the competitiveness of each manufacturing plant, relative to global competitors in the industry. The following eleven performance indexes include basic objectives in the production function, that is, cost, quality, delivery, and flexibility: unit cost of manufacturing, quality of product conformance, delivery performance, fast delivery, flexibility to change product mix, flexibility to change volume, inventory turnover, cycle time, speed of new product introduction, customer support and service, and product capability and performance.

4. Data Collection Methods

Data used for the subsequent analyses were gathered through the international joint research project on high performance manufacturing (HPM), some of the results are shown in Schroeder and Flynn [10]. They are concerned with some important aspects of manufacturing plants: environment, human resources, quality, JIT production,

information systems, technology development, manufacturing strategy, improvement, and performance. We acquired data from 164 plants located in five countries: Germany, Italy, Japan, the United Kingdom and the United States. The research includes data from forty-six Japanese manufacturing plants. Thirty-two plants are subjectively judged to be world class and the rest are randomly sampled from machinery, electrical & electronics, and automobile industries. In all plants twenty-six individuals across levels responded to fifteen types of questionnaires that partially share the same questions. The respondents included a plant manager, a plant superintendent, a plant research coordinator, a plant accountant, a human resource manager, an inventory/purchasing manager, an information systems manager, a production control manager, a process engineer, a quality manager, supervisors and direct workers. Plant-level data were calculated as an average value of all the valid responses at the plant for each quantitative question item and each measurement scale.

Those respondents were asked to answer around one hundred question items most of which were included to establish measurement scales for quality management as well as other manufacturing practices. A quality manager and a process engineer responded all the question items for twelve quality management measurement scales. Direct workers also answered the question items for quality management scales except *Quality in new products* and *Top management leadership for quality.* A plant manager responded the question items for these two measurement scales of quality system. The questionnaires for a production control manager and two supervisors included the question items concerning *Maintenance*. A human resource manager and two supervisors answered the question items for *Rewards for quality*. The quality management measurement scales are constructed by four to eight question items evaluated on a five-point Likert scale (1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree). Individual question items are shown in the supplement below.

A plant manager subjectively judged the competitive position of his/her plant in terms of eleven performance indexes. Each plant manager was asked to indicate his/her opinion about how the plant compares to its competitors in the industry on a global basis on a five-point Likert scale (1=Poor or low end of the industry, 2=Below average, 3=Average, 4=Better than average, 5=Superior or top of the industry).

5. Results of the Empirical Analysis

In this section we will show the main results from a serial of empirical analyses. Both reliability and validity of the quality management measurement scales are usually examined through the Cronbach's alpha coefficient and factor analysis respectively, whose results shall be given in the next subsection. Flynn et al. [3] discussed the methodological issues on empirical research in operations management. Matsui [6] [7] showed the detailed measurement analysis for technology development and production information systems utilized in the Japanese plants. This measurement analysis will be followed by the analysis of industry and class effects upon quality management activities. The last part of this section will explore the structural relationship of quality management system with other areas of production/operations management and competitive performance, relying on the technique of canonical correlation analysis.

5.1 Measurement analysis of quality management scales

We begin with a measurement analysis of twelve measurement scales on quality management, which are to be constructed by four to eight question items as shown in the supplement. It is general that reliability of a measurement scale be analyzed according to Cronbach's alpha coefficient, which should be more than 0.6 for a newly developed scale. On the other hand, validity of a measurement scale is checked by content, construct, and external criteria. Construct validity can be examined through factor analysis, where uni-dimensionality and factor loadings of more than 0.4 are essential checkpoints for validity. These analyses are applied to the individual-level data predominantly, including both world-class and randomly sampled manufacturing plants.

Table 1-a Reliability and validity (all plants, individual-level data)

	Cleanliness and Organization	Continuous Improvement	Customer Involvement	Customer Satisfaction		Feedback	
alpha coefficient:	0.80442	0.64756	0.67175	0.74178	0.82293	0.76000	0.76974
Factor loadings:							
Question item 1	0.69617	0.79641	0.63013	0.86284	0.86384	0.72450	0.73585
Question item 2	0.78904	0.78950	0.48900	0.76695	0.77127	0.69255	0.69872
Question item 3	0.83994	0.81828	0.66285	0.27901	deleted	0.71773	0.73731
Question item 4	0.61447	0.42254	0.55303	0.39056	deleted	0.52272	0.49468
Question item 5	0.85370		0.63051	0.70179	0.72337	0.69653	0.70523
Question item 6			0.75212	0.36654	deleted	0.69965	0.70645
Question item 7				0.80378	0.82460	0.38668	deleted
Question item 8				0.65201	0.66285		
Eigenvalue:	2.9191	2.1057	2.3446	3.2611	2.9837	2.9171	2.8144
Proportion:	58.38%	52.64%	39.08%	40.76%	59.67%	41.67%	46.91%
No. of factors:	1	1	1	2	1	2	1

Table 1-b Reliability and validity (all plants, individual-level data)

