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Total productive maintenance: a contextual view

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Abstract

While Total Productive Maintenance (TPM) has been promoted for its simplicity and its benefits to the maintenance delivery system, both the academic and practitioner literature has failed to identify the contextual issues that influence TPM adoption. This paper explores the contextual differences of plants to better understand what types of companies have adopted TPM programs. We propose a theoretical framework for understanding the use of TPM and how it depends on managerial factors such as Just-in-Time (JIT), Total Quality Management (TQM) and Employee Involvement (EI) as well as environmental and organizational factors such as country, industry and company characteristics. We test this framework using data from 97 plants in three different countries to determine what types of companies are most likely to aggressively pursue TPM practices. We find that specific contextual variables explain a significant portion of the variance in the level of TPM implementation. Our results indicate that while environmental contextual factors, such as country, help to explain differences in TPM implementation, managerial contextual factors, which are under the direction of plant management, are more important to the execution of TPM programs. We discuss environmental, organizational and managerial issues that should be considered when developing or improving maintenance systems. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Manufacturers have realized the need to continuously improve their operations to compete successfully. In an effort to increase organizational capabilities, companies have made investments in programs such as Just-in-Time (JIT) and Total Quality Management (TQM). However, benefits from these programs have often been limited because of unreliable or inflexible equipment (Garwood, 1990; Tajiri and Gotoh, 1992). Therefore, many companies, including Procter and Gamble, Dupont, Ford and Eastman Chemical, have looked toward Total Productive Maintenance (TPM) to augment their JIT and TQM programs in a drive for continual improvement. TPM addresses equipment maintenance through a comprehensive productive-maintenance delivery system covering the entire life of the equipment and involving all employees from production and maintenance personnel to top management.

Although there are numerous books and case studies that exalt the benefits of TPM (Nakajima,

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1988; Garwood, 1990; Suzuki, 1992; Tsuchiya, 1992; Koelsch, 1993; Steinbacher and Steinbacher, 1993), some companies have decided that this approach to maintenance will not work for their company (Patterson et al., 1995). While TPM does appear to offer an improvement to traditional maintenance practices, companies' concerns about the applicability of TPM to all operating environments are legitimate. The operations field has long been criticized for trying to apply the latest technique to every situation. It is important that new programs are studied in more detail to understand in which situations they are actually used to support manufacturers' improvement efforts.

We hypothesize that there are significant differences in the level of TPM development and implementation that can be explained by environmental, organizational and managerial factors. This paper explores those differences in order to better understand which companies do attempt to adopt TPM.

The paper is organized as follows. In Section 2, we review the literature that has focused on TPM. In Section 3, we discuss our theories on TPM and how it is influenced by the environmental, organizational and managerial context of the plant. In Section 4, we describe the details of the database used for the study. Then we discuss our measurement approach in Section 5. In Section 6, we present our analysis and discuss the results. Finally we present the conclusions from our analysis and suggest areas for future research.

2. Review of the TPM literature

While research that considers the mathematical modeling and statistical research base of equipment-maintenance has been extensive, little research has directly investigated TPM maintenance activities. Refer to McCall (1965), Pierskalla and Voelker (1976), Valdez-Flores and Feldman (1989), Shaked and Shanthikumar (1990) and Bain and Engelhardt (1991) for reviews of the maintenance and reliability literature. These papers focus on modeling the reliability of equipment and on developing policies to inspect, repair, or replace equipment based on its specific reliability characteristics. We are interested in academic research that goes beyond these traditional modeling approaches and adequately supports the implementation of TPM activities, practices, and management systems. McKone and Weiss (1995) identify significant gaps between industry practice and academic research and emphasize the need to bridge these gaps by providing guidelines for implementing TPM activities.

Our search of leading production and operations management academic journals [1] resulted in few articles that specifically address TPM. In contrast, trade-journals, such as Plant Engineering and Pulp and Paper, have a multitude of articles that briefly describe TPM programs at specific sites. These short descriptions provide little help in determining the most effective TPM activities and implementation plans or in explaining what type of companies have adopted TPM.

In the following review, we highlight the articles and books that provide the best descriptions of TPM and aid in the implementation process. Seiichi Nakajima, vice-chairman of the Japanese Institute of Plant Engineers (JIPE), the predecessor of the Japan Institute of Plant Maintenance (JIPM), promoted TPM throughout Japan and has become known as the father of TPM. In 1971, TPM was defined by JIPE as follows:

> TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities. (Tsuchiya, 1992, p. 4)

TPM provides a comprehensive company-wide approach to maintenance management which is usu-

[1] The authors searched through the ABI database. They focused their search efforts in academic articles such as Management Science, Operations Research, Production and Operations Management, Journal of Operations Management, Naval Research Logistics Quarterly and IIE Transactions rather than on trade journals.

ally divided into short-term and long-term elements. In the short-term, attention is focused on an autonomous maintenance program for the production department, a planned maintenance program for the maintenance department, and skill development for operations and maintenance personnel. In the long-term, efforts focus on new equipment design and elimination of sources of lost equipment time. In this paper we concentrate on the short-term maintenance efforts that could be normally found at the plant level of the organization. These autonomous and planned maintenance programs will be discussed in more detail in Section 3.

Numerous books on TPM have presented TPM improvement activities in plants and suggested steps for TPM implementation based on case studies (Hartmann, 1992; Suzuki, 1992; Tsuchiya, 1992, Chapter 4; Tajiri and Gotoh, 1992; Varughese, 1993; Steinbacher and Steinbacher, 1993, Chapter 15; Shimbun, 1995). Thilander (1992), however, has studied the benefits of different organizational aspects of TPM in two Swedish firms. The study shows the positive influence on productivity of having well-defined areas of responsibility, of appointing one individual who holds the overall responsibility for the maintenance of a machine line, and of establishing direct contact between the operators and maintenance technicians.

Hartmann (1992) specified many differences between TPM in Japan vs. the United States. He emphasized the need to customize the TPM process to work for the specific manager, in the specific environment, with the specific people. Hartmann indicates that there are country, plant, and management specific aspects of TPM implementation. Our study follows Hartmann's suggestions by empirically investigating the contextual issues that explain differences in a variety of dimensions of TPM implementation. Our study is the first, to our knowledge, that has taken this contextual view of TPM.

3. Definition of the framework

We now describe the framework which we use to study contextual issues and their relationship to the implementation of various TPM activities. We consider environmental, organizational, and managerial contextual factors that could be expected to affect the autonomous or planned maintenance activities. Details of data collection and measurement issues will be discussed in Sections 4 and 5.

3.1. TPM elements

In this paper we concentrate on the short-term maintenance efforts that could be normally found at the plant level of the organization. These short-term TPM efforts include both autonomous and planned maintenance activities. We have chosen to concentrate on short-term efforts for two reasons: (1) typically early TPM efforts begin with short-term efforts and (2) this is not a longitudinal study and cannot evaluate the long-term efforts well. We have defined seven elements of TPM that will be considered in the paper—four elements of autonomous maintenance and three elements of planned maintenance. These elements have been selected based on a review of the TPM literature.

