JIT AND TPM: THEIR RELATIONSHIP AND IMPACT ON JIT AND COMPETITIVE PERFORMANCES

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Abstract

Just-in-time (JIT) production and total productive maintenance (TPM) have been subjective to numerous studies in isolation. This study attempts to measure the impact of TPM on the level of JIT production implementation and development, and the impact of both on JIT performance and competitive performance. Multi-item scales have been constructed to measure key components of JIT and TPM for manufacturing firms in machinery, electrical & electronics, and automobile industries.

We use five scales to measure JIT production practices; Equipment Layout, JIT Delivery by Suppliers, Kanban/Pull System, Setup Time Reduction, and Repetitive Nature of Master Schedule. To measure TPM practices, we use four scales; Autonomous Maintenance, Preventive Maintenance, Maintenance Support, and Team Based Maintenance. To measure JIT performance we use inventory turnover and cycle time. Competitive performance of the plant has been measured based on five dimensions; cost, quality, flexibility, delivery, and on time new product launch.

Based on the survey data collected in Japan, Korea, USA, and Germany, we find that TPM will positively influence and facilitate the implementation level of JIT through Preventive Maintenance, Maintenance Support, and Team Based Maintenance. Country and industry explained a significant portion of variance in the implementation level of JIT production. The results indicate that both JIT and TPM in isolation explain a significant portion of the variance in all the measures of JIT performance and competitive performance after controlling for country and industry effect. Given the impact of JIT production on JIT performance and competitive performance, the addition of TPM resulted in an additional significant improvement in inventory turnover as well as in the measures of cost, quality and on time new product launch. Country and industry did not explain significant portion of the variance in both JIT and competitive performances.

Key words: Just-in-time production; Total productive maintenance; International comparison; Empirical research

1. Introduction

In the past two decades, Japanese manufacturing practices in general and Just-in-time (JIT) production in particular have received a great attention from western researchers and manufacturing firms in trial to catch-up Japan in terms of quality, productivity, and low cost. [1] asserted that manufacturing competitiveness is based on a foundation of integrating and overlapping practices. During our review of the literature, we found that although many researchers theoretically regard TPM as an element of JIT production, there are few papers that attempted to examine empirically the relationship between JIT and TPM.

In this paper we try to fill this gap by empirically examining the impact of TPM on JIT production. We also examine the impact of JIT and TPM on JIT performance and competitive performance.

The data were collected from four countries, Japan, USA, Germany, and Korea to investigate this relationship. The findings of this study are discussed to shed more light on TPM as a necessary infrastructure for successful JIT implementation.

2. Literature review

2.1. Just-in-time production

JIT production was developed at Toyota motor corp. in 1950s. One motivating reason for developing JIT was that after World War II, Japanese people had a very strong incentive to develop good manufacturing techniques to help them rebuild the economy [2]. Later, after the first oil shock in 1973, Toyota system attracted other Japanese companies as Toyota had shown huge profits while most of other Japanese companies had experienced considerable losses [3].

The notion of JIT production was described by Taiichi Ohno [4], the father of Toyota production system, as "All we are doing at the time line from the moment the customer gives us an order to the point when we collect the cash, and we are reducing that time line by removing the non-value-added waste". There are seven forms of waste were identified by Toyota engineers which JIT production aims to eliminate: waste of overproduction, waste of inventory, waste of repair/defects, waste of motion (unnecessary movement), waste of processing, waste of waiting, and waste of transport ([4], [5], [6], [7]).

There is no agreement on a clear definition of JIT. As the complex subject is usually summarized in a very brief statement, this results in information being omitted and causes confusion [8]. A comprehensive definition of JIT was suggested by [9] "JIT may be viewed as a production methodology which aims to improve overall productivity through the elimination of waste and which leads to improved quality. In the manufacturing/assembly process JIT provides the cost-effective production and delivery of only the necessary quality parts, in the right quantity, at the right time and place, while using a minimum of facilities, equipment, materials and human resources. JIT is dependent on the balance between the stability of the user's scheduled requirements and the supplier's manufacturing flexibility. It is accompanied through the application of specific techniques which require total employee involvement and team work".

Many researchers have attempted to identify the main elements of JIT. However, there is little consensus among researchers regarding the relative importance of these elements in the JIT implementation process [10]. The potential synergic benefits are not fully realized until all elements of a JIT system are integrated [11].

Research has shown several benefits obtained by implementing JIT production. According to [12], JIT not only provide companies with great increases in quality of their manufactured goods, but also help a company to cut response time to market by as much as 90 percent. The most cited JIT benefit is cost reduction. Other benefits included: inventory reduction, increased quality and productivity levels, improved relationship with suppliers, improved customer service, reduced lead time, reduced work in process and raw materials, increased inventory turnover, downtime reduction, workspace reduction ([6], [13], [14], [15], [16], [17])

There are also barriers that may potentially impede successful implementation of JIT production. The absence of senior management commitment and support was the most frequently reported reason for JIT failure. Supplier education is an often neglected part of JIT implementation, and companies seeking to implement JIT fully would benefit greatly by addressing this issue [14]. One important barrier is local culture in countries other than Japan. Many researchers insisted on Japanese culture as one of the main reasons for JIT success in Japan [10]. Other barriers include lack of formal training/education for management and workers, and lack of cooperation with suppliers [18], obstacles to employee participation [19], schedules may be more complex because changeovers are frequent [20], and lack of accurate forecasting system [21].

Based on our literature review, we focus on the following dimensions of JIT:

1. *Equipment Layout*: Use of manufacturing cells, elimination of forklifts and long conveyers, and use of smaller equipment designed for flexible floor layout, all associated with JIT.
2. *JIT Delivery by Suppliers*: Whether vendors have been integrated into production in terms of using kanban containers, making frequent (or just-in-time) delivery and quality certification.
3. *Kanban/Pull System*: Whether or not the plant has implemented the physical elements of kanban/pull system.
4. *Setup Time Reduction*: Measures whether the plant is taking measures to reduce setup times and lower lot sizes in order to facilitate JIT.
5. *Repetitive Nature of Master Schedule*: Use of small lot sizes, mixed model assembly, and a level daily production schedule in the plant.