	Maintenance		Process Control	Quality in New Products		Reward for Quality	
alpha coefficient:	0.67838	0.66133	0.77483	0.55903	0.54943	0.65222	0.77340
Factor loadings:							
Question item 1	0.71254	0.74717	0.49111	0.74751	0.85151	0.81928	0.83414
Question item 2	0.53512	0.43125	0.66642	0.69576	0.80896	0.60003	0.60039
Question item 3	0.62541	0.63168	0.73777	0.64783	0.49532	0.81631	0.81335
Question item 4	0.47377	deleted	0.81104	0.54563	deleted	0.79778	0.83737
Question item 5	0.54849	0.60293	0.60859			0.18978	deleted
Question item 6	0.57142	0.61533	0.79969			0.37657	deleted
Question item 7	0.64253	0.64678					
Eigenvalue:	2.4499	2.3037	2.8973	1.7602	1.6248	2.5119	2.4190
Proportion:	35.00%	38.40%	48.29%	44.01%	54.16%	41.86%	60.47%
No. of factors:	2	1	1	2	1	2	1

Table 1-c Reliability and validity (all plants, individual-level data)

	Supplier Quality Involvement		Top Management Leadership for Quality	TQM Link with Customers	
alpha coefficient:	0.62813	0.69419	0.80892	0.37038	0.55128
Factor loadings:					
Question item 1	0.65077	0.65465	0.69267	0.47837	0.47300
Question item 2	0.55003	0.54779	0.81846	0.76271	0.76408
Question item 3	0.68768	0.68409	0.57298	-0.00899	deleted
Question item 4	0.12482	deleted	0.58616	0.55695	0.56017
Question item 5	0.79647	0.79673	0.69032	0.81798	0.81184
Question item 6	0.66821	0.67483	0.69664		
Question item 7			0.77142		
Eigenvalue:	2.2954	2.2868	3.3785	1.7899	1.7804
Proportion:	38.26%	45.74%	48.26%	35.80%	44.51%
No. of factors:	2	1	1	2	2

As shown in Tables 1-a, 1-b, and 1-c, five measurement scales out of twelve, *Cleanliness and Organization* (CO3S), *Continuous Improvement* (CIMP), *Customer involvement* (CINV), *Process control* (PCTL), and *Top management leadership for quality* (TMLQ), immediately meet the criteria for reliability and validity. For another five measurement scales, *Customer satisfaction* (CSTF), *Feedback* (FDBK), *Maintenance* (MTNC), *Rewards for quality* (RWFQ), *Supplier quality involvement* (SQIV), two factors are found to be principle. Some question items have the first factor loadings of less than 0.4 and highly loaded by the second factor. They are question items 3, 4 and 6 for CSTF (loyal/repeat customers and reverse question on the priority of customer satisfaction) question item 7 for FDBK

(reverse question on work quality), question item 4 for MTNC (shift for maintenance), question items 5 and 6 for RWFQ (bonus system and nonfinancial incentives), and question item 4 for SQIV (delivery without inspection). These question items are judged to have different contents from the rest of question items for each scale. It would be appropriate to drop the questions items from the constructs to meet the uni-dimensionality condition. The remaining question items were simply averaged to obtain the score of each measurement scale. However, two potential scales, *Quality in New products* (QINP) and *TQM Link with Customers* (TLWC), will not be used for the subsequent analyses, because they face serious measurement problems.

Further, we constructed a super-scale on quality management by averaging ten reliable and valid measurement scales. The super-scale, *Quality management,* found both reliable and valid, which demonstrates the close relationships among ten scales. The measurement analysis is applied to the plant-level data predominantly, including both world class and randomly sampled manufacturing plants.

5.2 Comparison across industries and classes

In this subsection we explore industry effects and class effects (world class manufacturing plants vs. randomly sampled manufacturing plants) upon quality management activities in Japanese manufacturing companies. Hypotheses 1 and 2 are targets for testing, although the statistical null hypotheses should not assume any industry and class effects. Classifying forty-six plants into sub-samples and using analysis of variance techniques and t-tests for differences between means, we examined inter-industry and inter-class differences in quality management system. Table 2 shows that there is no significant inter-industry difference for any measurement scales. This result is contrary to the first hypothesis but understandable, because various quality management concepts such as quality control, continuous quality improvement and quality assurance are deeply instilled into people in most Japanese manufacturing companies regardless of their product and process. On the other hand, clear inter-class differences were detected for all measurement scales, especially highly significant for *Rewards for quality* (RWFQ), *Maintenance* (MTNC), *Top management leadership for quality* (TMLQ), *Process control* (PCTL), *Continuous Improvement* (CIMP), *Cleanliness and Organization* (CO3S) and *Supplier quality involvement* (SQIV) as well as *Quality management* (QM) super-scale. No significant inter-class difference is found only for *Customer involvement* (CINV). World-class manufacturing plants have committed themselves to the establishment of sophisticated quality management system than the randomly sampled manufacturing plants on average. There was no significant inter-class difference in variance for any scales. These results assume the normality of the relevant populations. The hypothesis that a sample was randomly selected from a normal population was rejected at 1% level by the Shapiro-Wilk test only for the electrical & electronics sample of RWFQ.