Autonomous maintenance can best be defined by considering the four main goals of the TPM program. First, the program brings production and maintenance people together in *teams* to stabilize conditions and halt deterioration of equipment (Nakajima, 1988, p. 59; Suzuki, 1992, p. 88). Second, by effectively developing and sharing responsibility for the critical daily maintenance tasks, production and maintenance people are able to improve the overall health of the equipment. Through autonomous maintenance, operators learn to carry out important daily tasks that maintenance people rarely have time to perform. These '*housekeeping*' tasks include cleaning and inspecting, lubrication, precision checks, and other light maintenance tasks and can be broken down into five S's—seiri (organization), seiton (tidiness), seiso (purity), seiketsu (cleanliness), and shitsuke (discipline) (Nakajima, 1988, p. 73; Tajiri and Gotoh, 1992, p. 20, p. 55; Suzuki, 1992, p. 95). After these tasks are transitioned to operators, maintenance people can focus on developing and implementing other proactive maintenance plans. Third, TPM is designed to help operators learn more about how their equipment functions, what common problems can occur and why, and how those problems can be prevented through early detection and treatment of abnormal conditions. This *cross-training* allows operators to maintain equipment and to identify and resolve many basic equipment problems (Nakajima, 1988, pp. 73, 90; Suzuki, 1992, pp. 119–123; Tajiri and Gotoh, 1992, pp. 25, 53). Fourth, the TPM program promotes *operator involvement* by preparing operators to become active partners with maintenance and engineering personnel in improving the overall performance and reliability of the equipment (Tajiri and Gotoh, 1992, pp. 20, 53). To achieve the goals of autonomous maintenance, it is clear the program must involve teams of production and maintenance people, daily activities to maintain the condition of the equipment, cross-training to improve operator skills, and participation of operating personnel in the maintenance delivery process.

Planned maintenance typically involves the work conducted by highly skilled maintenance technicians. As more tasks are transferred to operators through autonomous maintenance, the maintenance department takes a more proactive approach to maintenance and is able to develop a *disciplined planning* process for maintenance tasks, such as equipment repair/replacement, and on determining countermeasures for equipment design weakness (Nakajima, 1988, p. 87; Suzuki, 1992, p. 160). Typically, strong planning departments also have good *information tracking* systems that enable them to capture the process data, gather and disseminate data to operators, and identify trends or problems with equipment (Suzuki, 1992, p. 172). Maintenance technicians are held accountable for completing maintenance tasks within a scheduled time-frame while still meeting production requirements. *Schedule compliance* is an important indicator of the health of the planned maintenance system (Nakajima, 1988, p. 87).

Throughout this paper we will refer to these seven elements of TPM: four elements of autonomous maintenance—*teams* of production and maintenance personnel, *housekeeping* on the production line, *cross-training* of operators to perform maintenance tasks, and *operator involvement* in the maintenance delivery system; and three elements of planned maintenance—*disciplined planning* of maintenance tasks, *information tracking* of equipment and process condition and plans, and *schedule compliance* to the maintenance plan.

3.2. Contextual factors

Our motivation for studying contextual issues that help describe the development of TPM factors can be explained relative to two streams of research. Both research streams deviate from early theories that suggested that there was one universal approach to management for all organizations. Instead, the research indicates that the environment in which an organization exists and the characteristics of the organization help to specify the best management approach for that organization.

The first research stream is exemplified in the organization and environmental perspective of Lawrence and Lorsch (1967) and is also supported by others, including Thompson (1967), Lawrence (1981), Van de Ven and Drazin (1985) and Gresov and Drazin (1997). Lawrence and Lorsch place the organization in the context of its environment and recognize that an organization must interact with its environment, obtain resources from it, and transform them into products in order to survive. It is clear that not all organizations face the same environment; the environment of an organization differs in its degree of complexity. For example, Lawrence (1981) indicates that a particular industry (at a specified point in time) can be characterized by its resource constraints and its strategic uncertainty. An organization must adapt to its industry characteristics in order to be competitive in its environment. Similarly, the country in which an organization operates can constrain or enable an organization through such things as the resources that it provides and/or government support and restrictions of businesses. To investigate the environmental contextual factors that impact TPM implementation levels, we have considered two factors—country and industry—to help define the environment of the organization.

The second research stream that we consider takes a more micro perspective of the organization. Campbell (1974, 1990) presented the concept of a nested organizational hierarchy, where higher levels of an organization inhibit or enable lower levels of an organization. This theory suggests that a program at the plant level, such as TPM, may be influenced by the larger organization or company in which it operates. This theory has been considered and popularized more recently by Senge (1990) with regard to the learning organization. Senge confronts ''the illusion that the world is created of separate, unrelated forces'' and encourages organizations to understand the connection of tasks and departments to a larger system. These theories suggest that TPM programs can be hindered or enabled by the organization in which it is being implemented. Therefore, we explore factors, such as company size, unionization, plant age, equipment age, and equipment type, that help define the organization and the plant more specifically.

While both environmental and organizational contextual measures may be important to TPM, factors that explain the type of management system internal to the plant may also be important to TPM. In particular, Schonberger (1986) argues that JIT, TQM, EI and TPM are critical components of World Class Manufacturing. Therefore, it is believed that companies that have implemented other 'world class' manufacturing programs would be more likely to implement TPM or vice versa. In line with system thinking, TPM is not isolated from these other programs and should be considered with respect to the other management practices. Therefore, we develop measures that evaluate the level of JIT, TQM and EI implementation at the plant.

3.3. Hypotheses

As shown in Fig. 1, our framework considers the relationship among the environmental, organizational, and managerial factors, and the autonomous and planned TPM elements. We hypothesize that there are significant differences in the level of TPM development and implementation that can be explained by these contextual factors. We discuss our hypothesized relationships in this section.

While we cannot capture all the cultural or environmental differences of the plants, we explore TPM programs across different countries and industries. Of the three countries that we have data from, we expect TPM to be most developed in Japan. While TPM has been emphasized since the 1970s in Japan, little attention has been given to TPM in Western countries until the last decade. In addition, JIPM

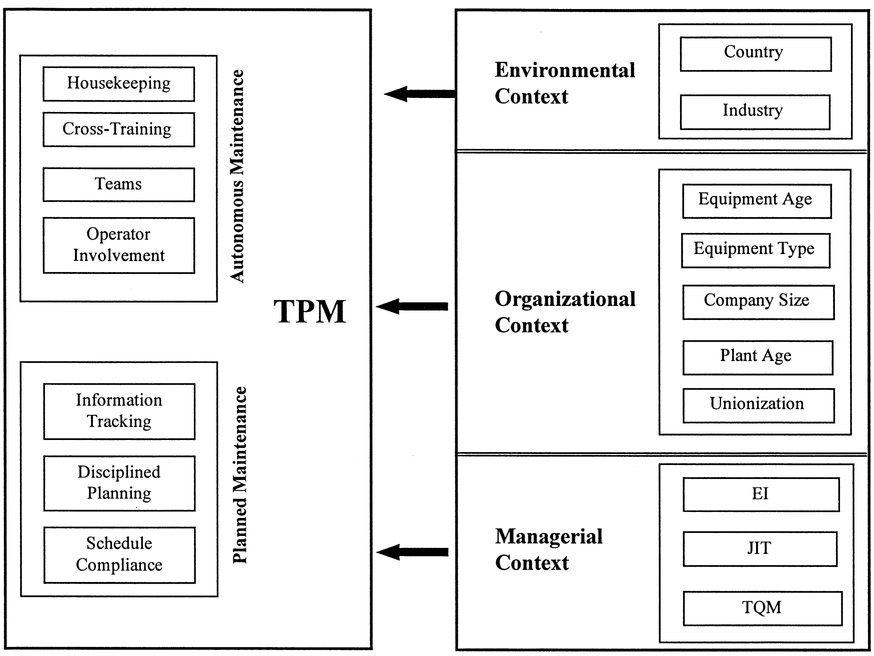

Fig. 1. Proposed framework.

maintenance awards have been received by many companies in Japan, several companies in Europe, but have yet to be awarded to an American company (Sugiura, 1995).