2.2 Total Productive Maintenance

The purpose of maintenance management is to reduce the adverse elects of breakdown and to maximize the production system availability at minimum cost [22]. TPM began in Japan in 1971 [23]. However, [24] indicated that it was introduced in the 1950s at General Electric Cooperation, and Later was further developed in Japan and re-imported in the West. TPM has been used by many companies; [25] asserted that most companies that have introduced TPM have been automobile or automobile-parts manufacturers. Although TPM has been traditionally associated with manufacturing, it has been proved extremely valuable for the service sector, including hotels, education and finance [26].

The word 'total' means total effectiveness, total maintenance system, and total participation of all employees [27]. The later is the most cited meaning, which includes autonomous maintenance by operators through small group activities. Maintenance is accomplished through a 'team' effort, with the operator being held responsible for the ultimate care of his/her equipment [23].The term maintenance embraces all the activities involved in keeping an entire production system or specific equipment within the system in working order [28]. While preventive maintenance involves a pattern of routine inspections and servicing to detect potential failure conditions and make minor adjustments or repairs which will help prevent major operating problems, breakdown maintenance usually is of an emergency nature, where facility and/or equipment are used until they fail to operate, and then are repaired, often at a premium cost [29].

As defined by the Japan institute of plant maintenance: "TPM aims at maximizing equipment effectiveness with a total system of preventive maintenance covering the entire life of the equipment involving everyone in all departments and at all levels, it motivates people for plant maintenance through small-group and voluntary activities" [25]. Example of western definitions of TPM if the definition of [30]: "The philosophy at the heart of the TPM process is that all the Assets on which production depends are kept always in Optimum Condition and Available for maximum output." According to Nakajima [31], there are eight pillars upon which TPM is built; focused improvement, autonomous maintenance, planned maintenance, training and education, quality maintenance, maintenance prevention, administrative TPM safety, and health and environment.

There are three major parts to TPM implementation; establishing a system in which everybody is personally involved in voluntary preventive maintenance activities; improving the maintenance crew's problem-solving skills and engaging in improvement activities aimed at zero breakdowns; and improving production-engineering capabilities in such areas as tools and dies, tool replacement time, tool design and defectives and repairs [25]. To measure TPM performance and effectiveness, overall equipment effectiveness (OEE) is often used, which measures six losses that TPM strives to eliminate; equipment failure, set-up and adjustment, speed losses, idling and minor stoppages, reduced speed, quality losses, defects in process, and reduced yield [24].

There are several benefits that are expected to be obtained by implementing TPM. [25] indicated that the main benefits include increase in labor productivity, decrease in number of equipment breakdowns, decrease in tool replacement time, increase in equipment operating ratio, decrease in cost of defectives, and increase in inventory turnover ratio.

There are also several factors that may potentially impede successful TPM implementation. [32] pointed some such factors as: Increasing daily rhythm of production, with the same team; Lack of time for the autonomous maintenance; one single operator commands more than one machine at the same time; Lack of personal training; Lack of follow-up of the progress of the program and its evaluation.[33] pointed out some other obstacles as the feeling of teams that there is no time for TPM; some workers may show no openness or willingness to learn.

Based on our literature review, we focus on the following dimensions of TPM:

1. *Autonomous Maintenance* : The involvement of workers in cleaning and inspecting their equipment, and their ability to detect and treat abnormal conditions of their equipment.
2. *Preventive Maintenance*: The use of diagnostic techniques to predict equipment lifespan, using technical analysis of major breakdowns, upgrading inferior equipment, and redesign equipment if necessary.
3. *Maintenance Support* : The availability of planned maintenance, maintenance standards plant-wide, and reliable maintence information systems.
4. *Team Based Maintenance*: The availability of cross-functional teams and small group problem solving to deal with equipment problems.

2.3 JIT and competitive performances

There are different measures to measure JIT performance and researchers did not agree on particular ones. [1] suggested that JIT performance can be measured by inventory turnover, cycle time, lead time, delivery performance, and other measures. [34] suggested fourteen variables to measure JIT performance such as: the extent of reduction of inventory due to JIT; the extent of reduction of rejects of finished goods due to JIT; the extent of improvement in on-time receipts from suppliers due to JIT; the extent of lead time reduction due to JIT, and the extent of improvement of relationship with suppliers due to JIT.

For our study, we focus on the following two dimensions to measure JIT performance:

1. Inventory turnover
2. Cycle time

There are also different ways to measure competitive performance. While reviewing the literature, we found that the most widely used measures are cost, quality, flexibility, and delivery (e.g. [35], [36], [37], [38], [39], [40]). In addition to theses measures, we include new product launch as a competitive performance measure. Finally, we use these five measures of competitive performance for our study as follows:

1. Cost: Unit cost of manufacturing
2. Quality: Conformance to product specifications.
3. Flexibility: Flexibility to change product mix.
4. Delivery: Fast delivery.
5. New product launch: On time new product launch.

3. Framework and research hypotheses

This research has been based on the proposed framework (Fig. 1). The framework considers the impact of TPM on JIT and the impact of both on JIT performance and competitive performance. We hypothesize that there is a significant positive impact of TPM on JIT implementation and development level. We also hypothesize that JIT has a positive impact on JIT and competitive performances, and the addition of TPM is expected to yield an additional incremental effect on both performances. We discuss our hypothesized relationships in this section.

The expected output of JIT implementation is not only shortened cycle time and increased inventory turnover ratio, but it is expected to affect overall plant competitiveness. As WIP inventories disappear and flow manufacturing is implemented, producing one piece at a time, it will be easy to find out any quality problems at the source and to achieve zero defects strategy. As a subsequent, cost is expected to decrease and delivery to become faster. The cells layout accompanied with the elimination of WIP inventories is expected to improve the flexibility of the plant to change volume and production mix. This situation is expected to facilitate plans to launch new products on time.

Several studies have shown that JIT is associated with higher competitive performance (e.g. [35], [42], [43], [44]). However, [39] have concluded that JIT practices have value only when they are used to build infrastructure, and have no direct effect on performance. [1] used hierarchical regression to test the impact of unique JIT variables on JIT performance (cycle time). They first entered the common infrastructure practices of JIT and TQM to the hierarchical regression and found that it has a strong positive relation with JIT performance. The addition of unique JIT variables to the common infrastructure variables led to further significant improvements in JIT performance. According to the existing literature, we have:

H1. JIT production significantly contributes to inventory turnover.
H2. JIT production significantly contributes to cycle time.
H3. JIT production significantly contributes to competitive performance of the plant.