Table 2 Mean values of quality management scales

Scales	Machinery	Electric	Auto	F	WCM	Random	t	All
CO3S	3.82	3.88	3.72	0.42	3.92	3.56	2.64**	3.81
CIMP	4.09	4.13	4.12	0.07	4.20	3.92	2.65**	4.11
CINV	3.58	3.51	3.62	0.37	3.61	3.47	1.34	3.57
CSTF	3.60	3.54	3.50	0.27	3.62	3.37	2.32*	3.55
FDBK	3.51	3.58	3.77	1.17	3.70	3.42	1.86*	3.62
MTNC	3.29	3.35	3.47	1.07	3.47	3.14	3.57**	3.37
PCTL	3.62	3.72	3.84	1.24	3.83	3.48	3.00**	3.73
RWFQ	3.68	3.66	3.67	0.01	3.83	3.31	3.58**	3.67
SQIV	3.71	3.85	3.85	0.87	3.88	3.63	2.50**	3.81
TMLQ	4.01	4.13	4.17	0.74	4.22	3.85	3.26**	4.10
Quality management	3.69	3.82	3.77	0.24	3.83	3.52	3.41**	3.73
Sample size	15	16	15		32	14		46

** significant at 1% level by one-tailed test * significant at 5% level by one-tailed test

To assess the industry effect and the class effect simultaneously, two-factor analysis of variance techniques or general linear models are helpful, whose result is shown in Table 3. The result is similar to the separate analysis of industry and class effects in Table 2, with one exception. MTNC and PCTL tend to show different mean values from one industry to another. The automobile plants seem to have high mean values, while the machinery plants seem to

have low mean values on average for these two measurement scales. This analysis of variance provides additional evidence that inter-class differences are highly significant for all quality management measurement scales. There are marginally significant interaction effects between industry and class for QM super-scale, MTNC and RWFQ.

Table 3 Two-factor ANOVA for quality management scales (F-value)

Scales	Model	Class	Industry	Class*Industry
Cleanliness and organization	1.91	6.10*	0.14	1.25
Continuous improvement	2.34	7.83**	0.43	1.86
Customer involvement	1.68	2.47	0.70	2.54
Customer satisfaction	2.22	5.03*	0.06	2.70
Feedback	2.60*	6.03*	2.45	2.11
Maintenance	6.19**	21.00**	4.23*	3.30*
Process control	4.92**	15.11**	3.83*	2.97
Reward for quality	4.27**	14.80**	0.47	3.27*
Supplier quality involvement	2.76*	8.42**	1.92	1.64
Top management leadership for quality	3.35*	13.88**	2.35	0.50
Quality management	4.57**	15.55**	1.55	3.31*

** significant at 1% level by one-tailed test * significant at 5% level by one-tailed test

In summary we can find strong evidence for hypothesis 2 on class effects, while clear industry effects cannot be detected for the Japanese manufacturing plants. Three industries we took up for the analysis might have similar attitudes and practices for quality management, opposed to hypothesis 1.

5.3 Structural relationship of quality management

This subsection deals with the relationships among quality management activities, other operations management practices, and competitive performance. Hypotheses 3 and 4 are tested here, although statistical null hypotheses assume no such relationships.

Table 4 Super-scales and competitive performance indexes

	First canonical variable	Second canonical variable
Canonical correlation	0.8548	0.7770
Likelihood ratio	0.0331	0.1228
Significance	0.0028	0.1445
Redundancy index	0.3080	0.0386
Correlations between super-scales and canonical variables of competitive performance indexes		
Organization (OG)	0.4079	0.1745
Human resource management (HRM)	0.5116	0.1208
Just-in-time production (JIT)	0.4888	0.3630
Quality management (QM)	0.5708	-0.3187
Information systems (IS)	0.5790	0.0903
Technology development (TD)	0.6647	-0.1072
Manufacturing strategy (MS)	0.8297	0.1327
Correlations between competitive performance indexes and canonical variables of super-scales		
Unit cost of manufacturing	0.4909	0.1049
Quality of product conformance	0.4491	-0.0960
Delivery performance	0.5324	0.1123
Fast delivery	0.5626	0.1960
Flexibility to change product mix	0.4025	0.2629
Flexibility to change volume	0.4711	-0.0272
Inventory turnover	0.5729	0.1812
Cycle time	0.6785	0.2310
Speed of new product introduction	0.6470	-0.2021
Customer support and service	0.5439	-0.3438
Product capability and performance	0.5043	-0.1737

Let us begin with the hypothesis 4 on the relationship between quality management and competitive performance. Table 4 shows the result of a canonical correlation analysis between eleven competitive performance indexes and seven

super-scales representing main operations management areas. A pair of the first canonical correlation variables gives clear evidence that quality management has a considerable impact on the manufacturing plant's competitiveness. The canonical correlation is approximately 0.85. The redundancy index shows that some one third of the variance in competitive performance indexes is explained by the first and the second canonical variables of super-scales. *Quality management* (QM) super-scale takes a similar position to *Information systems* (IS), following *Manufacturing strategy* (MS) and *Technology development* (TD) to account for the first canonical variable of competitive performance indexes. Correlation with the first canonical variable of competitive performance indexes is 0.83 for MS super-scale, followed by 0.66 for TD super-scale, 0.58 for IS super-scale, and 0.57 for QM super-scale. On the other hand, among competitive performance indexes, cycle time and speed of new product introduction show the highest correlations with the first canonical variable of super-scales.