Industry can also be an important factor in equipment maintenance since the type of equipment, customer demands and strategic uncertainty can differ significantly from industry to industry. For example, in the automobile industry, the large automakers have faced much competition in recent years and companies such as Toyota, Ford and Saturn are known to have development (or developed) programs. The automakers, in turn, have demanded that their suppliers also implement progressive programs such as TPM. The electronics and machinery industries have also faced strong competition but do not have the same degree of customer influence as the automobile industry. Therefore, we expect the electronics and machinery industries to make less, but significant, use of TPM than the automobile industry.

Our hypothesis for the relationship between environmental factors and TPM implementation is as follows.

H1: Environmental factors—country and industry—explain a significant portion of variation in TPM implementation levels.

Next, we consider contextual issues that are specific to each organization. First, factors such as the company size and unionization can impact the implementation of a maintenance program. Organizational size has been one of the best predictors of organizational structure and managerial behavior in the history of organizational design and behavior research (Drazin, 1995, p. 399). The authors' experiences have indicated that larger companies have been more willing and able to dedicate resources for TPM development. This is supported by Daft (1995), who indicates that an advantage of a larger company is the availability of more financial and human resources.

The relationship between unions and TPM may depend on the nature of the unions at the particular plant and their desire to change. Monden (1981) emphasizes that the existence of only one enterprise-union in each company in Japan makes job rotation and multi-skilling—both important to effective TPM programs—very easy. Moreover, the craft unions in US and European companies may disturb or resist the development of multifunctional workers and subsequently TPM development. We anticipate that companies with many unionized members will have more difficulty implementing autonomous maintenance due to the constraints of union work rules. For example, cross-training can be difficult since the process of modifying the worker roles requires negotiations with union representatives.

We also consider both plant age and equipment age as organizational contextual factors which may impact the type and extent of maintenance systems in place. One possible explanation for this relationship is that many companies begin their TPM programs as they acquire new equipment or setup new plants. It is easier to start the program when the equipment is in excellent condition. TPM procedures are established as equipment is brought on line. On the other hand, older equipment require extensive effort to restore the equipment to base condition. Another important explanation for the relationship between TPM and plant and equipment age is that the age of the equipment and the plant may be indicators of the overall age of the work systems. Older systems are likely to have been established before employee involvement programs became popular and may support traditional roles of maintenance and operating personnel. If a traditional 'I operate–you fix' mentality exists, it will be harder to implement autonomous maintenance since maintenance personnel need to relinquish their responsibility for some traditional maintenance tasks.

The type of equipment—standardized or customized—can determine the variety of equipment, the complexity of the equipment, and the emphasis placed on equipment in the process. Highly standardized equipment indicates that workers have to learn about fewer types of equipment and tools. Customized equipment may require more skills to operate and maintain the equipment and may lead to dedicated operating and maintenance personnel.

Our hypothesis for the relationship between organizational factors and TPM implementation is (given adjustments are made for environmental factors), as follows.

H2: Organizational factors—equipment age, equipment type, company size, plant age, and unionization—significantly add to the explanation of variation in TPM implementation levels.

Next, we consider a number of factors that plant management can influence. These managerial factors are the use of JIT, TQM and EI programs in the plant and are likely to relate to the use of TPM.

Many firms are reducing inventory through JIT initiatives in an effort to respond better to changing demands in the marketplace. From an equipment viewpoint, inventory reduction increases the costs associated with downtime. With the removal of decoupling inventory between work centers, the breakdown of one piece of equipment quickly affects the entire production flow. Therefore, the cost of a failure may include the cost of lost production for the entire production line. Inventory reduction places companies at risk for major outages associated with reactive maintenance. JIT also places emphasis on maintaining a set production schedule. JIT requires strong planned maintenance systems so that maintenance is conducted as scheduled rather than as a reaction to equipment problems. Therefore, we expect that strong JIT programs would be developed commensurate with strong TPM planned maintenance systems.

In recent years, there has been a step change in the standards for quality. In some plants it is no longer acceptable to have a percentage of non-conforming products; quality performance is measured in defective parts per million. In order to consistently achieve the new goal of reduction toward zero defects and to support TQM efforts, the equipment must be reliable and consistent. Production can no longer react to equipment failures but must focus on reducing the variation in equipment performance. Therefore, we believe that companies with a strong TQM program are more likely to develop a TPM program.

Many companies have come to recognize that employees can contribute significantly to the organization when they are allowed to participate in decisions that impact their area of responsibility. Employee involvement is evident in initiatives, such as quality improvement teams and employee suggestion programs, that support both JIT and TQM programs. Employee involvement is also critical to successful implementation of TPM. The operators, who are most familiar with the daily operation of the equipment, and the maintenance personnel, who are most familiar with the technical specifications and long run performance of the equipment, are the greatest sources of information for companies that want to improve their equipment performance. Both operating and maintenance technicians understand the equipment and can receive both short- and long-term benefits from reliable equipment. Involvement from all employees allows companies to make better use of its available resources. Therefore, we believe that companies with strong employee involvement programs are more likely to adopt TPM—involving operators through autonomous maintenance.

The strong interrelationship among TPM, JIT, TQM, and EI may indicate that adoption of JIT, TQM or EI programs coincide with the adoption of TPM practices. In some cases, companies may need to implement TPM to support their JIT and quality improvement efforts. In other cases, the TPM program may provide an environment of consistent and reliable equipment that enables companies to implement JIT and TQM. Typically, EI is considered to be central to each of the other programs. While our analysis will be unable to make the determination of which comes first, it can provide evidence of the relationship among the programs.

In summary, our hypothesis for the relationship between managerial factors and TPM implementation is (given adjustments are made for environmental and organizational factors) as follows.

H3: Managerial contextual factors—the use of JIT, TQM, and EI—significantly add to the explanation of variation in TPM implementation levels.

As shown in Fig. 1, our framework considers the relationship among the environmental, organizational, and managerial factors, and autonomous and planned TPM elements. We hypothesize that there are significant differences in the level of TPM development and implementation that can be explained by these contextual factors.

In summary, we are proposing a framework in line with the contextual theory of management (Lawrence and Lorsch, 1967; Thompson, 1967; Campbell, 1974; Lawrence, 1981; Van de Ven and Drazin, 1985; Campbell, 1990; Senge, 1990; Gresov and Drazin, 1997). This theory holds that management practices are not universal, but rather depend on the context or environment of the firm. Many programs such as TPM, TQM, JIT and EI have been proposed as good for everyone regardless of the context of the firm (Schonberger, 1986, 1990). We propose that contextual factors do make a difference on when and where TPM practices are adopted.

