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Int. J. Production Economics 70 (2001) 237–244

international journal of production economics

www.elsevier.com/locate/dsw

Linking maintenance strategies to performance

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Abstract

In order to achieve world-class performance, more and more companies are replacing their reactive, fire-fighting strategies for maintenance with proactive strategies like preventive and predictive maintenance and aggressive strategies like total productive maintenance (TPM). While these newer maintenance strategies require increased commitments to training, resources and integration, they also promise to improve performance. This paper reports the results of a study of the relationship between maintenance strategies and performance. Based on the responses from a survey of plant managers and maintenance managers, the analysis shows strong positive relationships between proactive and aggressive maintenance strategies and performance.

Keywords: Maintenance management; Total productive maintenance

1. Introduction

In order to achieve world-class performance, more and more companies are undertaking efforts to improve quality and productivity and reduce costs. For more and more companies, part of this effort has included an examination of the activities of the maintenance function. Effective maintenance is critical to many operations. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilization of equipment and delayed production schedules. Misaligned or malfunctioning equipment may result in scrap or products of questionable quality. Finally, poor maintenance may mean more frequent equipment replacement because of shorter life.

Traditionally, many companies employed a *reactive* strategy for maintenance, fixing machines only when they stopped working. More recently, improved technology and the increased sophistication of maintenance personnel have led some companies to replace this type of reactive approach. A *proactive* strategy for maintenance utilizes preventive and predictive maintenance activities that prevent equipment failures from occurring. An *aggressive* strategy, like total productive maintenance (TPM), focuses on actually improving the function and design of the production equipment. While these newer maintenance strategies require greater commitments in terms of training, resources and integration, they are also expected to provide higher levels of equipment and plant performance.

The purpose of this article is to empirically examine the performance implications of these different strategies for maintenance. As a part of the study,

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0925-5273/01/$ - see front matter
PII: S0925-5273(00)00067-0

exploratory factor analysis is utilized to determine whether the use of specific maintenance practices can be explained by these three maintenance strategies.

2. Review of the literature

Many authors have described different strategies for maintenance management. Bateman [1] described three basic types of maintenance programs, including reactive, preventive and predictive maintenance. Preventive and predictive maintenance represent two proactive strategies by which companies can avoid equipment breakdowns. Weil [2] added another approach in his description of the maintenance continuum by including TPM. TPM is an aggressive maintenance approach that seeks to improve equipment performance while continuing to avoid equipment failures. This paper focuses on the use of these three different strategies for maintenance: reactive or breakdown maintenance, proactive maintenance including preventive and predictive maintenance and aggressive maintenance.

2.1. Reactive maintenance

Reactive maintenance may be described as a fire-fighting approach to maintenance. Equipment is allowed to run until failure. Then the failed equipment is repaired or replaced [3]. Under reactive maintenance, temporary repairs may be made in order to return equipment to operation, with permanent repairs put off until a later time [4].

Reactive maintenance allows a plant to minimize the amount maintenance manpower and money spent to keep equipment running [5]. However, the disadvantages of this approach include unpredictable and fluctuating production capacity, higher levels of out-of-tolerance and scrap output, and increased overall maintenance costs to repair catastrophic failures [1,4].

2.2. Proactive maintenance

Proactive maintenance is a strategy for maintenance whereby breakdowns are avoided through activities that monitor equipment deterioration and undertake minor repairs to restore equipment to proper condition. These activities, including preventive and predictive maintenance, reduce the probability of unexpected equipment failures.

Preventive maintenance is often referred to as use-based maintenance. It is comprised of maintenance activities that are undertaken after a specified period of time or amount of machine use [6,7]. This type of maintenance relies on the estimated probability that the equipment will fail in the specified interval. The work undertaken may include equipment lubrication, parts replacement, cleaning and adjustment. Production equipment may also be inspected for signs of deterioration during preventive maintenance work.

The benefits of preventive maintenance are reduced probability of equipment breakdowns and extension of equipment life. The disadvantage of preventive maintenance is the need to interrupt production at scheduled intervals to perform the work.

Predictive maintenance is often referred to as condition-based maintenance. Specifically, maintenance is initiated in response to a specific equipment condition [5,6]. Under predictive maintenance, diagnostic equipment is used to measure the physical condition of equipment such as temperature, vibration, noise, lubrication and corrosion [8]. When one of these indicators reaches a specified level, work is undertaken to restore the equipment to proper condition. This means that equipment is taken out of service only when direct evidence exists that deterioration has taken place.