The main purpose of JIT production is waste elimination. Inventory is regarded as the main source of waste; therefore plants reach the optimal level of JIT implementation when they achieve zero inventory policy. The challenge will be to adhere to daily schedules and to keep cycle time as short as possible. Failure in meeting daily schedules will cause delays in delivering customer orders and may lead to the appearance of work in process inventory again in the plant floor which may affect the competitive position of the company. In such environment, downtime of machines will cause a serious threat to smooth production; therefore implementing total productive maintenance practices company-wide is expected to enhance smooth production and to improve the inventory turnover ratio of the plant. Daily schedules are expected to be met by avoiding machines breakdown, JIT links with suppliers and customers are expected to be met by enhancing smooth production. Also, TPM practices are expected to ease the implementation of pull system/kanban by avoiding process stoppage due to machine breakdowns. One important performance dimension in JIT environment is cycle time, and TPM practices are expected to have a crucial effect in reducing cycle time by preventing sudden stoppage and failure of machines. As a subsequent, TPM practices are expected to improve the delivery performance of the company with its customers which is a natural output of implementing JIT system. TPM is expected to enhance the confidence of managers to increase JIT purchasing and production. [36] found a positive significant relationship between TPM and low cost, high levels of quality, and strong delivery performance.

Then, we have

H4. TPM practices significantly contribute to JIT implementation level.
H5a. TPM is positively related to inventory turnover.
H5b. The addition of TPM, given the impact of JIT production, will further improve inventory turnover.
H6a. TPM is positively related to cycle time.
H6b. The addition of TPM, given the impact of JIT production, will further improve cycle time.
H7a. TPM is positively related to competitive performance of the plant.
H7b. The addition of TPM, given the impact of JIT production, will further improve competitive performance of the plant.

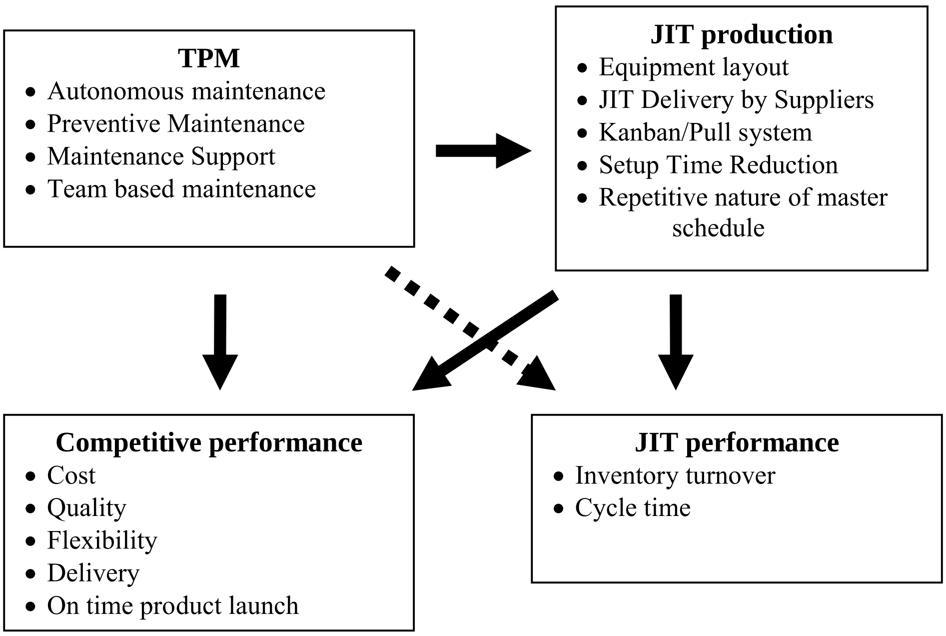

Fig.1. Research framework

4. Methodology

4.1 Description of data

The data used for this empirical research were collected as part of an ongoing High Performance Manufacturing (HPM) project (previously called world class manufacturing project (WCM)), round 3 being conducted by a team of researchers in ten countries: Japan, Korea, USA, Germany, Italy, Austria, Sweden, Finland, Spain, and UK. The HPM database was assembled in 2003 and 2004 and consists of randomly selected world-class and traditional manufacturing companies from three different industries; machinery, electrical & electronics and transportation. For this study, our sample comprised of 136 manufacturing plants located in Japan, USA, Germany, and Korea representing Asia Pacific, North America, and Europe. Table 1 shows the distribution of the plants used in this research classified by country and industry.

Table 1
Number of sample plants classified by country and industry

Country	Industry			Total
	Machinery	Electronics	Transportation	
Japan	10	12	13	35
USA	9	11	9	29
Germany	13	9	19	41
Korea	10	10	11	31
Total	42	42	52	136

The measurement instrument of this project was developed after conducting an extensive review of relevant literature by project members. The developed scales were reviewed by a panel of 3-5 experts to assure content validity, and the scales were revised as needed. The questionnaires were designed for various managers, supervisors, and direct workers, and pre-tested at several manufacturing plants and with academics for pilot testing, and was revised as needed. The original questionnaire was translated into each county's language by experts from those countries and then back translated to English to ensure equivalency.

The selected manufacturing companies were contacted personally by members of HPM in each country. The project members asked the executive in charge of manufacturing operations for the voluntary participation in the project. About 60% of contacted companies agreed to participate and assigned one plant manager to be responsible for data collection. Participating plants were promised to receive a comprehensive feedback concerning their managerial and operational practices compared to other plants. The right respondents in terms of experience, specialty, and knowledge were agreed upon between the team members and the assigned plant manager.

Then the questionnaires were completed by five direct workers, four supervisors, and ten managers who each received a different questionnaire, allowing respondents to address their particular area of expertise. In addition to that, multiple respondents were asked to complete each question in order to obtain greater reliability of the data and to eliminate potential respondent bias.

The items used to measure the different practices of JIT, TPM, JIT performance, and competitive performance can be found in appendixes A-D. For JIT and TPM questions, the respondents were asked to indicate their agreement or disagreement with the statements provided using seven-point Likert scales where 7 indicates strong agreement and 1 indicates strong disagreement. For JIT performance and competitive performance measures, respondents were asked to evaluate both performances relative to their competitors in the same industry on a global basis, using five point Likert scales where 5 indicates superior to competitors and 1 indicates poor, low end of industry.

4.2. Measurement analysis and research variables

As has been discussed earlier, five multi-item scales were selected to measure JIT production and four multi-item scales to measure TPM. To measure JIT performance, two non-scale items were selected, and five non-scale items were selected to measure competitive performance. Table 2 shows correlation matrix and summary of statistics of these measures.