4. Description of the data

The data used for empirical analysis of the framework were collected as part of the World Class Manufacturing (WCM) Study (Flynn et al., 1994) being conducted by a team of researchers at several universities in the USA, Asia and Europe. The WCM database used for our research was assembled in 1996 from three different regions of the world and three different industries using a common set of questionnaires. Part of this database addresses TPM and includes 97 different manufacturing plants.

The WCM database contains data from plants located in the USA, Japan and Italy (transplants are associated with its location and not the origin of its parent company). These three countries partially represent the three regions of the industrialized world: North America, Asia, and Europe. In each country, plants were selected from three industries: electronics, machinery and automobile industries. A stratified design was used to select approximately equal number of plants in each country and each industry. The study also selected approximately half of the plants with world class reputations and half from traditional plant lists. World class reputation was based on published studies of plants' best practices in practitioner journals such as Target and Industry Week, and the 'honor roll' of Schonberger (1986). As a result, many of the best plants in the world are included along with the more typical plants.

Table 1 shows the mean values of many contextual variables by country and industry and helps to describe the database in more detail. Notice that the USA sample has fewer unionized plants and larger parent companies. The machinery industry has older equipment, a higher number of unionized plants, and a higher percentage of standardized equipment. These differences will be discussed in more detail in Section 6.

Plants were selected randomly within strata (country and industry) and then were contacted by a member of the WCM research team to participate in the study. Two-thirds of the plants contacted decided to join the study. This relatively high response rate was assured by contacting the plants personally and by promising that they would receive a plant profile for comparison with other plants.

The data were collected using questionnaires that were distributed to 11 managers and 12 production workers in each plant. This battery of questionnaires

Table 1
Description of database

Contextual measures	Country			Industry		
	Japan	Italy	USA	Electronics	Machinery	Automobile
Number in sample	33	34	30	32	33	32
% World class plants	58%	53%	50%	59%	55%	47%
% Of companies that have unions	82%	85%	27%	55%	84%	71%
% Unionized employees (if unionized)	96%	58%	77%	68%	73%	87%
No. of employees in parent company	4713	1602	21,376	12,516	5012	6418
Equipment age	9.3	8.4	9.3	6.1	11.4	9.6
Plant age	34	35	31	28	40	31
% Standardized equipment	46%	59%	42%	46%	64%	38%

allowed for multiple respondents for each question thereby providing greater reliability of the data. In addition, it allowed respondents to address their particular area of expertise.

The data consists of two types of questions: objective and perceptual. The objective questions were answered by one respondent in each plant and addressed topics which can be measured on an objective basis such as: 'what percentage of the maintenance in the plant is performed by the workers rather than by a separate maintenance crew?'. The perceptual questions are arranged in multi-item scales to insure accurate representation of the construct of interest. Each scale consists of several questions pertaining to the same construct; the answers to the questions are averaged to arrive at a scale score. For example, the housekeeping construct is measured by taking the average of the five questions shown in Appendix A, and then aggregating over all respondents from the same plant.

In Section 5, the constructs of interest concerning TPM and contextual factors are described. These constructs are measured by a combination of perceptual scales and objective measures from the WCM database. Since the database was constructed to measure maintenance and its related context, these dimensions can be measured to an acceptable degree of content and construct validity as discussed in Section 5.

5. Measurement of variables

As shown in Fig. 1, we selected seven TPM measures and ten contextual measures from the WCM database which are briefly discussed in this section. In our database, 22 cases had a single missing value (out of the 17 measures) and one case had three missing values. Where necessary we replaced missing values with the mean measurement value for the country. A correlation matrix of the 17 measures is shown in Table 2. As each of the measures is briefly discussed, please refer to Appendices A–C for details of the survey questions used for our study.

5.1. Measurement of TPM

Our evaluation of the TPM implementation level at plants in our study considered both autonomous and planned maintenance variables. We utilized both objective and perceptual measures for assessing the TPM activities at each plant. The measures are shown in Appendix A. We selected questions from the WCM database that fit well with our literature review on TPM.

The autonomous maintenance variables include three perceptual measures for *housekeeping*, *cross-training* and *teams*, and an objective measure for *operator involvement*. For *housekeeping*, we utilize a five question scale from the WCM database. These questions relate closely to the 5-S approach, a system for industrial housekeeping practices that is discussed in books by Nakajima (1988), Shirose (1992), Suzuki (1992), Tajiri and Gotoh (1992). To assess the level of *cross-training*, we used five questions that relate to the amount of cross-training that is provided and utilized within the plant. Our measure evaluates the skills of operators and specifies whether or not an organization has established an environment where cross-training is possible. Similarly, for the autonomous maintenance *team* measure, we measured the general level of team involvement within the plant rather than the presence of maintenance and equipment related teams. We utilize a five-question team scale that assesses the general environment that is established for production and maintenance teams. Finally, for *operator involvement*, we use an objective measure of the percentage of operators who are directly involved in the maintenance delivery process. This measure provides another indicator of the implementation level of autonomous maintenance.

While both the operators and maintenance personnel are involved in the planning and execution of maintenance within a TPM program, the maintenance personnel are ultimately held accountable for long term maintenance planning and the state of readiness of the equipment. With the data that was available, we considered three measures of planned maintenance: two perceptual measures for *disciplined planning* and *information tracking*, and an objective measure for *schedule compliance*. A *disciplined planning* approach typically dedicates time for scheduled maintenance activities, assigns tasks to specific people and inspects for good quality workmanship. We consider four questions that address the planning of the maintenance department. An infor-

Table 2
Correlation matrix of independent and dependent variables

	Housekeeping	Cross-training	Teams	Information tracking	Disciplined planning	Operator involvement	Schedule compliance	Country (USA)
Housekeeping	1.000							
Cross-training	0.360	1.000						
Teams	0.449	0.631	1.000					
Information tracking	0.480	0.384	0.548	1.000				
Disciplined planning	0.455	0.534	0.513	0.653	1.000			
Operator involvement	−0.002	0.054	0.042	−0.054	0.086	1.000		
Scheduled compliance	0.164	0.054	0.164	0.271	0.325	0.372	1.000	
Country (USA)	−0.062	0.294	0.144	0.096	0.024	−0.154	−0.291	1.000
Country (Italy)	0.006	−0.583	−0.305	−0.193	−0.392	−0.042	−0.027	−0.492
Industry (Machinery)	−0.081	−0.161	−0.147	−0.351	−0.148	−0.011	−0.189	−0.010
Industry (Electronics)	0.092	0.122	0.032	0.055	0.059	−0.095	0.114	0.005
Equipment age	−0.254	−0.024	−0.106	−0.199	−0.179	−0.056	−0.098	0.046
Equipment type	−0.092	−0.284	−0.204	−0.210	−0.190	0.108	−0.156	−0.149
Company size	0.196	0.202	0.196	0.247	0.200	−0.172	−0.102	0.526
Plant age	−0.154	−0.243	−0.284	−0.225	−0.232	−0.112	0.054	−0.091
Union	−0.074	−0.009	0.042	0.054	0.144	0.066	0.068	−0.532
EI	−0.045	−0.440	−0.346	−0.038	−0.137	−0.185	0.038	−0.465
JIT	0.263	0.388	0.461	0.605	0.563	0.075	0.234	0.027
TQM	0.421	0.634	0.675	0.733	0.612	0.053	0.184	0.075

mation system that tracks past and current equipment performance is also important to a successful maintenance department. We assess the *information tracking* systems that are relevant to the equipment performance through five questions. Finally, compliance to a planned maintenance schedule is a measure of the successful application of the maintenance tools and execution of the plans. We use a self-reported *schedule compliance* measure as another indicator of planned maintenance implementation.

