New Developments in Just-in-Time Production: An Empirical Analysis of Japanese Manufacturing Companies

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Abstract

This paper proposes an analytical framework for high performance manufacturing and focus on the requirements for just-in-time (JIT) production systems and the roles and consequences of JIT production for manufacturing companies. The paper reports nine reliable and valid measurement scales concerning JIT production practices, using the data collected from thirty-five Japanese manufacturing plants in 2003 and 2004. Using these scales and a summarized super-scale, it is proved that JIT production interrelates with other operations areas. Fourteen scales are judged to be especially important, and they characterize high problem-solving capabilities of each individual and group, a solid base for quality management and preventive maintenance, advancements in theory of constraints and supply chain management, product and process technology development, and manufacturing strategy encouraging unique practices. *Setup time reduction*, *Daily schedule adherenc*e, *Equipment layout*, and *Synchronization of operations*, are highly correlated with many operations management areas. The result suggests that the interrelationship between manufacturing strategy and JIT production has been weakened within this decade. Another finding is that JIT production, especially *Equipment layout* and *Setup time reduction*, strongly contributes to competitive performance. In terms of the strength of the direct relationship with competitive performance, JIT production occupies the second position, following supply chain management, which sharply contrasts with the situation in the 1990s.

Keywords: Just-in-time production; Inventory management; Manufacturing, Empirical research; Japan

1. Introduction

Just-in-time (JIT) production has been one of the hottest areas in operations management since 1980s. It reflects the idea of producing the necessary items in the necessary quantities at the necessary time, and eliminating all sources of waste in operations. This idea is so simple to describe but so difficult to realize. Many things should be overcome; leveled master schedule, small lot size, setup time reduction, pull system, multi-functional workers, JIT layout and related equipments, perfect quality, autonomation, and supplier relations.

Further, JIT production should be integrated with other operations systems and practices to be fully utilized. Schonberger (1986) advocated the concept of world class manufacturing, which combined JIT production, total quality management (TQM), total preventive maintenance (TPM), and human resources management. Harrison (1992) and Flynn, Sakakibara and Schroeder (1995) emphasized the integration of JIT production and TQM. Monden (1998) described the Toyota production systems as a mixture of JIT production on the shop floor, human resources management, TQM, and information systems. The conceptualization of lean production by Womack, Jones and Roos (1990) can be interpreted as a mechanism to harmonize designing products, purchasing parts and components, manufacturing, and marketing. From a perspective of competitive strategy, Hamel and Prahalad (1994) listed many examples where an integrated technology or skill builds up core competence.

The main objective of this paper is to empirically analyze what requirements should be satisfied for the development of JIT production systems, and whether the implementation of JIT production systems can lead to improved decisions or practices in other operations management areas and finally higher competitive performance. This analysis is based on the measurement scales concerning JIT production and the survey data collected from Japanese manufacturing companies through extensive questionnaires in 2003 and 2004 as a part of the third round survey of High Performance Manufacturing Project. The main results are compared to the ones from the analysis for the second round survey data collected in the 1990s.

2. Analytical framework and hypotheses

Figure 1 shows an analytical framework with four major building blocks to assess the real value of JIT production for Japanese manufacturing companies: (1) human resource management and organization; (2) quality management, total preventive maintenance, theory of constraints, JIT production, and supply chain management; (3) technology development, new product development, and manufacturing strategy; (4) competitive performance. Organization together with human resource management provides an infrastructure on which elaborate manufacturing systems are established and manufacturing strategy is formulated. The second block consists of core manufacturing operations systems concerning quality, inventory, production planning, and information flow within manufacturing companies and throughout the supply chain. The third block includes more technological and strategic aspects of operations, which are closely related each other and interact with core manufacturing operations systems. These three blocks are put together to determine the competitive performance of manufacturing plants.