Predictive maintenance is premised on the same principle as preventive maintenance although it employs a different criterion for determining the need for specific maintenance activities. As with preventive maintenance, predictive maintenance reduces the probability of equipment breakdowns. The additional benefit comes from the need to perform maintenance only when the need is imminent, not after the passage of a specified period of time [7,9].

2.3. Aggressive maintenance

An aggressive maintenance strategy goes beyond efforts to avoid equipment failures. An aggressive maintenance strategy, like TPM, seeks to improve overall equipment operation. Maintenance may participate in these improvements through involvement in efforts to improve the design of new and existing equipment.

TPM is a philosophy of maintenance management developed in Japanese manufacturing plants to support the implementation of just-in-time manufacturing, advanced manufacturing technologies and to support efforts at improving product quality. TPM activities focus on eliminating the "six major losses". These losses include equipment failure, set-up and adjustment time, idling and minor stoppages, reduced speed, defects in process and reduced yield [10].

TPM has been described as a partnership approach to maintenance [11]. Under TPM, small groups or teams create a cooperative relationship between maintenance and production that helps in the accomplishment of maintenance work. Additionally, production workers become involved in performing maintenance work allowing them to play a role in equipment monitoring and upkeep. This raises the skill of production workers and allows them to be more effective in maintaining equipment in good condition.

Team-based activities play an important role in TPM. Team-based activities involve groups from maintenance, production and engineering. The technical skill of engineers and the experience of maintenance workers and equipment operators are communicated through these teams [9]. The objective of these team-based activities is to improve equipment performance through better communication of current and potential equipment problems [12,13]. Maintainability improvement and maintenance prevention are two team-based TPM activities.

Maintenance prevention teams work to improve equipment performance through improved equipment design. The maintenance function works with the engineering department during the early stages of equipment design. This allows the team to design and install equipment that is easy to maintain and operate [12,14].

Maintainability improvement teams work to improve the ways in which maintenance is performed [9]. Maintenance, production workers, craftworkers and engineers work together to identify and correct conditions that make maintenance difficult [15,16]. This allows the full range of solutions to be considered and deployed as appropriate.

Maintenance involvement in team-based activities has several benefits. The efforts of maintenance improvement teams should result in improved equipment availability and reduced maintenance costs. Maintainability improvement should result in increased maintenance efficiency and reduced repair time.

3. The research methodology

The information reported here is a part of a survey of maintenance management practices. To be included in the sample, each plant had to be primarily involved in a metalworking industry. The industries included: primary metals (Standard Industrial Classification (SIC) 33), fabricated metal products (SIC 34), industrial and metalworking machinery (SIC 35), precision instruments (SIC 36), and transportation equipment (SIC 37).

The plants included in the survey sample were identified using the Harris Indiana Industrial Index [17]. The survey was sent to the maintenance manager and production manager at each plant in the sample. A total of 708 surveys were sent to 354 plants. To encourage response rates, the surveys were addressed directly to the individual. The name of the plant manager was obtained from the Harris Directory. The name of the maintenance manager was obtained by placing a telephone call to each plant. The survey respondents included 125 plant managers (43.6%) and 162 (56.4%) maintenance managers with dual responses received from 56 plants. The 287 responses represent a response rate of 40.5%. For plants with dual responses, the average of the responses is used. Comparison of responding plants to non-responding plants on the basis of size, age and industry showed that no response bias occurred.

Respondents were asked to provide information about the operating characteristics of their plants. This information is shown in Table 1. The number of employees reported ranged from very small at 37 employees to very large at 13,730 employees, with

Table 1
Characteristics of respondent plants

	Percent
Number of employees	
Less than 200	16.0
200–500 employees	48.5
500–1000 employees	16.9
More than 1000 employees	14.3
Unknown	4.3
Maintenance employees	
Less than 20 maintenance employees	46.3
20–50 maintenance employees	26.9
50–100 maintenance employees	13.0
100–500 maintenance employees	10.8
More than 500 maintenance employees	2.6
Unknown	0.4
Annual maintenance budget	
Less than $1 million	24.2
$1–5 million	28.6
$5–15 million	10.0
More than $15 million	6.1
Unknown	31.1

a mean of 710. The size of the maintenance department ranged from 0 to 3500 employees, with a mean of 67. The highest proportion of plants was between 25 and 50 years old.

3.1. Measures

A brief discussion of the measures used in the study follows. The actual survey questions are shown in the appendix.