5.2. Environmental and organizational context

The measures used for the environmental contextual variables are relatively straightforward and are described in Appendix B. We have three countries represented [USA (sample size = 30), Italy (34), and Japan (33)] and three industries [machinery (33), electronics (32) and automobile (32)]. Recall that we also consider plant age, equipment age, percentage of equipment that is standardized, percentage of unionized employees, and the size of the company as organizational contextual variables. We measured company size in terms of the number of employees rather than sales due to currency differences. The company size allows us to evaluate the relative magnitude of resources available for TPM efforts.

5.3. Managerial context

For the managerial contextual variables, our goal was to measure the general level of JIT, TQM, and EI program development. See Appendix C for details of the survey questions. To measure the implementation of JIT, we considered various JIT practices and developed an average of five scales used in Sakakibara et al. (1993, 1997). Our measurement captures JIT delivery by suppliers, JIT delivery to customers, pull system support, repetitive nature of the master production schedule, and setup reduction efforts within the plant. This is a comprehensive measurement of JIT involving five different scales which measure different aspects of JIT.

To measure the implementation level of TQM, we consider customer involvement, rewards for quality, supplier quality management, and top management leadership for quality. Previous studies have found that these aspects of TQM adequately represent a

Country (Italy)	Industry (Machinery)	Industry (Electronics)	Equipment age	Equipment type	Company size	Plant age	Union	EI	JIT	TQM
1.000										
0.065	1.000									
−0.010	−0.504	1.000								
−0.096	0.339	−0.441	1.000							
0.213	0.306	−0.078	0.143	1.000						
−0.329	−0.146	0.212	−0.189	−0.090	1.000					
0.074	0.226	−0.157	0.473	0.066	−0.101	1.000				
−0.094	0.123	−0.216	0.101	0.166	−0.155	0.072	1.000			
0.526	−0.133	0.070	0.011	0.114	−0.252	0.044	0.089	1.000		
−0.269	−0.253	−0.052	−0.149	−0.250	0.150	−0.232	0.134	−0.059	1.000	
−0.392	−0.224	−0.009	−0.015	−0.204	0.183	−0.121	0.160	−0.267	0.547	1.000

broad-based view of the construct (Flynn et al., 1994, 1996).

While there are many forms of employee involvement, we focus on the level of responsibility given to each employee. This dimension of employee involvement can be summarized as the centralization of authority. As mentioned in Section 3, we believe that a less centralized organization will be more likely to give some level of authority to line operators and allow them to become more involved in the maintenance process. A less centralized organization typically has a higher level of employee involvement.

5.4. Reliability and validity

Our research uses data from the WCM Study and many of the constructs, e.g., housekeeping and teams, were used and tested in previous studies (Sakakibara et al., 1993; Flynn et al., 1994, 1996; Sakakibara et al., 1997). In addition, the items used for each construct fit well with the concepts of TPM discussed in the literature review and therefore have a high degree of content validity.

For the dataset used for our analysis, we used Cronbach's alpha and factor analysis within and between countries. Cronbach's alpha scores for each of the plant-level scales ranged from 0.76 to 0.90 (see Appendices A and C). We also evaluated the reliability of the scales by country and the alpha scores ranged from 0.72 to 0.96. Using factor analysis we verified that each plant-level scale for TPM contained only one dimension (eigenvalues greater than 1.0 for only one factor). The loadings of each item on the scales were all greater than 0.59. These results suggest that for each TPM variable, the set of items makes a homogenous scale representing a single construct.

6. Analysis

We used a hierarchical regression approach to the statistical analysis. This approach allows us to understand which environmental, organizational and managerial contextual issues are most important to TPM implementation. At each step of the analysis, we add additional variables and test whether the new variable set significantly contributes to the explanation of the TPM implementation level. We start first with the environmental factors, then the organizational factors and finally add the managerial factors—moving from macro-level factors to micro-level factors.

Results of the evaluation of assumptions of normality, homogeneity of variance–covariance matrices, linearity and multicollinearity were satisfactory for each of the regressions on the five perceptual measures of TPM. Results of the evaluation of assumptions led to transformation of the two objective measures of TPM to satisfy the linearity and normality assumptions. A square root transformation of the operator involvement measure and a squared transformation of the schedule compliance measure were applied and the resulting models satisfied all the assumptions. The resulting regressions are presented in Tables 3–5. We use a 0.10 significance level for our analysis and discussion.

6.1. Environmental context

Since industry and country are often considered to be important to the manufacturing practices adopted within organizations, we first explore the relationship between these environmental variables and our TPM measures. The results of the regression equations are shown in Table 3. The first block of variables, country and industry, significantly contributes to the explanation of the level of *cross-training* of workers ($R^2_{adj} = 0.331,\ p < 0.001$), *teams* ($R^2_{adj} = 0.072,\ p < 0.029$), *information tracking* system ($R^2_{adj} = 0.135,\ p < 0.002$), *disciplined planning* ($R^2_{adj} = 0.170,\ p < 0.001$), and *schedule compliance* ($R^2_{adj} = 0.071,\ p < 0.070$).

Much of the explanation of the autonomous maintenance practices at the plants that we investigated was explained by the country in which the plant was located. Italy has significantly lower levels of cross-training ($p < 0.001$) and use of teams ($p < 0.011$) than Japan and the USA. Our results indicate that Italy has the weakest autonomous maintenance practices. The differences between Japan and USA were inconclusive for housekeeping, cross-training, and teams. Japan only has a higher level of operator involvement ($p < 0.064$) than the USA.

However, when we consider the planned maintenance practices, Japan had the highest level of disciplined planning, followed by the USA (USA coefficient of -0.235 with $p < 0.043$) and then by Italy (Italy coefficient of -0.509 with $p < 0.001$). Japan also appears to have the highest level of compliance to maintenance schedules, followed by Italy and then the USA (USA is significantly lower than the other two countries, $p < 0.013$).

These country differences could be attributed to several factors. First, there may exist some cultural differences that support or hinder TPM implementation. Second, TPM has been emphasized in Japan for over three decades. Thus, it is not surprising to find a

Table 3
Results of regressions involving environmental contextual variables

Independent	Autonomous maintenance					
	Housekeeping		Cross-training		Teams	
	Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T
Country (USA)	−0.0808	0.5267	0.0120	0.9046	−0.0028	0.9809
Country (Italy)	−0.0274	0.8249	−0.5757	0.0000	−0.2984	0.0106
Industry (Machinery)	−0.0481	0.7022	−0.0886	0.3705	−0.1546	0.1863
Industry (Electronics)	0.0716	0.5713	0.0744	0.4540	−0.0493	0.6735
Constant	3.7717	0.0000	3.8374	0.0000	3.8627	0.0000
No. of cases	97		97		97	
R^2	0.0145		0.3590		0.1102	
Adjusted R^2	−0.0284		0.3311		0.0715	
Significant F	0.8522		0.0000		0.0282	

greater level of implementation since Japanese companies may have initiated TPM programs far before the American or Italian companies. Finally, there are some other measures that differ significantly from country to country. As shown in Table 1, Italy has small parent companies and may lack the support and resources for TPM efforts. The USA companies have more customized equipment and may find it difficult to train operators to maintain the equipment. These factors, that differ among countries, may be determinants of maintenance policies.