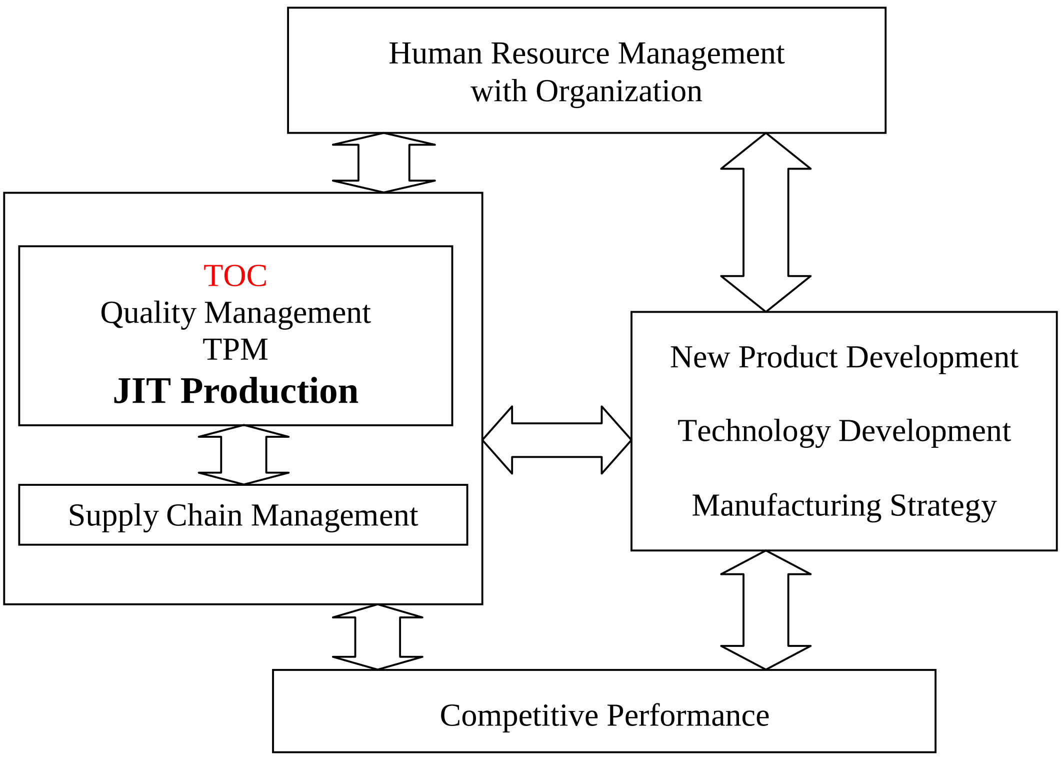

Figure 1: Analytical framework for high performance manufacturing

This paper focuses on JIT production systems within the framework. In addition it explores their relationships with human resource management, organization, theory of constraints, quality management, total preventive maintenance, new product development, technology development, manufacturing strategy, and competitive performance. It is assumed that JIT linkage is a key factor determining competitive performance not merely directly but also indirectly through the impact upon other manufacturing practices and strategy. The following two hypotheses are to be tested:

Hypothesis 1: JIT production interrelates with human resource management, quality management, total preventive maintenance, theory of constraints, supply chain management, new product development, technology development, and manufacturing strategy.

Hypothesis 2: JIT production contributes to competitive performance of the plant.

3. Research variables

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

3.1 JIT production measurement scales

The first set of variables is concerned with the role of JIT production systems for manufacturing companies. To measure various practices on JIT production the following nine scales are introduced:

1) *Daily schedule adherence* (DSA) assesses whether there is time for meeting each day's schedule including catching up after stoppages for quality considerations or machine breakdown.
2) *Equipment layout* (EL) measures use of manufacturing cells, elimination of forklifts and long conveyers, and use of smaller equipment designed for flexible floor layout, which are all associated with JIT manufacturing.
3) *Just-in-time delivery by suppliers* (JDS) measures whether vendors have been integrated into production in terms of using kanban containers, making frequent or JIT delivery and quality certification.
4) *Just-in-time link with customers* (JLC) assesses whether the plant has applied the JIT delivery concept and the pull system concept in the operational link with customers.
5) *Kanban* (KAN) measures whether or not the plant has implemented the physical elements of a kanban/pull system.
6) *Repetitive nature of master schedule* (RMS) assesses use of small lot sizes, mixed model assembly, and level daily production schedule in the plant.
7) *Setup time reduction* (STR) evaluates whether the plant is taking measures to reduce setup times and lower lot sizes in order to facilitate JIT production.
8) *Small lot size* (SLS) measures whether or not the plant has moved towards producing in small batches as opposed to producing in large lots.
9) *Synchronization of operations* (SOP) measures whether manufacturing capacities and workloads are well balanced within the plant and throughout the supply chain in order to keep total inventory minimal.