To ensure that JIT and TPM scales are reliable indicators of their constructs, factor analysis was carried out. Only items that had a factor loading of at least 0.40 and eginevalue of at least 1 were retained (Table 3 and Table 4). Three JIT variables failed to meet this cutoff loading leaving a total of 24 variables constructing the five JIT constructs. Four TPM variables failed to meet the cutoff loading leaving a total of 17 variables constructing the four TPM constructs.

Cronbach's α coefficient was used to evaluate the reliability of the scales. Four JIT scales have met the recommended standard of $\alpha \geq 0.70$ and considered to be internally consistent [45]. The reliability of the fifth scale was $\alpha = 0.670$. Nunnally recommends a minimum standard of 0.60 for newly developed scales; therefore we decided to retain this scale.

The five JIT scales were averaged into a single overall JIT super scale. Factor analysis was carried out for the super scale and all the factor loadings were higher than 0.40 with eginevalue of 2.822 and Cronbach's α coefficient of 0.785 as shown in table 3. We also carried out a super scale of competitive performance. All factor loadings were higher than 0.40 with eginevalue of 2.313, and Cronbach's α coefficient of 0.700. The four TPM scales were also averaged into a single TPM super scale. The factor loadings were higher than 0.40 with eginevalue of 2.698 and Cronbach's α coefficient of 0. 836 as shown in table 4.

Table 2
Means, standard deviations, and correlations among variables[a]

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.Equipment layout	5.08	.65	1														
2.JIT Delivery by Suppliers	4.57	.71	.53**	1													
3.Kanban/pull system	3.86	.93	.46**	.51**	1												
4.Setup Time Reduction	4.84	.71	.51**	.56**	.36**	1											
5.Repetit. nature of M. sch.	4.36	.98	.27**	.58**	.27**	.40**	1										
6.Autonomous Maintenance	5.17	.54	.37**	.30**	.18*	.41**	.16	1									
7.Preventive Maintenance	4.86	.69	.53**	.54**	.33**	.66**	.36**	.46**	1								
8.Maintenance Support	4.71	.79	.48**	.51**	.32**	.66**	.34**	.43**	.68**	1							
9.Team Based Maintenance	4.89	.65	.59**	.57**	.38**	.61**	.30**	.42**	.70**	.63**	1						
10.Inventory turnover	3.47	.90	.21*	.22*	.13	.19*	.18*	.21*	.18*	.20*	.36**	1					
11. Cycle time	3.56	.73	.23*	.14	.17	.23*	.10	.23**	.20*	.09	.33**	.64**	1				
12.unit cost of manufacturing	3.27	.88	.17	.32**	.14	.39**	.21*	.31**	.36**	.30**	.43**	.46**	.43**	1			
13. Confor. to product speci.	3.86	.69	.17	.09	.03	.25**	.02	.23*	.25**	.27**	.19*	.16	.28**	.29**	1		
14. Flex. to change product mix	3.83	.80	.21*	.18*	.16	.20*	.13	.11	.17	.17	.27**	.21*	.30**	.22*	.31**	1	
15. fast delivery	3.99	.71	.41**	.26**	.17	.22*	-.05	.09	.22*	.24**	.25**	.25**	.27**	.25**	.33**	.37**	1
16. on time new product launch	3.55	.88	.32**	.25**	.151	.31**	.07	.30**	.33**	.38**	.35**	.34**	.38**	.36**	.44**	.18*	.44**

[a]N=136

*P ≤ 0.05

**P≤ 0.01

Table 3
Factor analysis: JIT scales

Variables	Descriptions	Initial factor loading	Revised factor loading	Reliability coefficient α	Eigenvalue	Proportion
	Equipment layout					
JSPLN02		0.739				
JSMHN01		0.543				
JSMHN05		0.484				
JSMHN06		0.773				
JSMHN07		0.781				
JSMHN08		0.662				
				α = 0.741	2.722	45.361%
	JIT Delivery by Suppliers					
JSVNN01		0.767				
JSVNN02		0.690				
JSVNN09		0.720				
JSVNN10		0.610				
JSVNN11		0.469				
				α = 0.670	2.174	43.488%
	Kanban/Pull system					
JSVNN03		0.740				
JSVNN04		0.749				
JSPLN06		0.805				
JSPLN07		0.831				
				α =0.789	2.449	61.228%
	Setup Time Reduction					
JSSUN01		0.699	0.715			
JSSUN02		0.618	0.580			
JSSUN04		0.610	deleted			
JSSUN05		0.741	0.792			
JSSUN07		0.763	0.816			
JSSUR08		0.610	0.581			
				α = 0.738	2.478	49.554%
	Repetitive Nature of Master Schedule					
JSMSN01		0.823	0.849			
JSMSN02		0.784	0.782			
JSMSN06		0.747	0.760			
JSMSN08		0.332	deleted			
JSMSN09		0.799	0.808			
JSMSR10		0.245	deleted			
				α = 0.813	2.563	64.066%
	JIT super scale					
JSMH		0.745				
JSVN		0.870				
JSPL		0.693				
JSSU		0.767				
JSMS		0.665				
				α = 0. 785	2.822	56.441%
	Competitive performance					
GRCPN 01		0.607				
GRCPN 02		0.716				
GRCPN 04		0.593				
GRCPN 06		0.723				
GRCPN11		0.747				
				α = 0.700	2.313	46.250%

Table 4
Factor analysis: TPM scales

Variables	Descriptions	Initial factor loading	Revised factor loading	Reliability coefficient α	Eigenvalue	Proportion
	Autonomous Maintenance					
MSAMN01		0.426	0.427			
MSAMN02		0.722	0.728			
MSAMN03		0.675	0.674			
MSAMR04		0.114	deleted			
MSAMN05		0.753	0.749			
MSAMN06		0.709	0.711			
				α =0.683	2.232	44.641%
	Preventive Maintenance					
MSPMN01		0709				
MSPMN02		0.554				
MSPMN03		0.730				
MSPMN04		0.763				
MSPMR05		0.550				
				α =0.681	2.229	44.577%
	Maintenance Support					
MSMSN01		0.704	0.722			
MSMSN02		0.550	0.536			
MSMSR03		-0.317	deleted			
MSMSN04		0.795	0.802			
MSMSN05		0.763	0.767			
				α = 0.672	2.042	51.039%
	Team Based Maintenance					
MSTMN01		0.662	0.730			
MSTMR02		-0.613	deleted			
MSTMN03		0.730	0.797			
MSTMN04		0.679	0.781			
MSTMR05		-0.556	deleted			
				α = 0.655	1.777	59.232%
	TPM super scale					
MSAM	0.675					
MSPM	0.885					
MSMS	0.853					
MSTM	0.855					
				α = 0. 836	2.698	67.443%