While country provides some explanation for the differences in TPM implementation, we have insufficient evidence to link the adoption of TPM to specific industries. This is somewhat surprising since we had expected industry to be a very significant factor in the use of TPM practices. Perhaps the three particular industries studied here are not that different in their use of TPM or industry may indeed not specifically represent factors that are important in influencing the use of TPM.

6.2. Organizational context

Next we considered the organization-specific contextual characteristics. The results of the regressions are shown in Table 4. Surprisingly, the inclusion of these new organizational variables did not significantly improve the explanation of variance, R^2, for any of the TPM variables except *housekeeping* $(R^2_{adj} = 0.073,\ p < 0.015)$ and *disciplined planning* $(R^2_{adj} = 0.214,\ p < 0.081)$. These results only partially support our initial hypothesis H2. Better housekeeping practices were reported for larger companies and for companies with a lower percentage of unionized employees. In addition, a more disciplined planning approach was taken in larger companies. However, overall, few of the organizational factors were significant in explaining differences in TPM implementation.

Our results suggest that the state of the organization's resources may not limit a company's ability to implement TPM. If this can be confirmed by future studies, it will represent a major improvement in our understanding of TPM. For example, it would mean that small plants as well as large plants can implement TPM. Also, it is possible, as Shiba et al. (1993) suggest, that the real issue is not whether or not unions exist in the plant but whether or not the workforce is open to making the changes that are required by TPM.

6.3. Managerial context

Next we considered variables that are under the direction of plant management. The close relationship between JIT, TQM, EI and TPM suggests that plants which implement the first three programs may also consider TPM to be critical to their manufacturing strategy or vice versa. As shown in Table 5, the

Autonomous maintenance		Planned maintenance					
Operator involvement		Information tracking		Disciplined planning		Schedule compliance	
Coefficient	Significant *T*	Coefficient	Significant *T*	Coefficient	Significant *T*	Coefficient	Significant *T*
− 1.5536	0.0640	0.0170	0.8959	− 0.2352	0.0425	− 2441.41	0.0121
− 1.1491	0.1413	− 0.1851	0.1454	− 0.5092	0.0000	− 1453.62	0.1623
− 0.5289	0.5028	− 0.4867	0.0003	− 0.1267	0.2642	− 1027.06	0.3127
− 0.8782	0.2746	− 0.1846	0.1547	− 0.0073	0.9485	544.26	0.5723
6.7018	0.0000	3.6206	0.0000	3.2529	0.0000	7106.42	0.0000
87		97		97		69	
0.0634		0.1707		0.2045		0.1252	
0.0177		0.1346		0.1699		0.0705	
0.2456		0.0016		0.0003		0.0693	

Table 4
Results of regressions involving environmental and organizational contextual variables

Independent	Autonomous maintenance					
	Housekeeping		Cross-training		Teams	
	Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T
Country (USA)	−0.4887	0.0121	−0.0302	0.8456	−0.0730	0.6894
Country (Italy)	−0.1461	0.3020	−0.5422	0.0000	−0.2391	0.0785
Industry (Machinery)	0.0423	0.7399	−0.0049	0.9626	−0.0578	0.6344
Industry (Electronics)	−0.1166	0.3891	0.1130	0.3043	−0.0572	0.6574
Equipment age	−0.0190	0.1703	0.0111	0.3240	0.0038	0.7705
Equipment type	−0.0007	0.6767	−0.0023	0.0798	−0.0019	0.2146
Company size	1.0×10^{-5}	0.0101	-1.1×10^{-7}	0.9729	4.0×10^{-6}	0.2860
Plant age	−0.0017	0.5320	−0.0053	0.0200	−0.0062	0.0198
Unionization	−0.0033	0.0590	−0.0002	0.8784	0.0004	0.8112
Constant	4.3248	0.0000	4.0010	0.0000	4.0435	0.0000
No. of cases	97		97		97	
R^2	0.1596		0.4164		0.1947	
Adjusted R^2	0.0726		0.3560		0.1114	
Significant F	0.0730		0.0000		0.0207	
Significant F change	0.0150		0.1404		0.1161	

inclusion of these managerial variables results in a significant improvement in the explanation of variance, R^2, for *housekeeping* ($R^2_{adj} = 0.251$, $p < 0.001$), *cross-training* ($R^2_{adj} = 0.561$, $p < 0.001$), *teams* ($R^2_{adj} = 0.481$, $p < 0.001$), *operator-involvement* ($R^2_{adj} = 0.130$, $p < 0.044$), *information track-*

Table 5
Results of regressions involving environmental, organizational and managerial contextual variables

Independent	Autonomous maintenance					
	Housekeeping		Cross-training		Teams	
	Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T
Country (USA)	−0.3809	0.0342	0.0232	0.8608	−0.0012	0.9935
Country (Italy)	0.0501	0.7224	−0.2881	0.0073	0.1057	0.3569
Industry (Machinery)	0.1688	0.1661	0.0829	0.3601	0.0639	0.5168
Industry (Electronics)	−0.0340	0.7859	0.2013	0.0332	0.0733	0.4712
Equipment age	−0.0214	0.0942	0.0120	0.2054	0.0061	0.5518
Equipment type	2.3×10^{-5}	0.9875	−0.0016	0.1508	−0.0009	0.4713
Company size	7.7×10^{-6}	0.0316	-2.3×10^{-6}	0.3849	9.7×10^{-7}	0.7367
Plant age	−0.0006	0.8074	−0.0043	0.0217	−0.0048	0.0192
Unionization	−0.0037	0.0206	−0.0006	0.6326	−0.0001	0.9573
EI	0.0159	0.9146	−0.1930	0.0838	−0.2727	0.0258
JIT	0.0413	0.8168	0.0735	0.5799	0.1991	0.1707
TQM	0.6909	0.0001	0.6232	0.0000	0.7716	0.0000
Constant	1.5604	0.0660	1.9668	0.0023	1.2271	0.0747
No. of cases	97		97		97	
R^2	0.3445		0.6162		0.5455	
Adjusted R^2	0.2509		0.5614		0.4806	
Significant F	0.0002		0.0000		0.0000	
Significant F change	0.0001		0.0000		0.0000	

Autonomous maintenance		Planned maintenance					
Operator involvement		Information tracking		Disciplined planning		Schedule compliance	
Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T
−2.4623	0.0648	−0.0377	0.8522	−0.3937	0.0276	−4626.94	0.0066
−2.3128	0.0165	−0.1096	0.4634	−0.5099	0.0002	−2189.09	0.0766
−0.7177	0.3781	−0.4079	0.0031	−0.0340	0.7720	−615.35	0.5613
−1.5472	0.0794	−0.2439	0.0904	−0.0979	0.4325	−14.46	0.9891
−0.1254	0.1592	−0.0100	0.4916	−0.0119	0.3506	−78.34	0.4731
0.0191	0.0727	−0.0013	0.4387	−0.0013	0.3916	−9.0997	0.5192
-3.1×10^{-5}	0.235	7.0×10^{-6}	0.0906	6.0×10^{-6}	0.0967	0.0138	0.6416
−0.0138	0.4279	−0.0030	0.2938	−0.0037	0.1422	21.94	0.4167
−0.0168	0.1585	0.0012	0.5242	−0.0006	0.7286	−26.76	0.0945
9.4700	0.0000	3.7348	0.0000	3.5726	0.0000	9984.22	0.0000
87		97		97		69	
0.1652		0.2419		0.2879		0.1972	
0.0677		0.1635		0.2142		0.0747	
0.1050		0.0029		0.0003		0.1333	
0.1079		0.1594		0.0811		0.3926	

ing ($R^2_{adj} = 0.630$, $p < 0.001$), and *disciplined planning* ($R^2_{adj} = 0.463$, $p < 0.001$). These results mostly support our initial hypothesis, H3.