Each measurement scale is constructed by several question items evaluated on a seven-point Likert scale (1=Strongly disagree, 2=Disagree, 3=Slightly disagree, 4=Neutral, 5=Slightly agree, 6=Agree, 7=Strongly agree). More precisely, four to seven question items are used to construct the measurement scales. Individual question items are shown in the appendix.

3.2 Other measurement scales

The second category of variables consists of measurement scales in the areas of organization, human resource management, quality management, production information systems, technology development and manufacturing strategy. Each measurement scale is a construct using several question items measured on a five-point Likert scale. The list of respective measurement scales is as follows:

1) Human resource management
   Cooperation; Coordination of decision making; Employee suggestions; Commitment; Flatness of organization structure; Human goodness; Management breadth of experience; Multi-functional employees; Recruiting and selection; Supervisory interaction facilitation; Small group problem solving; Shop floor contact; Task-related training for employees; Centralization of authority; Rewards/manufacturing coordination
2) Theory of constraints
   TOC philosophy; Implementation of TOC
3) Quality management
   Cleanliness and organization; Customer focus; Customer involvement; Customer satisfaction; Organization-wide approach; Prevention; Process emphasis; Feedback; Process control; Supplier quality involvement; Top management leadership for quality; TQM link with customers; Supplier partnership
4) Total preventive maintenance
   Autonomous Maintenance; Maintenance Support; Team Based Maintenance; Preventive Maintenance
5) Supply chain management
   Coordination of plant activities; Stability of demand; Supply chain planning
6) New product development
   Customer Involvement; Project Complexity; Manufacturing Involvement in New Product Development; Project Priority; Team Rewards; Team Spirit; Supplier Involvement
7) Technology development
   Effective process implementation; Inter-functional design efforts; Mass customization; Modularization of products; New product introduction cooperation
8) Manufacturing strategy
   Achievement of functional integration; Anticipation of new technologies; Communication of manufacturing strategy; Competitive intensity of industry; Formal strategic planning; Integration between functions; Leadership for functional integration; Manufacturing as a competitive resource; Manufacturing-business strategy linkage; Proprietary equipment; Unique practices

3.3 Super-scales for main areas of production management

In the analysis below, super-scales are introduced to summarize the measurement scales in the following areas of production management: *Human resources management* (HR), *Quality management* (QM), *Total preventive maintenance* (TPM), *Theory of constraints*

(TOC), *Just-in-time production systems* (JIT), *Supply chain management* (SCM), *New product development* (NPD), *Technology development* (TECH), and *Manufacturing strategy* (MS).

3.4 Performance indicators

The last set of variables is concerned with competitive performance indicators relative to global competitors in the industry. Each plant manager subjectively judges them 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). The following thirteen performance indicators cover the 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; Product capability and performance; On time new product launch; Product innovativeness; Customer support and service. Objective performance indicators were also collected from each plant. They do not necessarily reflect the actual competitiveness of each plant, however, because of high variability in demand pattern, product complexity, and process technology.

4. Data collection

Data for this analysis was collected through the international collaboration on high performance manufacturing (HPM) in 2003 and 2004 as the third round survey for Japanese manufacturing companies. The data is comparable to those data from the second round survey conducted in mid-1990s, whose analytical results are shown in Schroeder and Flynn (2001). The third round survey includes data from thirty-five Japanese manufacturing companies, while the second round survey had forty-six plants, both from machinery, electrical & electronics, and automobile industries. In all plants nineteen individuals across levels responded to twelve different types of questionnaires that partially share the questions in the third round. Those numbers were reduced from twenty-six persons and fifteen types of questionnaires. The respondents in the third round include a plant manager, a plant superintendent, a plant accountant, a human resource manager, an inventory manager, an information systems manager, a production control manager, a process engineer, a quality manager, a member of new product development project, four supervisors and direct labor. Plant-level data are calculated as an average value of all the valid responses at the company for each qualitative question item.

Those respondents were asked to answer around one hundred question items most of which are included to construct measurement scales for JIT production as well as other manufacturing practices and strategy. An inventory manager, a production control manager, and four supervisors were asked to answer the question items for all of nine JIT production scales.