Table 5 Quality management scales and competitive performance indexes

	First canonical variable	Second canonical variable	Third canonical variable
Canonical correlation	0.9156	0.8223	0.7578
Likelihood ratio	0.0065	0.0405	0.1250
Significance	0.0008	0.1439	0.6147
Redundancy index	0.1505	0.2143	0.0414
Correlations between quality management scales and canonical variables of competitive performance indexes			
Cleanliness and organization	0.5246	-0.0668	0.4376
Continuous improvement	0.3749	0.1133	0.4547
Customer involvement	0.5614	0.1170	0.4690
Customer satisfaction	0.4547	0.2668	0.3919
Feedback	0.1079	0.2878	0.5768
Maintenance	0.2788	0.3386	0.3633
Process control	0.3357	0.2358	0.3760
Reward for quality	0.4981	0.0035	0.3333
Supplier quality involvement	0.4999	0.1972	0.2154
Top management leadership for quality	0.4302	0.4572	0.0073
Correlations between competitive performance indexes and canonical variables of quality management scales			
Unit cost of manufacturing	0.1181	0.4328	0.4082
Quality of product conformance	0.4980	0.4258	0.0074
Delivery performance	0.3039	0.5260	0.0322
Fast delivery	0.0025	0.6557	0.0646
Flexibility to change product mix	0.2027	0.3690	-0.3230
Flexibility to change volume	0.2471	0.3983	0.1263
Inventory turnover	0.2690	0.5918	0.1477
Cycle time	0.2517	0.5340	0.2040
Speed of new product introduction	0.6037	0.2833	0.2005
Customer support and service	0.7617	0.1591	-0.0155
Product capability and performance	0.4919	0.3161	-0.0624

A canonical correlation analysis between ten quality management scales and the competitive performance indexes shown in Table 5 proves that *Customer involvement* (CINV), *Cleanliness and organization* (CO3S), *Supplier quality involvement* (SQIV) and *Rewards for quality* (RWFQ) have strong effects upon the first canonical variable of competitive performance indexes. In addition, the first canonical variable of the quality management scales is highly correlated with such performance indexes as customer support & service and speed of new product introduction, besides of quality of product conformance and product capability & performance. A pair of the second canonical variables suggests the relationship between *Top management leadership for quality* (TMLQ) and competitive performance indexes such as fast delivery, inventory turnover, cycle time, etc. According to the redundancy index, more than a third of variance in the competitive performance indexes is explained by the first two canonical variables of quality management scales. That is more than the variance explained by the first canonical variable of seven super-scales shown in Table 4.

These results for the Japanese manufacturing plants support the hypothesis 4 that excellent quality management surely improves the competitive position of manufacturing plants. The successes achieved by Japanese manufacturing industries could be partly attributed to their unique practices in quality management. Our results, however, reveal that deliberate manufacturing strategy and technology development by manufacturing departments should be more important reason why certain Japanese manufacturing companies have gained competitive advantages in global marketplace. Quality management can contribute to competitive performance improvement indirectly through its impact upon technology development and manufacturing strategy, which will be explored further in the rest of this paper.

Table 6 Correlations between super-scales

	QM	OG	HRM	JIT	IS	TD
OG	0.67574					
HRM	0.76489	0.89447				
JIT	0.56176	0.69448	0.72708			
IS	0.68643	0.54898	0.69832	0.76519		
TD	0.79257	0.59581	0.69816	0.57585	0.74049	
MS	0.64120	0.61454	0.70068	0.66362	0.75012	0.78547

A final topic for analyzing is to ascertain requirements for and roles of quality, that is hypothesis 3. Table 6 gives simple correlation coefficients between super-scales for the main areas of operations management, all of which are significantly more than zero. *Quality management* is closely related with *Technology development* (0.79), *Human resource management* (0.76), *Information systems* (0.69), *Organization* (0.68), *Manufacturing strategy* (0.64), and *Just-in-time production* (0.56) in a descending order.