5. Results and discussion

We start our analysis by testing hypothesis H4, which stated that TPM practices significantly contribute to JIT implementation level. This hypothesis was tested by hierarchical regression analysis using JIT super scale as dependent variable (Table 5). In the first equation, we entered country and industry control variables; USA, Germany, Korea, Electronics, and Machinery. In the second equation we entered the control variables and TPM scales. The first equation shows that country and industry alone significantly contribute to the explanation of the variance in the level of JIT implementation and development ($R^2adj = 0.357$, $P < 0.01$). Part of this explanation was attributed to the industry effect as Machinery and Electronics have significantly lower levels of JIT implementation than Automobile industry. This seems to be logical as JIT production was initiated by Toyota Company and since then automobile companies were regarded as the most intensive users of JIT. Country in which the plant was located explained the other part of the variance of JIT implementation. The results show that Germany has significantly lower levels of JIT implementation ($P< 0.01$) than Japan, and Korea has significantly higher levels of JIT implementation ($P< 0.01$) than Japan. Although this finding might appear surprisingly as Japan is expected to have higher levels of JIT implementation, however, we should consider that many Korean and western manufacturers have paid a lot of attention on Japanese operational practices during the last two decades in a trial to catch up Japan in terms of high quality and low cost products and many of them have implemented JIT production in their plants.

The second equation shows that the addition of TPM practices explained a significant portion (29.3%) of the variance in JIT implementation level and development. Three of TPM practices, Preventive Maintenance, Maintenance Support, and Team Based Maintenance proved to be strongly significant and positively related to JIT implementation level. The fourth practice, Autonomous Maintenance was not significantly related. Obviousely, based on these results, we cannot conclude that autonomous maintenance should be ignored by managers because it didnot contribute positively to explain the variance in JIT implementation level. Autonomous maintenance has significant positive correlation with four practices of JIT, however, for our given sample, the regression analysis sorted out TPM strong and weak practices that contribute to the explanation of variance in JIT implementation level and autonomous maintenance was sorted out the less important compared to the other three. The results lead to a deduction that Preventive Maintenance, Maintenance Support, and Team Based Maintenance provide management with more confidence to increase the level of JIT production without worrying about equipment breakdowns and sudden stoppage of the production lines.

Table 5
Hierarchical regression analysis of JIT super scale

Variables	Model (1) Coefficient	Model (2) Coefficient
(Constant)	4.808***	1.780***
Machinery	-0.427***	-0.254***
Electronics	-0.242***	-0.246***
USA	0.063	0.087
Germany	-0.288***	-0.216***
Korea	0.322***	0.226***
MSAM		0.086
MSPM		0.210**
MSMS		0.189**
MSTM		0.208**
R^2	0.381	0.673
Adj. R^2	0.357	0.650
F	15.986***	28.861***
Change in R^2		0.293
F change	15.986***	28.219***

* $P\leq 0.1$.
** $P\leq 0.05$.
*** $P\leq 0.01$.

To test hypotheses H1, H5a and H5b we use hierarchical regression analysis with inventory turnover as dependent variable (Table 6). In the first equation, we entered country and industry control variables. In the second equation, we added JIT super scale into the model. In the third equation, we added TPM super scale into the model so that we can measure the incremental impact of TPM on inventory turnover given the impact of the control variables and JIT production. In equation (2'), we entered TPM super scale into the equation after controlling for country and industry to test the direct impact of TPM on inventory turnover not given the effect of JIT. The first equation shows that country and industry alone did not contribute to the explanation of the variance of inventory turnover. The second equation shows that the addition of JIT explained a significant portion (8.1%) of the variance in inventory turnover among responding plants. The third equation shows that the addition of TPM explained an additional significant portion (3.4%) of the variance in inventory turnover among responding plants. Equation (2') shows that TPM after controlling for country and industry effect explained 10.8% of the variance in inventory turnover among the responding plants. Hypotheses H1, H5a and H5b have been supported.

Table 6
Hierarchical regression analysis of Inventory turnover

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (2')
(Constant)	3.463***	.882	.235	.590
Machinery	-.020	.118	.095	.058
Electronics	-.168	-.077	-.140	-.179
USA	.095	.082	.115	.128
Germany	.066	.163	.132	.101
Korea	.082	-.027	-.010	.019
JIT		.351***	.141	
TPM			.268**	.352***
R^2	.034	.116	.149	.142
Adj. R^2	-.008	.068	.096	.096
F	.804	2.441**	2.782**	3.095***
Change in R^2		.081	.034	.108
F change	.804	10.294***	4.385**	14.081***

* P≤ 0.1.
** P≤ 0.05.
*** P≤ 0.01.

Next, we test hypotheses H2, H6a and H6b. We use hierarchical regression analysis with cycle time as dependent variable (Table 7). In the first equation, we entered country and industry control variables, the first equation shows that country and industry alone did not contribute to the explanation of the variance of cycle time. In the second equation, we added JIT super scale into the model. The second equation shows that the addition of JIT explained a significant portion (11.3%) of the variance in inventory turnover among responding plants. In the third equation, we added TPM super scale into the model so that we can measure the incremental impact of TPM on cycle time given the impact of the control variables and JIT production. Although there was a slight increase in R^2, it was not significant, therefore the results failed to support the hypothesis concerning the incremental improvement of cycle time after the addition of TPM. In equation (2'), we entered TPM super scale into the equation to test the direct impact of TPM on inventory turnover after controlling for country and industry. The results show that TPM explained a significant portion of 8.2% of the variance in inventory turnover among the plants.
Hypotheses H2 and H6a have been supported, while hypothesis H6b has been rejected.