5. Results of empirical analysis

5.1 Measurement analysis of JIT production scales

A starting point is the measurement analysis of nine measurement scales on JIT production. The reliability of measurement scales is usually judged according to the

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

Scale	Daily schedule adherence			Equipment layout		
alpha coefficient:	0.7024		0.8026	0.4252		0.8194
Factor loadings:	Factor 1	Factor 2	Factor 1	Factor 1	Factor2	Factor 1
Question item 1	0.837	-0.111	0.843	0.752	-0.131	0.763
Question item 2	0.625	0.323	0.607	0.285	0.549	deleted
Question item 3	0.812	0.031	0.808	0.267	0.817	deleted
Question item 4	0.244	0.703	deleted	0.835	-0.201	0.844
Question item 5	0.131	0.796	deleted	0.819	-0.240	0.840
Question item 6	0.732	-0.328	0.758	0.793	0.111	0.793
Question item 7	0.769	-0.220	0.779			
Eigenvalue:	2.956	1.402	2.913	2.715	1.095	2.628
Proportion:	42.22%	20.02%	58.26%	45.25%	18.26%	65.71%
No. of factors:	2		1	2		1

Scale	Just-in-time delivery by suppliers			Just-in-time link with customers			Kanban
alpha coefficient:	0. 6791		0.7006	0.6785		0.7679	0.8886
Factor loadings:	Factor 1	Factor 2	Factor 1	Factor 1	Factor 2	Factor 1	Factor 1
Question item 1	0.838	-0.188	0.860	0.827	0.053	0.832	0.864
Question item 2	0.682	0.268	0.674	0.255	0.915	deleted	0.847
Question item 3	0.781	-0.021	0.794	0.701	-0.408	0.718	0.852
Question item 4	0.517	-0.632	0.565	0.651	-0.118	0.652	0.899
Question item 5	0.446	0.713	deleted	0.407	0.019	deleted	
Question item 6				0.848	0.092	0.863	
Eigenvalue:	2.244	1.014	2.145	2.549	1.030	2.377	2.999
Proportion:	44.88%	20.29%	53.61%	42.48%	17.16%	59.44%	74.96%
No. of factors:	2		1	2		1	1

Scale	Repetitive nature of master schedule			Setup time reduction	Small lot size	Synchronization of operations
alpha coefficient:	0.7374		0.6640	0.8019	0.7447	0.7034
Factor loadings:	Factor 1	Factor 2	Factor 1	Factor 1	Factor 1	Factor 1
Question item 1	0.753	-0.363	deleted	0.706	0.764	0.756
Question item 2	0.706	0.254	0.703	0.609	0.689	0.775
Question item 3	0.768	-0.292	0.768	0.748	0.754	0.678
Question item 4	0.450	0.723	deleted	0.755	0.812	0.614
Question item 5	0. 671	-0.306	0.692	0.776		0.552
Question item 6	0.560	0.354	0.661	0.711		
Eigenvalue:	2.621	1.023	1.998	3.106	2.286	2.313
Proportion:	43.69%	17.05%	49.95%	51.77%	57.15%	46.27%
No. of factors:	2		1	1	1	1

Cronbach's alpha coefficient, which should be more than 0.6 for a newly developed scale. The validity of measurement scales is tested against 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. These analyses are applied to the individual-level data, including both world-class and randomly sampled manufacturing plants. The methodological issues on empirical research in operations management are discussed by Flynn et al. (1990). Matsui (2001, 2002) reports the measurement analysis for quality management, information systems, technology development and manufacturing strategy in the Japanese plants.

As shown in Table 1, those nine measurement scales meet these criteria for reliability and validity. Note that two factors are found to be principle for *Repetitive nature of master schedule* and *Small lot size*. All the question items for these two measurement scales are kept, because the first factor loadings of question items are all more than 0.4, the eigenvalue for the second factor is relatively small, which is 1.1782 for *Repetitive nature of master schedule* and 1.017 for *Small lot size*, and dropping any question item decreases the alpha coefficient and deteriorates the reliability. Several question items are dropped for four measurement scales to improve their reliability and validity. The remaining question items are simply averaged to obtain the scores for each scale.