Maintenance practices. To measure maintenance practices, respondents were asked to report the level of importance that their maintenance department placed on nine different maintenance activities (e.g., monitoring the production equipment status, analyzing equipment failure causes and effects, restoring equipment to operation).

Performance measures. To assess performance, respondents were asked to report the level of maintenance contribution to improvements in product quality, equipment availability and reduction in production costs in the previous two years. Responses were recorded using a five-point Likert-type scale (1 = less than 20% of performance improvement was the result of maintenance efforts, 5 = more than 80% of performance improvement was the result of maintenance efforts).

3.2. Data analysis

In this section, the statistical methods used to analyze the data are discussed. The analysis was done in two steps. First, it was necessary to derive constructs for the different maintenance strategies. Second, the performance implications of the strategies were tested.

3.2.1. Identification of maintenance approaches

As a first step, it was necessary see if it was possible to empirically derive constructs consistent with the three maintenance strategies. To check for underlying dimensions, the nine questions concerning specific maintenance practices were examined using exploratory factor analysis. The relationships between the different maintenance practices were analyzed using principal component factor analysis with varimax rotation. This procedure produced three factors representing different maintenance strategies, each factor having an eigenvalue greater than 1.0. These three factors account for 61.4% of variation. Table 2 shows zero-order correlations between the measures of maintenance practices. Table 3 shows the factor structure.

The factors may be interpreted as representing the three different maintenance strategies discussed above. Three items load on factor 1. These items, helping to improve the production process, helping to design the production process and helping the purchasing department in OEM selection, represent an improvement-oriented approach to maintenance. Factor 1 may be described as an aggressive maintenance strategy. The items loading on factor 2 include monitoring production equipment status, analyzing equipment failure causes and effects, maintaining equipment in operation and performing preventive/predictive maintenance work. These factors are all consistent with an approach to maintenance that seeks to prevent breakdowns, a proactive strategy. The two items that load on factor 3, restoring equipment to operation and installing new equipment, represent the traditional, reactive strategy for maintenance.

Table 2
Summary statistics

Variable	Means	S.D.	Correlations[a] 1	2	3	4	5	6	7	8	9	10	11	12
1. RESP1	3.64	1.21												
2. RESP2	3.85	0.95	0.38											
3. RESP3	4.68	0.61	0.08	0.16										
4. RESP4	4.38	0.80	0.20	0.27	0.15									
5. RESP5	3.82	1.04	0.24	0.39	0.04	0.46								
6. RESP6	3.56	0.95	0.01	0.03	0.32	0.08	0.01							
7. RESP7	3.34	1.18	0.33	0.27	0.07	0.20	0.15	0.14						
8. RESP8	2.72	1.30	0.29	0.34	0.08	0.14	0.22	0.23	0.72					
9. RESP9	3.07	1.27	0.21	0.28	− 0.02	0.06	0.17	0.25	0.37	0.53				
10. PERF1	2.59	1.02	0.27	0.23	− 0.11	0.09	0.19	0.05	0.20	0.20	0.17			
11. PERF2	3.22	0.96	0.25	0.18	− 0.13	0.15	0.22	0.09	0.11	0.13	0.08	0.51		
12. PERF3	2.65	0.95	0.28	0.17	− 0.09	0.08	0.24	0.04	0.19	0.21	0.21	0.54	0.40	

[a]Correlations above 0.13 are significant at $p < 0.05$.

Table 3
Factor analysis of maintenance responsibilities

Questionnaire items		Factor 1: aggressive maintenance	Factor 2: proactive maintenance	Factor 3: reactive maintenance
RESP1	Monitoring the production equipment status	0.37602	**0.48622**	− 0.10107
RESP2	Analyzing equipment failure causes and effects	0.32873	**0.63605**	0.04726
RESP3	Restoring equipment to operation	− 0.09439	0.18630	**0.81371**
RESP4	Maintaining equipment in operation	− 0.03323	**0.75225**	0.19772
RESP5	Performing preventive/predictive maintenance work	0.07879	**0.78673**	− 0.07566
RESP6	Installing new equipment	0.29266	− 0.14053	**0.74331**
RESP7	Helping improve the production process	**0.78775**	0.19018	0.08352
RESP8	Helping design the production process	**0.86721**	0.16767	0.09528
RESP9	Helping the purchasing department in original equipment (OEM) manufacturer selection	**0.75363**	0.04875	0.03142
	Eigenvalue	2.29190	1.94690	1.28893
	Percentage of variance explained	25.5	21.6	14.3

3.3. Performance

Based on the literature, the proactive and aggressive maintenance strategies would be expected to lead to improvements in maintenance performance while a reactive strategy would hurt performance. Multiple regression analysis was used to test the relationships between maintenance strategies and performance. Table 4 shows the results of the analysis.