Table 7 Quality management and organization

	First canonical variable
Canonical correlation	0.8720
Likelihood ratio	0.1141
Significance	0.0001
Redundancy index	0.3327
Correlations between quality management scales and canonical variable of organization scales	
Cleanliness and organization	0.6225
Continuous improvement	0.5583
Customer involvement	0.4151
Customer satisfaction	0.4036
Feedback	0.7041
Maintenance	0.7723
Process control	0.6476
Reward for quality	0.4880
Supplier quality involvement	0.4997
Top management leadership for quality	0.4887
Correlations between organization scales and canonical variable of quality management scales	
Centralization of Authority	-0.0519
Commitment	0.8500
Coordination of decision making	0.7351
Pride in work	0.3348

We further explore these relationships into the level of measurement scale. Tables 7 through 12 summarize the results of a series of canonical correlation analyses between quality management scales and measurement scales for other six important areas in production/operations management one by one. In every case the first canonical correlation is more than 0.85, much higher than the simple correlation coefficients in Table 6, and are judged to be quite significant by the likelihood ratio test. The redundancy indexes represent the variance of quality management scales explained by the canonical variable of measurement scales for some other area or the variance of measurement scales for the other area explained by the canonical variable of quality management scales. The maximum of these two values is listed in the tables. The variance of quality management scales is explained by the canonical variable of organization scales in Table 7 and human resource management scales in Table 8. In other cases, the canonical

variable of quality management scales accounts for the variance of measurement scales for just-in-time production in Table 9, information systems in Table 10, technology development in Table 11, and manufacturing strategy in Table 12. Surveying correlations between measurement scales and the first canonical variables, we can find that quality management system is closely related to the following eighteen scales: *Commitment* and *Coordination of decision making* from organization; *Task-related training for employees*, *Small group problem solving* and *Multi-functional employees* from human resource management; *Just-in-time delivery by suppliers*, *Equipment layout*, *Daily schedule adherence*, *Setup time reduction*, *MRP adaptation to JIT* and *Repetitive nature of master schedule* from just-in time production; *Benefits of information systems* and *Stability/predictability of short term production* from information systems; *Effective process implementation*, *Product design simplicity* and *Inter-functional design efforts* from technology development; *Distinctive competence* and *Anticipation of new technologies* from manufacturing strategy.

Table 7 shows that quality management system depends on certain organizational settings in commitment and coordination of decision making. One third of the variance of quality management scales is explained by the first canonical variable of four organization scales. On the other hand, *Maintenance* and *Feedback* have closely correlated with the first canonical variable of human resource management scales. This leads to the conclusion that one of the requirements for excellent quality management, particularly in total preventive maintenance and timely feedback of critical information to the right place, is cultivating organizational culture which induces employees to strongly commit themselves to the organization and have close coordination in making decisions.

Table 8 Quality management and human resource management

	First canonical variable	Second canonical variable	Third canonical variable
Canonical correlation	0.9348	0.7539	0.7327
Likelihood ratio	0.0038	0.0301	0.0697
Significance	0.0002	0.1231	0.2504
Redundancy index	0.5145	0.0299	0.0174
Correlations between quality management scales and canonical variables of HRM scales			
Cleanliness and organization	0.7579	-0.0208	0.0799
Continuous improvement	0.6984	-0.2300	-0.0641
Customer involvement	0.5961	-0.2076	-0.0953
Customer satisfaction	0.6111	-0.0530	-0.0868
Feedback	0.7437	-0.3211	0.1395
Maintenance	0.8285	-0.0025	0.0149
Process control	0.8121	-0.2255	-0.1966
Reward for quality	0.7243	-0.1225	0.1461
Supplier quality involvement	0.7280	0.0138	-0.2045
Top management leadership for quality	0.5791	0.0289	-0.1442
Correlations between HRM scales and canonical variables of quality management scales			
Documentation of shop floor procedure	0.6015	-0.1035	-0.2014
Employee suggestions	0.6951	-0.1375	0.2771
Incentives for group performance	0.6312	-0.0912	0.0350
Recruiting and selection	0.6663	-0.0892	0.1953
Rewards/manufacturing coordination	0.6374	0.0833	0.2672
Shop floor contact	0.5228	0.0242	-0.0713
Small group problem solving	0.8113	-0.2438	0.0741
Supervisory interaction facilitation	0.6603	0.0752	0.1532
Task-related training for employees	0.8596	0.0829	-0.0571
Compensation for breath of skill	0.6366	0.1876	0.1053
Manufacturing/human resources fit	0.6120	0.1359	-0.1170
Multi-functional employees	0.7984	-0.1266	0.0901

As shown in Table 8 human resource practices which emphasize *Task-related training for employees*, *Small group problem solving* and *Multi-functional employees* have promoted various quality management activities such as *Maintenance*, *Process control*, *Cleanliness and organization*, *Feedback*, *Supplier quality involvement*, *Rewards for quality*. The first canonical variable of human resource management scales can explain more than a half of the variance in quality management scales. Developing skills and problem solving competence of human resources,

particularly in the settings of group decision making, is a prerequisite for sophisticated quality management system.