Table 2: JIT production scales and competitive performance indicators

	First canonical variable	Second canonical variable
Canonical correlation	0.9741	0.9212
Likelihood ratio	0.0001	0.0015
Significance	0.0157	0.2128
Redundancy index: JIT production	0.2915	0.2370
Redundancy index: performance	0.0268	0.1751
Correlations between JIT production scales and canonical variables of competitive performance indicators		
Daily schedule adherence	0.5234	0.6351
Equipment layout	0.1555	0.7167
Just-in-time delivery by suppliers	0.5565	0.6463
Just-in-time link with customers	0.5464	0.4435
Kanban	0.7672	0.1584
Repetitive nature of master schedule	0.5080	0.4047
Setup time reduction	0.3056	0.7070
Small lot size	0.0465	0.1285
Synchronization of operations	0.5242	0.5091
Correlations between competitive performance indicators and canonical variables of JIT production scales		
Unit cost of manufacturing	0.0641	0.5938
Quality of product conformance	-0.2247	0.1864
Delivery performance	0.0617	0.1195
Fast delivery	0.3598	0.0626
Flexibility to change product mix	-0.0404	0.4640
Flexibility to change volume	0.1150	0.6365
Inventory turnover	0.3479	0.3898
Cycle time	0.0855	0.2805
Speed of new product introduction	0.1049	0.5170
Product capability and performance	0.0453	-0.1444
On time new product launch	-0.0231	0.5980
Product innovativeness	-0.1707	0.3216
Customer support and service	0.0361	0.3009

Further, a super-scale on JIT production is calculated by averaging the reliable and valid measurement scales. The super-scale, *Just-in-time production systems* (*JIT*), is proved reliable and valid, which demonstrates the close relationships among the nine measurement scales. The measurement analysis is applied to the plant-level data.

5.2 JIT production and competitive performance

This section tests the hypothesis 2, that is, the relationship between JIT production and competitive performance. A canonical correlation analysis between nine JIT production scales and competitive performance indicators proves that *Equipment layout* and *Setup* *time reduction*, among others, have widespread impacts on performance indicators, particularly, with respect to unit manufacturing cost, flexibility, and new product introduction, from the second canonical correlation in Table 2. The first and second canonical correlations are more than 0.9, and the likelihood ratio shows high significance. According to the redundancy index, around 18% of variance of the competitive performance indicators is explained by the second canonical variable of the JIT production scales, while only 3% of variance of the competitive performance indicators can be explained by the first canonical variable of the JIT production scales. The pair of the first canonical variables is supposed to mainly capture the impact of performance on JIT production practices centered on Kanban systems.

Table 3: Super-scales and competitive performance indicators

	First canonical variable
Canonical correlation	0.9732
Likelihood ratio	0.00004
Significance	0.0715
Redundancy index: super-scale	0.3816
Redundancy index: performance	0.1852
Correlations between super-scales and canonical variable of competitive performance indicators	
Human resource management (HR)	0.4963
Just-in-time production (JIT)	0.7350
Theory of constraints (TOC)	0.5673
Quality management (QM)	0.6577
Total preventive maintenance (TPM)	0.7094
Supply chain management (SCM)	0.7772
New product development (NPD)	0.3281
Technology development (TECH)	0.5812
Manufacturing strategy (MS)	0.6568
Correlations between competitive performance indicators and canonical variable of super-scales	
Unit cost of manufacturing	0.4501
Quality of product conformance	0.1845
Delivery performance	0.2300
Fast delivery	0.1548
Flexibility to change product mix	0.2798
Flexibility to change volume	0.4248
Inventory turnover	0.7994
Cycle time	0.3205
Speed of new product introduction	0.5986
Product capability and performance	0.1369
On time new product launch	0.5044
Product innovativeness	0.3765
Customer support and service	0.3494

When the JIT production scales are replaced by nine super-scales in order to explore the role of JIT production from a wider perspective, the redundancy index explaining variance of the performance indicators by the first canonical variable of super-scales jumps up to more than 18%, and the canonical correlation model becomes highly significant, as shown in Table 3. The direct impact of *JIT* on competitive performance is relatively strong. In terms of the correlation with the first canonical variable of competitive performance indicators, *JIT* occupies the second position, following supply chain management at the top. This result sharply contrasts with the analysis for the second round data where *MS* was ranked first, and followed by *TECH*, *IS* (information system), *QM*, *HR*, then *JIT*.

These results for the Japanese manufacturing companies strongly support the hypothesis 2 that the implementation of JIT production, particularly through the efficient and compact equipment layout, reduction in setup time, linkage with customers and suppliers, and synchronization of operations, strengthens the competitive position of the plant and company. One of the most important factors for competitiveness of recent Japanese manufacturing sector can be attributed to JIT production, its natural extension, that is, supply chain management, and the various practices and capabilities to advance the existing production system further. It might be the case in the 1980s, while most Japanese manufacturing companies shifted their focuses from JIT production, quality management, or total preventive maintenance to manufacturing strategy, technology development, and new product development and introduction in the 1990s, facing the bursting of the bubble economy, and the rapid growth of manufacturing in other Asian countries. Some of them restructured their businesses, and outsourced manufacturing operations to the third party. Recently in favorable market conditions, however, high performance Japanese manufacturers are trying to return to the basics of manufacturing operations, recover their lost operational competitiveness and establish new capabilities by combining efficient production systems, innovative new products and sophisticated strategic design and implementation. That is a reason why the relationships between JIT production and other operations management areas should be well explored.