To test hypotheses H3, H7a and H7b concerning the impact of JIT and TPM on the competitive performance of the plant, we use again hierarchical regression analysis with competitive performance as dependent variable (Table 8). Similar to pervious regressions, we entered country and industry control variables in the first equation. The results show that country and industry alone did not contribute to the explanation of the variance of competitive performance. In the second equation, we added JIT super scale into the model. The results show that JIT explained a significant portion (21.4%) of the variance in competitive performance among responding plants. In the third equation, we added TPM super scale into the model so that we can measure the incremental impact of TPM on

Table 7
Hierarchical regression analysis of Cycle time

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (2')
(Constant)	3.560***	1.104*	.888	1.549**
Machinery	.048	.215**	.207*	.124
Electronics	-.018	.092	.067	-.021
USA	-.057	-.068	-.051	-.019
Germany	.037	.156	.145	.076
Korea	-.027	-.152	-.143	-.075
JIT		.415***	.325**	
TPM			.115	.308***
R^2	.010	.123	.129	.092
Adj. R^2	-.034	.076	.074	.043
F	.220	2.616***	2.349***	1.891*
Change in R^2		.113	.006	.082
F change	.220	14.465***	.778	10.157***

* P≤ 0.1. ** P≤ 0.05. *** P≤ 0.01.

competitive performance given the impact of the control variables and JIT production. The results show that the addition of TPM resulted in an additional significant explanation (8%) of the variance in competitive performance. Equation (2') shows that TPM after controlling for country and industry effect explained 27.3% of the variance in competitive performance among the responding plants.

All in all, hypotheses H3, H7a, and H7b have been supported.

Table 8
Hierarchical regression analysis of competitive performance

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (2')
(Constant)	3.801***	1.294***	.714	1.091**
Machinery	-.065	.169*	.135	.069
Electronics	-.085	.066	-.024	-.091
USA	-.047	-.064	-.006	.018
Germany	-.021	.144	.104	.051
Korea	-.081	-.251**	-.221**	-.170*
JIT		.570***	.247*	
TPM			.413***	.560***
R^2	.013	.227	.307	.285
Adj. R^2	-.030	.186	.264	.248
F	.295	5.581***	7.145***	7.581***
Change in R^2		.214	.080	.273
F change	.295	31.617***	13.005***	43.469***

* P≤ 0.1.
** P≤ 0.05.
*** P≤ 0.01.

To further investigate the relationship between JIT, TPM and competitive performance, we performed additional analysis to test the impact of JIT and TPM on individual competitive performance measures (Table 9). We conducted hierarchical regression analysis separately for each competitive performance measure as a dependent variable. In a similar way to previous regressions, we entered country and industry control variables into the first equation. The results showed that country and industry alone did not significantly contribute to the explanation of the variance of the individual measures of competitive performance; therefore we did not report them in Table 9. In the second equation, we entered JIT super scale into each model. In the third equation, we added TPM super scale into each model so that we can measure the incremental impact of TPM on each individual measure of competitive performance given the impact of the control variables and JIT production. The results show that the addition of JIT explained a significant portion of the variance for each individual measure of competitive performance. The addition of TPM into the models in the third equation resulted of an additional significant increase of R^2 for three measures of competitive performance- Unit cost of manufacturing (4.4%), Conformance to product specifications (4.6%), and On time product launch (7.4%). Equation (2') shows that not given the effect of JIT, TPM significantly explained a significant portion of the variance for all the individual measures of competitive performance.

Table 9
Hierarchical regression analysis of individual competitive performance measures.

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (2')
Dependent variable: Unit cost of manufacturing				
JIT		.418***	.178	
TPM			.306**	.411***
R^2	.044	.158	.201	.190
Adj. R^2	.002	.113	.152	.147
F	1.040	3.522***	4.036***	4.426***
Change in R^2		.114	.044	.147
F change	1.040	15.279***	6.157**	20.470***
Dependent variable: Conformance to product specifications				
JIT		.340***	.094	
TPM			.315**	.370***
R^2	.081	.157	.204	.201
Adj. R^2	.041	.113	.154	.159
F	2.034*	3.550***	4.130***	4.767***
Change in R^2		.076	.046	.119
F change	2.034*	10.311***	6.565**	17.020***
Dependent variable: Fast delivery				
JIT		.269**	.129	
TPM			.179	.255***
R^2	.052	.099	.114	.108
Adj. R^2	.010	.052	.059	.010
F	1.250	2.093*	2.080*	2.306**
Change in R^2		.048	.015	.057
F change	1.250	6.034**	1.905	7.250***
Dependent variable: Flexibility to change volume				
JIT		.442***	.311**	
TPM			.167	.352***
R^2	.054	.183	.196	.162
Adj. R^2	.013	.140	.146	.117
F	1.312	4.251***	3.933***	3.663***
Change in R^2		.129	.013	.108
F change	1.312	17.980***	1.838	14.641***
Dependent variable: On time product launch				
JIT		.473***	.159	
TPM			.399***	.494***
R^2	.007	.154	.228	.219
Adj. R^2	-.037	.109	.180	.177
F	.159	3.425***	4.722***	5.279***
Change in R^2		.147	.074	.212
F change	.159	19.627***	10.730***	30.675***

* P≤ 0.1.
** P≤ 0.05.
*** P≤ 0.01.

6. Conclusions

Based on our study, the following conclusions are drawn. First, country and industry alone explained a significant portion of variation in JIT implementation level. As for industry, the results showed that the automobile industry has higher levels of JIT implementation and significantly differs from electronics and machinery industries. Germany showed lower levels of JIT implementation compared to Japan while Korea showed higher levels. This provides us with evidence to deduce that JIT production is not any more a unique Japanese production strategy, other plants outside Japan can successfully implement it and even outperform their Japanese counterparts. Country and industry alone did not explain significant portion of variance for all the measures of JIT and competitive performance. This implies that performance depends on manufacturing and managerial capabilities and strategies which are the pillars of superior performance regardless of the industry or country the plant belongs to.

Second, this study emphasized that JIT production has a positive and significant impact on JIT performance measures- inventory turnover and cycle time. Also, JIT production showed positive and significant impact on competitive performance super scale as well as on each individual measure of competitive performance. This provides guidance for managers considering or attempting to implement of JIT production which is highly associated with performance.

Third, the results showed that TPM has a direct positive and significant impact on all the measures of JIT and competitive performances after controlling for country and industry effect. In addition to that, the addition of TPM, given the effect of country & industry and JIT production, resulted in an additional significant impact on inventory turnover, cost, quality, and on time product launch. This implies that TPM should be considered as one of the main pillars for plants implementing JIT production to improve the performance, as JIT production alone cannot yield superior performance results. For plants not implementing JIT production, TPM should be considered as a strategic competing tool to improve overall plant performance.