Table 9 Quality management and just-in-time production

	First canonical variable	Second canonical variable
Canonical correlation	0.9269	0.7881
Likelihood ratio	0.0098	0.0693
Significance	0.0001	0.0530
Redundancy index	0.4603	0.0731
Correlations between quality management scales and canonical variables of JIT scales		
Cleanliness and organization	0.4724	-0.2373
Continuous improvement	0.5546	-0.2569
Customer Involvement	0.3244	0.0564
Customer Satisfaction	0.3701	-0.0296
Feedback	0.6588	-0.0586
Maintenance	0.8195	0.2657
Process control	0.6799	0.0078
Rewards for quality	0.5870	-0.1856
Supplier quality involvement	0.6370	-0.3874
Top management leadership for quality	0.6296	-0.1163
Correlations between JIT scales and canonical variables of quality management scales		
Daily schedule adherence	0.7839	0.0641
Equipment layout	0.8003	0.2315
Just-in-time delivery by suppliers	0.8238	-0.0115
Just-in-time link with Customers	0.4928	0.4389
Kanban	0.4775	0.3632
MRP adaptation to JIT	0.7512	0.1980
Repetitive nature of master schedule	0.7346	0.1745
Setup time reduction	0.7572	0.3837
Small lot size	0.2733	0.3421

Table 10 Quality management and information systems

	First canonical variable	Second canonical variable
Canonical correlation	0.8521	0.7337
Likelihood ratio	0.0507	0.1850
Significance	0.0339	0.6042
Redundancy index	0.3536	0.0357
Correlations between quality management scales and canonical variables of information system scales		
Cleanliness and organization	0.3669	0.2410
Continuous improvement	0.4342	0.1750
Customer Involvement	0.4373	0.0904
Customer Satisfaction	0.3180	0.2771
Feedback	0.5677	0.1779
Maintenance	0.7026	0.1200
Process control	0.6158	0.0770
Rewards for quality	0.5682	0.4606
Supplier quality involvement	0.6413	0.1034
Top management leadership for quality	0.6032	-0.0297
Correlations between information system scales and canonical variables of quality management scales		
Accounting	0.4482	0.1687
Benefits of information systems	0.7784	-0.1711
Coordination with corporation	0.5735	-0.1356
Dynamic performance measures	0.5787	0.3900
External information	0.5936	0.1909
Internal quality information	0.6261	-0.0108
Manufacturing plans	0.4204	0.1706
Stability/predictability of short term production	0.7353	0.1068

From Table 9 we can find that the first canonical variable of quality management scales is correlated with *Just-in-time delivery by suppliers*, *Equipment layout*, *Daily schedule adherence*, *Setup time reduction*, *MRP adaptation to JIT* and *Repetitive nature of maser schedule*, while the first canonical variable of just-in-time production scales is

closely related to *Maintenance* among others. The first and the second canonical variables of quality management scales can explain more than a half of the variance in just-in-time production scales. These results support the argument that excellent quality management and total preventive maintenance are critical steps to establishing the ideal just-in-time production system.

Table 10 shows that the first canonical variable of quality management scales is highly correlated with many manufacturing strategy scales such as *Benefits of information systems* and *Stability/predictability of short term*, while the first canonical variable of information systems scales is closely related to *Maintenance.* More than one third of the variance of the information systems scales is explained by the first canonical variable of quality management scales. A variety of practices concerning total quality management and total preventive maintenance not only necessitate past or existing information but also generate the latest performance information and contribute to the strategic use of production information systems, whether they are computer-based or human-oriented. Also, total preventive maintenance approach has been quite effective to increase the stability and predictability of short time production.

Table 11 Quality management and technology development

	First canonical variable
Canonical correlation	0.8837
Likelihood ratio	0.1018
Significance	0.0001
Redundancy index:	0.6160
Correlations between quality management scales and canonical variable of technology scales	
Cleanliness and organization	0.5325
Continuous improvement	0.6382
Customer Involvement	0.5113
Customer Satisfaction	0.5126
Feedback	0.6031
Maintenance	0.5939
Process control	0.7721
Rewards for quality	0.6861
Supplier quality involvement	0.7151
Top management leadership for quality	0.8019
Correlations between technology scales and canonical variable of quality management scales	
Effective process implementation	0.8015
Inter-functional design efforts	0.7741
Product design simplicity	0.7781

As shown in Table 11, the first canonical variable of quality management scales is closely related to all of three technology development scales, while the first canonical variable of technology development scales is highly correlated with *Top management leadership for quality*, *Process control* and *Supplier quality involvement*. More than sixty percent of the variance of the technology development scales is explained by the first canonical variable of quality management scales. Suppliers' involvement and top management leadership are typical elements of sophisticated quality management system, and statistical process control, reward for quality, and continuous quality improvement represent more fundamental practices on the shop floor. We can conclude that establishing a solid base for total quality management serves as a prerequisite or preparation for the commitment of manufacturing departments to both product and process technology development.

Table 12 shows that the first canonical variable of quality management scales is correlated with many manufacturing strategy scales, particularly *Distinctive competence* and *Anticipation of new technologies*. Almost a half of the variance of manufacturing strategy scales is explained by the first and the second canonical variables of quality management scales. On the other hand, the first canonical variable of the manufacturing strategy scales is closely related to *Top management leadership for quality*. Distinctive competence in quality and related areas is based on the excellent quality management system committed by top management.