5.3 JIT and other operations management practices

The final part of analysis is concerned with the hypothesis 1 and look into the relationship among operations management practices to find out requirements or facilitators for JIT production and its influence on other important areas in operations. Simple correlation coefficients between the super-scales on operations management, as shown in Table 4, are all significantly more than zero except between *NPD* and others. *JIT* is closely correlated with all of *SCM* (0.80), *TPM* (0.79), *TOC* (0.70), *HR* (0.70), *TECH* (0.66), *QM* (0.58), and *MS* (0.58).

Table 4: Correlation coefficient between super-scales

	JIT	HR	TOC	QM	TPM	SCM	NPD	TECH
HR	0.70074							
TOC	0.70319	0.68729						
QM	0.57810	0.69961	0.65423					
TPM	0.78587	0.88186	0.77538	0.77478				
SCM	0.80174	0.74724	0.68664	0.62961	0.79198			
NPD	0.33238	0.23585	0.32472	0.26076	0.31226	0.24591		
TECH	0.65833	0.60571	0.60666	0.72163	0.76802	0.63013	0.40785	
MS	0.57762	0.69357	0.67465	0.68549	0.76690	0.67002	0.19092	0.73234

These relationships can be explored further by using canonical correlation techniques into the level of measurement scale. Table 5 summarizes the result of a series of canonical correlation analyses between nine JIT production scales and measurement scales for other operations areas. In every case the first canonical correlation is more than 0.84, much higher than the corresponding simple correlation coefficient, and is judged to be significant by the likelihood ratio test except the canonical correlations between JIT production and new product development ($p=0.2565$) and between JIT production and manufacturing strategy ($p=0.2430$). The redundancy index for JIT production is more than forty percent as explained by the first canonical variable of total preventive maintenance, and supply chain management scales. The redundancy index explained by the first canonical variable of JIT production scales is more than forty percent for theory of constraints, total preventive maintenance, and supply chain management, which demonstrates the extensive impact of JIT production. This analysis suggests the direction of influence between JIT production and other operations areas. JIT production has interdependent relationships with total preventive maintenance, supply chain management, technology development, quality management, and manufacturing strategy. On the other hand, the influence of theory of constraints on JIT production is less than the opposite.

Table 5: Summary of canonical correlation analysis between JIT and other operation management areas (the first canonical correlation variable only)

	HR	TOC	QM	TPM	SCM	NPD	TECH	MS
Canonical correlation	0.9433	0.8417	0.9048	0.9015	0.9240	0.8765	0.8818	0.9146
Likelihood ratio	0.0003	0.1942	0.0006	0.0793	0.0498	0.0357	0.0761	0.0085
Significance	0.0369	0.0004	0.0061	0.0012	0.0001	0.2565	0.0174	0.2430
Redundancy index (JIT)	0.3371	0.3316	0.3360	0.4740	0.4565	0.1903	0.3865	0.2625
Redundancy index (other)	0.3183	0.6414	0.3437	0.5668	0.4629	0.1046	0.3430	0.2586

The first canonical variable of JIT production scales is closely related to the following fourteen scales: *Coordination of decision making* (0.8446), *Small group problem solving* (0.7561), and *Shop floor contact* (0.7205) from human resource management; *TOC philosophy* (0.8417) and *Implementation of TOC* (0.7567) from theory of constraints; *Process control* (0.7513) from quality management; *Team Based Maintenance* (0.8692), *Preventive Maintenance* (0.7789), and *Maintenance Support* (0.7416) from total preventive maintenance, *Supply chain plannin*g (0.8164) and *Coordination of plant activities* (0.7571) from supply chain management; *Effective process implementation* (0.8424) and *Inter-functional design efforts* (0.7998) from technology development; *Unique practices* (0.7007) from manufacturing strategy. Figures in parentheses represent the correlations with the first canonical variable of JIT production scales. Those practices are regarded as requisites for JIT production implementation, which are considerably similar to those for the second round data collected in 1990s, besides newly introduced areas such as theory of constraints and supply chain management. One obvious change is found in the impact of manufacturing strategy. The impact on JIT production weakened, although strategic thrust for unique practices to attain sustainable competitive advantage is supportive of JIT production. Functional integration is no longer the crucial but moderate initiative for JIT production.