Fourth, the results indicated that TPM significantly affects and facilitates the implementation level of JIT production. As the burden of sudden machine breakdown is decreased, the level of JIT implementation is increased.
The limitation of our study is that, as in other empirical research in operations management, the measurement scales of JIT and TPM used for our research may not capture all the practices implemented by the surveyed plants.

Similar research should be undertaken for less developed countries. Also, further research is needed with a larger sample and additional industries so that casual modeling techniques of analysis could be applied. Finally, further research is needed to investigate how TPM affects other operational practices and employee involvement.

References

[1] Flynn B., sakakibara, S., Schroeder R., 1995. Relationship between JIT and TQM: Practices and performance. Academy of management Journal. Vol. 38, No. 5, pp.1325-1360.

[2] Cheng, T. C. E. and Podolsky, S., 1996. Just-in-time manufacturing, An Introduction. London: Chapman & Hall.

[3] Monden Yasuhiro, 1983. Toyota Production System. Industrial Engineering and Management Press, Norcross, Georgia.

[4] Liker, J., 2004. The Toyota Way: 14 management principles from the world's greatest manufacturer. New York: McGraw-Hill.

[5] Womack,J., Jones,D., and Roos, D., 1990. The machine that changed the world: based on the Massachusetts Institute of Technology 5-million dollar 5-year study on the future of the automobile. New York: Rawson Associates.

[6] Imai, M., 1997. Gemba Kaizen: A commonsense, low-cost approach to management. New York: McGraw-Hill.

[7] Taylor, D. and Brunt, D., 2001. Manufacturing operations and supply chain management: the lean approach. London: Thomson Learning.

[8] Hallihan, A., Sackett, P. and Williams, G. M., 1997. JIT manufacturing: the evolution to an implementation model founded in current practice. International Journal of Production Research, vol. 35, No. 4, pp. 901-920.

[9] Voss, C.A. and Robinson, S.J., 1987. Application of Just-in-time manufacturing techniques in the UK. International Journal of Operations and Production management, 7(4), 46-52.

[10] Ramarapu, N.K., Mehra, S. and Frolick, M.N., 1995. A comparative analysis and review of JIT implementation research. International Journal of Operations & production management; Vol. 15, No. 1, pp.38-49.

[11] Goyal SK, Deshmukh SG., 1992 A critique of the literature on just-in-time manufacturing. International Journal of Operations and Production Management, 12(1): 18-28.

[12] Hay, E. (1988*).* The just-in-time breakthrough: implementing the new manufacturing basics. New York: Wiley.

[13] Mehra, S., Inman, R., 1992. "Determining the critical elements of just-in-time implementation", Decision Sciences; 23, 1; pg. 160.

[14] Sohal Amrik, Ramsay Liz, Samson Danny, 1993. JIT manufacturing:Industry analysis and a methodology for implementation. International Journal of Operations and Production Management, Vol.13, Iss. 7, 22-35.

[15] Markham, I. S. and McCart, C. D., 1995. "The road to successful implementation of Just-In-Time systems", production and inventory management journal; 36, 3; pg.67.

[16] Yasin, M. and Wafa, M., 1996. "An empirical examination of factors influencing JIT success", International Journal of Operations & production management; Vol. 16, Iss. 1; pg. 19.

[17] Sriparavastu, L. and Gupta, T., 1997. "An empirical study of just-in-time and total quality management principles implementation in manufacturing firms in the USA", International Journal of Operations & production management; Vol. 17, Iss. 12; pg. 1215.

[18] Salaheldin, I. S., 2005. JIT implementation in Egyptian manufacturing firms: some empirical evidence. International Journal of operations & Production Management, Vol. 25, No. 4, pp.354-370.

[19] Lawrence, J. J. and Lewis, H. S., 1996. "Understanding the use of just-in-time purchasing in a developing country the case of Mexico", International Journal of operations & Production Management; Vol. 16, Iss. 6; pg. 68.

[20] Brown, K. and Mitchell, R., 1991. "A comparison of Just-in-Time and Batch Manufacturing: The Role of Performance Obstacles", The Academy of Manufacturing Journal, Vol.34, No. 4.

[21] Wafa, M. A. and Yasin, M. M., 1998. "A conceptual framework for effective implementation of JIT An empirical investigation", International Journal of operations & Production Management; Vol. 18, Iss. 11; pg. 1111.

[22] Lofsten Hans, 2000.Measuring maintenance performance- in search for a maintenance productivity index .Int. J. Production Economics 63, 47-8.

[23] Chan, F.T.S; Lau, H.C.W; Ip, R.W.L; Chan, H.K.; Kong, S., 2005. Implementation of total productive maintenance: A case study. Int. J. Production Economics 95, 71–94.

[24] Waeyenbergh Geert and Pintelon Liliane, 2002.A framework for maintenance concept development. Int. J. Production Economics 77, 299–313.

[25] Imai Masaaki, 1986. KAIZEN-the key to Japan's competitive success. Random House Business Division, New York. 1st edition.

[26] Al-Hassan Khalid, Fat-Lam Chan Joseph, Metcalfe Viggo Andrew. The role of total productive maintenance in business excellence. Total Quality Management, Vol. 11, NOS. 4/5&6, 2000, 596-601.

[27] Nakajima, S., 1988. Introduction to Total Productive Maintenance (TPM). Productivity Press, Cambridge.

[28] Garrett Leonard and Silver Milton, 1973. Production Management Analysis. Harcourt Brace Jovanovich inc.

[29] Monks Joseph, 1977. Operations management: theory and problems. McGraw-Hill Book Company. 1st edition.

[30] Willmott Peter, 1994. Total Productive Maintenance. Butterworth-Heinemann Ltd.p.2.

[31] Nakajima, 1989. TPM Development Program: Implementing Total Productive Maintenance. Productivity Press Inc.

[32] Rodrigues Marcelo and Hatakeyama Kazuo, 2006. Analysis of the fall of TPM in companies. Journal of Materials Processing Technology 179, 276–279.

[33] Lycke Liselott, 2003. Team development when implementing TPM. Total Quality Management, Vol. 14, No. 2, 205–213.

[34] Yasin, MM. and Small, M., 1997. An Empirical Investigation of JIT Effectiveness: an organizational perspective. International Journal of management Science, Vol. 25, No. 4, pp.461-471.