In summary these results for the Japanese manufacturing plants clearly support hypothesis 3 that excellent quality

management supports and/or is supported by operations management practices in other areas such as organization, human resource management, just-in-time production, information systems, technology development and manufacturing strategy. A series of canonical correlation analyses demonstrates that quality management depends certain organizational settings (*Commitment*; *Coordination of decision making*), and human resource management practices (*task-related training for employees*; *small group problem solving*; *multi-functional employees*), and that effective quality management practices strongly support just-in time production (*Just-in-time delivery by suppliers*; *Equipment layout*; *Daily schedule adherence*; *Setup time reduction*; *MRP adaptation to JIT*; *Repetitive nature of master schedule*), information systems (*Benefits of information systems*; *Stability/predictability of short term production*), technology development (*Effective process implementation*; *Product design simplicity*; *Inter-functional design efforts*), and manufacturing strategy (*Distinctive competence*; *Anticipation of new technologies*). In determining the role of quality management activities for competitive performance, we should take account of their indirect impacts via manufacturing strategy, technology development, information systems and just-in-time production.

Table 12 Quality management and manufacturing strategy

	First canonical variable	Second canonical variable
Canonical correlation	0.8917	0.7558
Likelihood ratio	0.0148	0.0720
Significance	0.0002	0.0639
Redundancy index	0.4440	0.0332
Correlations between quality management scales and canonical variables of manufacturing strategy scales		
Cleanliness and organization	0.4372	-0.4148
Continuous improvement	0.5044	-0.0985
Customer Involvement	0.4472	-0.0132
Customer Satisfaction	0.5360	0.1341
Feedback	0.4873	-0.3512
Maintenance	0.6829	-0.3473
Process control	0.6462	-0.1650
Rewards for quality	0.5036	-0.2396
Supplier quality involvement	0.6411	-0.0796
Top management leadership for quality	0.7247	0.1708
Correlations between manufacturing strategy scales and canonical variables of quality management scales		
Anticipation of new technologies	0.7678	-0.2307
Communication of manufacturing strategy	0.6250	-0.3051
Distinctive competence	0.7976	-0.0062
Formal strategic planning	0.6626	-0.2971
Functional integration	0.6546	-0.0094
Manufacturing-business strategy linkage	0.6756	0.0433
Manufacturing strategy strength	0.6196	-0.1299
Product competitive performance comparison	0.6736	0.2508
Proprietary equipment	0.5554	-0.0777

6. Conclusions

We proposed an analytical framework for high performance manufacturing, which includes (1) organization and human resource management, (2) quality management, just-in-time production, and information systems/information technology, (3) technology development, and operations or manufacturing strategy, and (4) competitive performance, and thereby established four hypotheses on quality management. Then, we proposed twelve measurement scales concerning quality management and found that at least ten measurement scales, *Cleanliness and Organization*, *Continuous Improvement*, *Customer involvement*, *Process control*, *Top management leadership for quality*, *Customer satisfaction*, *Feedback*, *Maintenance*, *Rewards for quality*, and *Supplier quality involvement*, are satisfactory in terms of reliability and validity for the data set of forty-six Japanese manufacturing plants. Using these scales and a summarized super-scale, we examined inter-industry and inter-class differences in quality management system and its relationship with other operations management practices and competitive performance to explore the requirements for and the roles of quality management. The main conclusions we derive from a series of statistical analyses are summarized as follows:

a) There are no major differences in quality management activities among three industries. This result is contrary to

hypothesis 1 but understandable, because various quality management concepts are deeply instilled into people in most Japanese manufacturing companies regardless of their product and process.

b) World class manufacturing plants establish more sophisticated quality management system than randomly sampled plants in terms of all quality management measurement scales except one scale, *Customer involvement*.

c) Quality management depends certain organizational settings and human resource management practices, and that effective quality management practices strongly support just-in time production, information systems, technology development, and manufacturing strategy. *Commitment*, *Coordination of decision making*, *task-related training for employees*, *small group problem solving* and *multi-functional employees* are judged to be especially important prerequisites for excellent quality management. Total preventive maintenance has a strong impact upon various just-in-time production practices and benefits of information systems. *Top management leadership for quality*, *Process control* and *Supplier quality involvement* promote the commitment of manufacturing departments to technology development. *Top management leadership for quality* is also influential to many aspects of manufacturing strategy.

d) Effective quality management contributes to the improvement in competitive performance. Especially, *Customer involvement, Cleanliness and organization, Supplier quality involvement* and *Rewards for quality* have strong impacts upon the competitive position of the manufacturing plants.

e) In terms of the strength of direct relationship with competitive performance indexes, quality management occupies the position similar to information systems, following manufacturing strategy and technology development. Quality management clearly surpasses organization, human resource management, and just-in-time production in the contribution to competitive performance. Further, we should take account of indirect impacts of quality management activities upon competitiveness via manufacturing strategy, technology development, information systems and just-in-time production.