The implementation level of JIT helped explained a significant portion of the variance in information tracking ($p < 0.007$) and disciplined planning sys-

Autonomous maintenance		Planned maintenance					
Operator involvement		Information tracking		Disciplined planning		Schedule compliance	
Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T	Coefficient	Significant T
−3.5110	0.0070	0.2092	0.1341	−0.2277	0.1328	−4788.72	0.0074
−1.4562	0.1944	0.1684	0.1292	−0.3234	0.0081	−1469.81	0.2652
−1.2203	0.1724	−0.1341	0.1595	0.1551	0.1340	−691.58	0.5447
−1.4439	0.1725	−0.0681	0.4870	0.0370	0.7272	395.25	0.7237
−0.1009	0.5188	−0.0145	0.1457	−0.0134	0.2146	−48.70	0.6576
0.0211	0.0462	0.0001	0.9470	−0.0002	0.8500	−5.2897	0.7117
-2.8×10^{-5}	0.3718	2.3×10^{-6}	0.4124	2.8×10^{-6}	0.3595	0.0100	0.7577
−0.0159	0.3732	−0.0005	0.8095	−0.0018	0.3970	22.84	0.4021
−0.0197	0.0652	0.0005	0.6785	−0.0010	0.4499	−27.86	0.0813
−2.8897	0.0043	0.2230	0.0574	0.1359	0.2820	−1532.30	0.2839
0.1581	0.5708	0.3890	0.0063	0.4168	0.0069	2046.59	0.2375
0.1845	0.7073	1.0201	0.0000	0.5725	0.0001	161.43	0.9167
16.9688	0.0116	−2.1135	0.0018	−50.4643	0.5152	6484.77	0.4665
87		97		97		69	
0.2514		0.6765		0.5297		0.2451	
0.1300		0.6302		0.4625		0.0833	
0.0293		0.0000		0.0000		0.1462	
0.0436		0.0000		0.0000		0.3240	

tems ($p < 0.007$). With JIT, planning and information systems are essential to the company's ability to meet customers' orders with low levels of inventory. Maintenance, which often requires a large block of downtime, must be included in the JIT planning schedule. In addition, if maintenance is not properly conducted, interruptions to production due to unscheduled downtime can hinder the plant's ability to implement JIT and meet the customer's demands as scheduled.

Companies that have implemented strong quality programs, also have strong autonomous and planned maintenance systems ($p < 0.001$ for all perceptual measures). There are several possible explanations for this result. First, TQM and TPM have similar support systems such as team work, skill development, and process control. Once the systems are established they can be used to support both maintenance and quality improvement efforts. Second, high quality products are a result of good design, quality raw materials, reliable processes, and consistent equipment. The maintenance of the equipment is important to sustaining production of high quality products. As companies continue to improve their quality, they must also improve their maintenance delivery system and the overall equipment performance. Finally, some companies implement TPM programs to establish control of their operating environment. Once equipment performance is managed, they are able to focus on quality improvement efforts. Clearly TQM and TPM programs are closely related.

Also, employee involvement plays a significant role in defining the implementation level of autonomous maintenance teams ($p < 0.026$), cross-training ($p < 0.084$), and operator involvement ($p < 0.005$). Traditionally, employee involvement programs encourage the use of teams. In addition, once employees become more involved in the workplace, they are given the authority to take on more tasks. An information system frequently helps support these employee efforts. In this case, operators become more involved in the maintenance delivery system.

Although we did not find evidence to support all of our hypotheses, it is too early to state that these factors do not explain differences in TPM implementation. We have found some support that the variance in the TPM development level at different companies appears to be explained in large part by the level of JIT, TQM and EI implementation within the plant. The implementation of TPM appears to be more tightly linked to the management of the plant than to environmental and organizational factors.

Our results, which show that the plant-level managerial factors provide the most explanation for TPM implementation, indicate that plants are more autonomous than initially suggested by Lawrence and Lorsch (1967) and Campbell (1974). While environmental and organizational factors may be important, they do not explain a large portion of the variation in TPM implementation. Perhaps the difference in implementation can be elaborated thru the explanation of a learning organization by Senge (1990). TPM implementation may have more to do with the type of management systems and the organization's ability to learn and practice TPM—whether or not the organization is a learning organization. Yet, it is still surprising that the company and its environment does not play a more important role in the plant's learning ability and its subsequent development of TPM.

7. Conclusions

We conducted this study to better understand what types of companies have adopted TPM programs. The contextual variables considered in this research explain between 25% and 63% of the variance in the perceptual TPM measures. This indicates that TPM is dependent on contextual differences between companies. TPM, at least as described and measured in this paper, is not widely adopted by every type of company.

We were able to demonstrate that some environmental contextual measures provide an explanation of the variation in TPM implementation. Country provides some explanation for the differences between plant's TPM implementation levels. As hypothesized, Japan appears to have comparable or higher levels of planned maintenance implementation than USA and Italy. Japanese companies have strong planning systems to support their TPM efforts. Italy, on the other hand, appears to have weak TPM practices, especially autonomous maintenance practices. Although there are differences in TPM implementation between countries, the country where the plant is located only provides a partial explanation of TPM implementation. It was necessary to consider other factors to explain the variation in TPM implementation.

TPM programs have been implemented by many companies and can be adopted by companies in different environments and within various types of organizations. Our results indicate that the managerial contextual variables, which are under the jurisdiction of plant management, are *more* important to the execution of TPM programs than environmental and organizational variables. Clearly, the use of TPM programs is strongly linked to the management of the plant. While many consultants have promoted the simplicity of TPM and its direct benefits to the bottom line, they often fail to identify contextual issues that may make TPM implementation difficult and ineffective. It is important that managers do not consider TPM the *best* maintenance delivery system for *all* situations. Plant-specific and environment-specific issues should be considered when developing or improving the maintenance system. In particular, management should assess the status of the managerial systems within the plant, decide whether their organization is prepared for TPM implementation, and assess the fit of TPM practices with other systems.

We believe that this contextual approach can and should be applied to other areas of research in operations management as well as TPM. Traditionally, research has identified the potential benefits of programs such as JIT, TQM and TPM but has largely failed to identify what situations are best suited for these improvement efforts. A contextual research approach will provide a better understanding of a program and under what conditions it is most commonly used.