Human resource management including organizational characteristics strongly correlate with such JIT practices as *Just-in-time link with customers* (0.7623) and *Repetitive nature of master schedule* (0.7394) to keep enlarging the individual and group problem solving competence. It is, however, modestly related with Just-in-time delivery by suppliers (0.5625). This is different from the result for the second round data, where organizational characteristics and human resource management had strong impact on Just-in-time delivery.

Theory of constraints approach serves as a prerequisite for implementing JIT production practices such as *Synchronization of operations* (0.7766), *Setup time reduction* (0.7695), and *Equipment layout* (0.7659). Similarly, the establishment of solid quality systems promotes *Setup time reduction* (0.7863), *Equipment layout* (0.7654), and *Daily schedule adherence* (0.7494), but modestly contributes to *Just-in-time delivery by suppliers*

(0.5690). On the other, total preventive maintenance has a widespread impact on JIT production practices such as *Repetitive nature of master schedule* (0.7905), *Setup time reduction* (0.7820), *Synchronization of operations* (0.7648), *Daily schedule adherence* (0.7560), *Just-in-time link with customers* (0.7537), *Just-in-time delivery by suppliers* (0.7242), and *Equipment layout* (0.7224). Likewise, supply chain management has a close relationship with *Synchronization of operations* (0.8589), *Equipment layout* (0.8230), *Setup time reduction* (0.8116), *Daily schedule adherence* (0.7902), *Just-in-time delivery by suppliers* (0.7576), *Just-in-time link with customers* (0.7724), and *Repetitive nature of master schedule* (0.7250).

Technology development in terms of product and process design and implementation has highly interrelated with JIT production practices such as *Setup time reduction* (0.8393), *Daily schedule adherence* (0.7896), *Equipment layout* (0.7847) and *Synchronization of operations* (0.7669). The impact of JIT production upon technology development was more dominant than the reverse for the second round data. In the same way, the first canonical variable of the manufacturing strategy scales is closely related to *Daily schedule adherence* (0.7936), *Setup time reduction* (0.7581), and *Synchronization of operations* (0.7049). The relationships are reasonable, because those JIT production practices are typical examples of unique practices the companies are trying to establish. Implementing JIT production systems still needs a long-term and strategic perspective and occupies a constant part of manufacturing strategy.

In summary these results for the Japanese manufacturing companies basically support the hypothesis 1 that JIT production interacts with human resource management, quality management, total preventive maintenance, theory of constraints, supply chain management, new product development, technology development, and manufacturing strategy. Although the relationships between new product development and JIT production are marginal, other pairs are highly linked each other so as to construct operational capabilities.

6. Conclusions

This paper proposes an analytical framework for high performance manufacturing and focus on two hypotheses on the requirements for and the roles of JIT production. Then, it reports nine reliable and valid measurement scales concerning practices on JIT production, using the data collected from thirty-five Japanese manufacturing plants in 2003 and 2004. Using these scales and a summarized super-scale, a series of analyses are done for the relationships of JIT production with other operations areas and competitive performance. The main findings are as follows:

a) JIT production interrelates with other operations areas such as human resource management, theory of constraints, quality management, total preventive maintenance, new product development, technology development, and manufacturing strategy. Fourteen scales are judged to be especially important prerequisites or consequences of JIT production. Those scales jointly characterize high problem-solving capabilities of each individual and group, a solid base for quality management and preventive maintenance, advancements in theory of constraints and supply chain management, product and process technology development, and manufacturing strategy encouraging unique practices. *Setup time reduction*, *Daily schedule adherence*, *Equipment layout*, and *Synchronization of operations*, among JIT production scales, are highly correlated with many operations management areas.

b) The interrelationship between manufacturing strategy and JIT production has been weakened within this decade.

c) JIT production systems strongly contribute to competitive performance. Especially, *Equipment layout* and *Setup time reduction* have strong impact upon the competitive position of the manufacturing companies.

d) In terms of the strength of the direct relationship with competitive performance, JIT production occupies the second position, following supply chain management, which is regarded as a natural extension of JIT production. This sharply contrasts with the situation in the 1990s.