[35] Cua, K., McKone, K., Schroeder R., 2001. Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. Journal of Operations Management 19, 675-694.

[36] McKone K., Schroeder R., Cua K., 2001. The impact of total productive maintenance on manufacturing performance. Journal of Operations Management 19, 39-58.

[37] Ward Peter, Duray Rebecca, Leong, Keong, Sum, Chee-Chuong, 1995. Business environment, operations strategy, and performance: An empirical study of Singapore manufacturers. Journal of Operations management 13, 99-115.

[38] Hayes, R. and Wheelwright S., 1984. Restoring our competitive edge: competing through manufacturing. Wily, New York.

[39] Sakakibara Sadoa, Flynn Barbara B., Schroeder Roger G. and Morris William T., 1997. The Impact of Just-in-time Manufacturing and its Infrastructure on manufacturing Performance. Management Science, Vol. 43, No. 9, September.

[40] Hill T., 1989. Manufacturing strategy Text and Cases. Irwin, Homewood, IL.

[41] Ahmad Sohel and Schroeder Roger, 2003. The impact of human resource management practices on operational performance: recognizing country and industry differences. Journal of Operations Management 21, 19-43.

[42] Huson, M., Nanda, D., 1995. The impact pf Just-In-Time manufacturing on firm performance in the US. Journal of Operations Management 12, 297-310.

[43] Lawrence J., Hottenstein, M., 1995. The relationship between JIT manufacturing and performance in Mexican plants affiliated with U.S. companies. Journal of Operations management 13, 3-18.

[44] Fullerton Rosemary and McWatters Cherly, 2002. The role of performance measures and incentive systems in relation to the degree of JIT implementation. Accounting, Organization and Society 27, 711-735.

[45] Nunnally, J., 1967. Psychometric theory. McGraw Hill, New York. pp. 245.

Appendix A
Measures of JIT practices

Equipment Layout

JSPLN02	We have laid out the shop floor so that processes and machines are in close proximity to each other.
JSMHN01	We have organized our plant floor into manufacturing cells.
JSMHN05	Our machines are grouped according to the product family to which they are dedicated.
JSMHN06	The layout of our shop floor facilitates low inventories and fast throughput.
JSMHN07	Our processes are located close together, so that material handling and part storage are minimized.
JSMHN08	We have located our machines to support JIT production flow.

Just-in-Time Delivery by Suppliers

JSVNN01	Our suppliers deliver to us on a just-in-time basis.
JSVNN02	We receive daily shipments from most suppliers.
JSVNN09	We can depend upon on-time delivery from our suppliers.
JSVNN10	Our suppliers are linked with us by a pull system.
JSVNN11	Suppliers frequently deliver materials to us.

Kanban

JSVNN03	Suppliers fill our kanban containers, rather than filling purchase orders.
JSVNN04	Our suppliers deliver to us in kanban containers, without the use of separate packaging.
JSPLN06	We use a kanban pull system for production control.
JSPLN07	We use kanban squares, containers or signals for production control.

Setup Time Reduction

JSSUN01	We are aggressively working to lower setup times in our plant.
JSSUN02	We have converted most of our setup time to external time, while the machine is running.
JSSUN04	We have low setup times of equipment in our plant*.
JSSUN05	Our crews practice setups, in order to reduce the time required.
JSSUN07	Our workers are trained to reduce setup time.
JSSUR08	Our setup times seem hopelessly long.

Repetitive Nature of Master Schedule

JSMSN01	Our master schedule repeats the same mix of products, from hour to hour and day to day.
JSMSN02	The master schedule is level-loaded in our plant, from day to day.
JSMSN06	A fixed sequence of items is repeated throughout our master schedule.
JSMSN08	Within our schedule, the mix of items is designed to be similar to the forecasted demand mix*.
JSMSN09	We use a repetitive master schedule from day to day.
JSMSR10	Our master schedule does not facilitate JIT production*.

Appendix B
Measures of TPM

Autonomous Maintenance
(Based on Nakajima)

MSAMN01	Cleaning of equipment by operators is critical to its performance.
MSAMN02	Operators understand the cause and effect of equipment deterioration.
MSAMN03	Basic cleaning and lubrication of equipment is done by operators.
MSAMR04	Production leaders, rather than operators, inspect and monitor equipment performance*.
MSAMN05	Operators inspect and monitor the performance of their own equipment.
MSAMN06	Operators are able to detect and treat abnormal operating conditions of their equipment.

Preventive Maintenance
(Based on Nakajima)

MSPMN01 We upgrade inferior equipment, in order to prevent equipment problems.
MSPMN02 In order to improve equipment performance, we sometimes redesign equipment.
MSPMN03 We estimate the lifespan of our equipment, so that repair or replacement can be planned.
MSPMN04 We use equipment diagnostic techniques to predict equipment lifespan.
MSPMR05 We do not conduct technical analysis of major breakdowns.

Maintenance Support

MSMSN01 Our production scheduling systems incorporate planned maintenance.
MSMSN02 Spare parts for maintenance are managed centrally.
MSMSR03 Each of our plants establishes its own maintenance standards*.
MSMSN04 Equipment performance is tracked by our information systems.
MSMSN05 Maintenance personnel solve most maintenance problems by themselves

Team Based Maintenance
MSTMN01 We find that equipment performance is improved by the work of cross-functional teams.
MSTMR02 Our maintenance teams are comprised of specialized maintenance personnel*.
MSTMN03 In the past, many equipment problems have been solved through small group sessions.
MSTMN04 Groups are formed to solve current equipment problems.
MSTMR05 Maintenance personnel solve most maintenance problems by themselves*.

Appendix C
JIT Performance Scales

Please circle the number that indicates your opinion about how your plant compares to its competition in your industry, on a global basis.
1: Poor, low end of industry; 2: Equivalent to competitors; 3: Average; 4: Better than average; 5: Superior

Inventory turnover	1	2	3	4	5
Cycle time (from raw materials to delivery)	1	2	3	4	5

Appendix D
Competitive Performance Scales

Please circle the number that indicates your opinion about how your plant compares to its competition in your industry, on a global basis.
1: Poor, low end of industry; 2: Equivalent to competitors; 3: Average; 4: Better than average; 5: Superior

Unit cost of manufacturing	1	2	3	4	5
Conformance to product specifications	1	2	3	4	5
Fast delivery	1	2	3	4	5
Flexibility to change volume	1	2	3	4	5
On time new product launch	1	2	3	4	5