It is also important to identify the critical dimensions of TPM and their impact on manufacturing performance. Many companies fail to invest in maintenance programs because they manage maintenance by a budget and fail to see the strategic implications of a strong maintenance program. Since this paper has demonstrated a strong relationship among TPM and the contextual factors, the authors plan to conduct research that further investigates the nature of these relationships. For example, research that provides a better understanding of the relationships among TPM, JIT, TQM and EI and their development can support the successful implementation of TPM. In addition, the authors plan to further investigate TPM implementation and its relationship to manufacturing performance. Empirical research that provides a better understanding of TPM implementation and the benefits of TPM programs will be important to future TPM development.

Appendix A. Measurement of TPM implementation

Concept	Factor	Measure
Autonomous maintenance	Housekeeping	Our plant emphasizes putting all tools and fixtures in their place
	$\alpha = 0.8508$[a]	We take pride in keeping our plant neat and clean
		Our plant is kept clean at all times
		I often have trouble finding the tools I need[b]
		Our plant is disorganized and dirty[b]
	Cross-training	Employees receive training to perform multiple tasks
	$\alpha = 0.8350$[a]	Employees at this plant learn how to perform a variety of tasks/jobs
		The longer an employee has been at this plant, the more tasks or jobs they learn to perform
		Employees are cross trained at this plant so that they can fill in for others if necessary
		At this plant, employees only learn how to do one job/task[b]

	Teams $\alpha = 0.8766$[a]	During problem solving sessions, we make an effort to get all team members' opinions and ideas before making a decision Our plant forms teams to solve problems In the past 3 years, many problems have been solved through small group sessions Problem solving teams have helped improve manufacturing processes at this plant Employee teams are encouraged to try to solve their problems as much as possible
	Operator involvement	What percent of the maintenance on the machines involved in the production of this product is performed by the workers, rather than by a separate maintenance crew?[c]
Planned maintenance	Disciplined planning $\alpha = 0.7673$[a]	We dedicate a portion of every day solely to maintenance We emphasize good maintenance as a strategy for achieving quality and schedule compliance We have a separate shift, or part of a shift, reserved each day for maintenance activities Our maintenance department focuses on assisting machine operators perform their own preventive maintenance
	Information tracking $\alpha = 0.8199$[a]	Charts plotting the frequency of machine breakdowns are posted on the shop floor Information on productivity is readily available to employees A large percent of the equipment or processes on the shop floor are currently under statistical quality control We use charts to determine whether our manufacturing processes are in control We monitor our processes using statistical process control
	Schedule compliance	What percent of the time is the maintenance schedule (for equipment used to produce this product) followed?[c]

[a] α = Refers to Cronbach's alpha, used to measure the reliability of the scale.
[b] Indicates that the variable is reversed scored.
[c] Response is in terms of percentage. All other responses are in the scale score format with 1 being strongly disagree and 5 being strongly agree.

Appendix B. Measurement of environmental and organizational contextual factors

Concept	Factor	Measure
Environment	Country	Nationality (country of location) of parent corporation USA—Country (USA) = 1 Italy—–Country (Italy) = 1 Japan—-Country (USA) = Country (Italy) = 0

	Industry	Based on SIC Machinery—–Industry (MACH) = 1 Electronics—-Industry (ELEC) = 1 Automobile—-Industry (MACH) = Industry (ELEC) = 0
Organization	Company size	How many people are employed by your parent company?
	Unionization	What percent of your workforce is unionized?
	Plant age	In what year was the plant originally built? (1996 − Year built)
	Equipment age	Roughly what percent of the equipment in this plant falls into each of these age categories? ______Less than 2 years old (Used 1) ______3–5 years old (4) ______6–10 years old (8) ______11–20 years old (15.5) ______Over 20 years old (25) Equipment age is a weighted average of the percentage given by the respondent and the age in parentheses
	Equipment type	What percent of the equipment and processes currently being used in manufacturing falls into each of the following categories? ______% Standard equipment purchased from vendors

Appendix C. Measurement of managerial contextual factors

Concept	Factor	Measure
JIT $\alpha = 0.9046$[a]	JIT delivery by suppliers	Our suppliers deliver to us on a just-in-time basis We receive daily shipments from most suppliers Our suppliers are certified, or qualified, for quality We have long-term arrangements with our suppliers Our suppliers deliver to us on short notice We can depend upon on-time delivery from our suppliers Our suppliers are linked with us by a pull system
	JIT link with customers	Our customers receive just-in-time deliveries from us Most of our customers receive frequent shipments from us We are expected to supply on short notice to our customers We always deliver on time to our customers We can adapt our production schedule to sudden production stoppages by our customers Our customers have a pull type link with us

	Pull system support	We use a back-flushing system, where components are subtracted from inventory every time a product is made
		We have laid out the shop floor so that process and machines are in close proximity to each other
		Direct Labor is authorized to stop production for quality problems
		We use a pull system for production control
		The control of production is in the hands of the workers
		Generally, workers on the production floor have the authority to decide how to handle production problems
		We have low work-in-process inventory on the shop floor
		When we have a problem on the production floor, we can identify its location easily
	Repetitive nature of master schedule	Our master schedule repeats the same mix of products from hour to hour and day to day
		The master schedule is level-loaded in our plant from day to day
		We make every model every day
		A fixed sequence of items is repeated throughout our master schedule
		We are able to use a mixed model schedule because our lot sizes are small
		Within our schedule, the mix of items is designed to be similar to the forecasted demand mix
	Setup reduction	We are aggressively working to lower setup times in our plant
		We have converted most of the setup time to external time while the machine is running
		We have low setup times of equipment in our plant
		Our crews practice setups to reduce the time required
		Our workers are trained to reduce set-up time
		Management emphasizes importance of set-up time reduction
TQM $\alpha = 0.8916$[a]	Customer involvement	We frequently are in close contact with our customers
		Our customers seldom visit our plant[b]
		Our customers give us feedback on quality and delivery performance
		Our customers are actively involved in the product design process
		We strive to be highly responsive to our customers' needs
		We regularly survey our customers' requirements
	Rewards for quality	Workers are rewarded for quality improvement
		Supervisors are rewarded for quality improvement
		If I improve quality, management will reward me
		We pay a group incentive for quality improvement ideas
		Our plant has an annual bonus system based on plant productivity
		Non-financial incentives, such as jackets, coffee cups, etc., are used to reward quality improvement

	Supplier quality management	We strive to establish long-term relationships with suppliers Our suppliers are actively involved in our new product development process Quality is our number one criterion in selecting suppliers We rely on a small number of high quality suppliers We use mostly suppliers which we have certified We maintain close communication with suppliers about quality considerations and design changes
	Top management leadership for quality	All major department heads within our plant accept their responsibility for quality Plant management provides personal leadership for quality products and quality improvement The top priority in evaluating plant management is quality performance All major department heads within our plant work towards encouraging just-in-time production Our top management strongly encourages employee involvement in the production process Plant management creates and communicates a vision focused on quality improvements Plant management is personally involved in quality improvement projects
EI $\alpha = 0.8464$[a]	Centralization of authority	I can do almost anything I want without consulting my boss[b] Even small matters have to be referred to someone higher up for a final answer This plant is a good place for a person who likes to make his own decisions[b] Any decision I make has to have my boss's approval There can be little action taken here until a supervisor approves a decision

[a] α = Refers to Cronbach's alpha, used to measure the reliability of the scale.
[b] Indicates that the variable is reversed scored.

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