One of the most important implications is that JIT production systems, along with supply chain management, play a pivotal role for manufacturing operations in Japan. JIT production strongly interrelates with organizational behavior and human resource management, theory of constraints approach, quality management initiatives, supply chain management, product and process technology development, and manufacturing strategy formulation and implementation. A lot of operational practices are linked together. Most Japanese world class companies have been accumulating their capabilities to exploit this linkage structure and the synergy effects among different operations areas to attain sustainable competitiveness in the global market. JIT production and supply chain management is regarded as one of key linking nodes. Our analysis reveals that those Japanese manufacturers are returning to the basics of their operations after restructuring and outsourcing their businesses and while introducing a lot of new products into the market.

Finally, there are possibilities to extend our research further in some directions. More comprehensive structure to determine manufacturing performance should be drawn and analyzed. This paper uses a sample consisting of thirty-five manufacturing companies located in Japan, which clearly limits the availability of analytical techniques. The same methodology adopted in this paper could be applied to other operations management areas, and then those results be amalgamated. The sample size problems might be solved when the data for manufacturing companies in other countries are pooled with the Japanese sample. Another research direction in the future is a comparative analysis of JIT production systems, using data from US, European and Asian manufacturing companies.

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Appendix: Question Items for JIT Scales

1) *Daily schedule adherence*
   1. We usually meet the production schedule each day.
   2. Our daily schedule is reasonable to complete on time.
   3. We usually meet the production schedule each day.
   4. We build time into our daily schedule to allow for machine breakdowns and unexpected production stoppages.
   5. We build extra slack into our daily schedule, to allow for catching up.
   6. We cannot adhere to our schedule on a daily basis.
   7. It seems like we are always behind schedule.

2) *Equipment layout*
   1. We have laid out the shop floor so that processes and machines are in close proximity to each other.
   2. We have organized our plant floor into manufacturing cells.

3. Our machines are grouped according to the product family to which they are dedicated.
4. The layout of our shop floor facilitates low inventories and fast throughout.
5. Our processes are located close together, so that material handling and part shortage are minimized.
6. We have located our machines to support JIT production flow.

3) *Just-in-time delivery by suppliers*

1. Our suppliers deliver to us on a just-in-time basis.
2. We receive daily shipments from most suppliers.
3. We can depend upon on-time delivery from our suppliers.
4. Our suppliers are linked with us by a pull system.
5. Suppliers frequently deliver materials to us.

4) *Just-in-time link with customers*

1. Our customers receive just-in-time deliveries from us.
2. Most of our customers receive frequent shipments from us.
3. We always deliver on time to our customers.
4. We can adapt our production schedule to sudden production stoppages by our customers.
5. Our customers have a pull type link with us.
6. Qur customers are linked with us via JIT systems.

5) *Kanban*

1. Suppliers fill our kanban containers, rather than filling purchase orders.
2. Our suppliers deliver to us in kanban containers, without the use of separate packaging.
3. We use a kanban pull system for production control.
4. We use kanban squares, containers or signals for production control.

6) *Repetitive nature of master schedule*

1. Our master schedule repeats the same mix of products, from hour to hour and day to day.
2. The master schedule is level-loaded in our plant, from day to day.
3. A fixed sequence of items is repeated throughout our master schedule.
4. Within our schedule, the mix of items is designed to be similar to the forecasted demand mix.
5. We use a repetitive master schedule from day to day.
6. Our master schedule does not facilitate JIT production.

7) *Setup time reduction*

1. We are aggressively working to lower setup times in our plant.
2. We have converted most of the setup time to external time, while the machine is running.
3. We have low setup times of equipment in out plant.
4. Our crews practice setups, in order to reduce the time required.
5. Our workers are trained to reduce setup time.
6. Our setup times seem hopelessly long.

8) *Small lot size*

1. We have large lot sizes in out plant.
2. We tend to have large lot sizes in our master schedule.
3. We emphasize small lot sizes, to increase manufacturing flexibility.
4. We make our products in the smallest lot sizes possible.

9) *Synchronization of operations*

1. Capacities are balanced in our supply network.
2. Our manufacturing capacity is balanced throughout the entire manufacturing process.
3. We can easily determine bottleneck operations in our supply chain.
4. We have large in-process inventories between different operations.
5. Our suppliers do not use large inventories to supply us.