Referring to our framework, we could empirically analyze paths from organization and human resource management to quality management, paths from quality management to just-in-time production, information systems, technology development and manufacturing strategy, and paths from all of those through competitive performance, and find that these paths are tightly connected.

Finally, further research for more comprehensive structure of manufacturing performance is supposed to be necessary and fruitful. We should conduct similar analyses concerning other production/operations management practices and draw the entire picture of competitive performance drivers. Another possibility is a comparative analysis of quality management, using data set of US, European and Japanese manufacturing companies.

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Supplement: Question items of quality management scales

(1) *Cleanliness and organization*

1. Our plant emphasizes putting all tools and fixtures in their place.
2. We take pride in keeping our plant neat and clean.
3. Our plant is kept clean at all times.
4. I often have trouble finding the tools I need.
5. Our plant is disorganized and dirty.

(2) *Continuous improvement*

1. All employees believe that it is their responsibility to improve quality in the plant.
2. Continuous improvement of quality is stressed in all work processes throughout our plant.
3. I am constantly working to improve quality.
4. Quality improvement is not a high priority for me.

(3) *Customer involvement*

1. We frequently are in close contact with our customers.

2. Our customers seldom visit our plant.
3. Our customers give us feedback on quality and delivery performance.
4. Our customers are actively involved in the product design process.
5. We strive to highly responsive to our customers' needs.
6. We regularly survey our customers' requirements.

(4) *Customer satisfaction*

1. Our customers are pleased with the products and services we provide for them.
2. Our customers seem happy with our responsiveness to their problems.
3. There is a very small chance that our customers will turn to our competitors.
4. We have a large number of repeat customers.
5. Customer standards are always met by our plant.
6. Customer satisfaction is of moderate importance to our plant.
7. Our customers have been well satisfied with the quality of our products over the past three years.
8. In general, our plant's level of quality performance over the past three years has been low, relative to industry norms.

(5) *Feedback*

1. Charts showing defect rates are posted on the shop floor.
2. Charts showing schedule compliance are posted on the shop floor.
3. Charts plotting the frequency of machine breakdown are posted on the shop floor.
4. I am never told whether I am doing a good job.
5. Information on quality performance is readily available to employees.
6. Information on productivity is readily available to employees.
7. My manager never comments about the quality o my work.

(6) *Maintenance*

1. Our equipment is in a high state of readiness for production at all times.
2. We dedicate a portion of every day solely to maintenance.
3. We emphasize good maintenance as a strategy for achieving quality and schedule compliance.
4. We have a separate shift, or part of a shift, reserved each day for maintenance activities.
5. We have a relatively high rate of downtime for repairs, compared with our industry.
6. We have a problem with repeated breakdowns for which we are unable to determine the cause.
7. Our maintenance department focuses on assisting machine operators perform their own preventive maintenance.

(7) *Process control*

1. Customer requirements are thoroughly analyzed in the new product design process.
2. Processes in our plant are designed to be "fool proof."
3. A large percent of the equipment or processes on the shop floor are currently under statistical quality control.
4. We make extensive use of statistical techniques to reduce variance in processes.
5. We use charts to determine whether our manufacturing processes are in control.
6. We monitor our processes using statistical process control.

(8) *Quality in new products*

1. New product designs are thoroughly reviewed before the product is produced and sold.
2. Customer requirements are thoroughly analyzed in the new product design process.
3. Reducing the cost of new products is a more important priority than new product quality.
4. Schedule concerns are more important than quality in the new product development process.

(9) *Rewards for quality*

1. Workers are rewarded for quality improvement.
2. Supervisors are rewarded for quality improvement ideas.
3. If I improve quality, management will reward me.

4. We pay a group incentive for quality improvement ideas.
5. Our plant has an annual bonus system based on plant productivity.
6. Nonfinancial incentives, such as jackets, coffee cups, etc., are used to reward quality improvement.

(10) *Supplier quality involvement*

1. We strive to establish long-term relationships with suppliers.
2. Our suppliers are actively involved in our new product development process.
3. Quality is our number one criterion in selecting suppliers.
4. We rely on a small number of high quality suppliers.
5. We use mostly suppliers which we have certified.
6. We maintain close communication with suppliers about quality considerations and design changes.

(11) *Top management leadership for quality*

1. All major department heads within our plant accept their responsibility for quality.
2. Plant management provides personal leadership for quality products and quality improvement.
3. The top priority in evaluating plant management is quality performance.
4. All major department heads within our plant work towards encouraging just-in-time production.
5. Our top management strongly encourages employee involvement in the production process.
6. Plant management creates and communicates a vision focused on quality improvements.
7. Plant management is personally involved in quality improvement projects.

(12) *TQM link with customers*

1. Quality is the number one criterion used by our customers in selecting us as a supplier.
2. Our processes are certified, or qualified, by our customers.
3. We deliver without inspection at the customers plant.
4. Our customers involve us in their quality improvement efforts.
5. Our customers can rely on us for quality products and processes.

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