The first column in the table reports the results of the regression with contribution to improvement in product quality as the dependent variable. As expected, both the proactive and aggressive maintenance strategies have significant, positive relationships with the dependent variable. In contrast, reactive maintenance has a negative, marginally significant relationship with the dependent variable. The results for the other dependent variables are similar. In the second column, contribution to improvement in equipment availability, both the proactive and aggressive maintenance strategies are positive and significant while the reactive maintenance strategy is negative and marginally

Table 4
Results of regression analysis of maintenance strategies on maintenance performance[a]

Independent variables	EFF1: improvement of product quality	EFF2: improvement in equipment availability	EFF3: reduction in production costs
Factor 1: aggressive maintenance	0.253[e]	0.136[c]	0.236[e]
	(0.066)	(0.063)	(0.061)
Factor 2: proactive maintenance	0.194[d]	0.212[e]	0.183[d]
	(0.065)	(0.062)	(0.060)
Factor 3: reactive maintenance	− 0.112[b]	− 0.107[b]	− 0.115[b]
	(0.037)	(0.065)	(0.062)
Constant	2.592[e]	3.222[e]	2.657[e]
	(0.065)	(0.063)	(0.060)
Overall F	8.963[e]	6.395[e]	9.386[e]
Adjusted R^2	0.098	0.069	0.102
N	221	220	221

[a]Standard errors are in parentheses.
[b]$p < 0.10$.
[c]$p < 0.05$.
[d]$p < 0.01$.
[e]$p < 0.001$.

significant. Finally, with contribution to reduction in production costs as the dependent variable, the proactive and aggressive maintenance strategies are positive and significant and the reactive maintenance strategy has a significant negative coefficient.

4. Discussion

The intent of this paper was to explore different maintenance strategies and their relationship with maintenance and plant performance. The results of the exploratory factor analysis are consistent with the three different maintenance strategies described in the literature. Factor 3 is consistent with the traditional reactive strategy for managing maintenance. Under this approach, maintenance views its role as installing equipment and repairing equipment once it breaks.

Factor 2 is consistent with a proactive strategy for maintenance. Performing predictive and preventive maintenance are activities that will help a plant proactively avoid equipment failures. The other activities that load onto this factor are also consistent with a proactive approach. Indeed, monitoring production equipment status and analyzing equipment failure causes and effects provide support for knowing how often to perform preventive maintenance and which equipment conditions to monitor through predictive maintenance.

Factor 1 represents the aggressive strategy for maintenance. The activities that load on this factor represent aggressive maintenance involvement in improving equipment performance. The activities, helping to design and improve the production process and assisting in OEM selection, reflect a maintenance organization that interacts with other functional areas to identify equipment design improvements.

According to the literature, the three different maintenance strategies outlined above are expected to have differing impacts on performance. Proactive and aggressive maintenance strategies are expected to be associated with improved performance. A reactive maintenance strategy is expected to be associated with lower performance. The regression analysis bears out these expectations. The reactive strategy has a marginally significant negative relationship with all three performance measures. Both the proactive and aggressive strategies have significant positive relationships with the measures of performance.

4.1. Managerial implications

The constructs extracted through factor analysis can be useful to managers developing maintenance strategies. Managers will not only be aware of the performance implications of the different strategies, they can understand some of the practices necessary to support each of the strategies. For example, in the case of the proactive strategy, preventive and predictive maintenance activities should be accompanied by equipment monitoring and analysis. Likewise, an aggressive maintenance strategy can include contributions to design changes in both new and existing equipment.

The findings on performance can also help in justifying the use of these strategies. As stated earlier, the proactive and aggressive approaches require increased levels of maintenance training, resources and integration. By demonstrating the impact that these strategies can have on plant performance, managers may be more comfortable in making these investments in maintenance.

Appendix. Questionnaire items

Maintenance tasks

How much emphasis is placed on each of the following activities as *responsibilities of your plant's maintenance department*? (circle number)

	Not applicable	Not important		Somewhat important		One of the most important
Monitoring the production equipment status	0	1	2	3	4	5
Analyzing equipment failure causes and effects	0	1	2	3	4	5
Restoring equipment to operation	0	1	2	3	4	5
Maintaining equipment in operation	0	1	2	3	4	5
Performing preventive/predictive maintenance work	0	1	2	3	4	5
Installing new equipment	0	1	2	3	4	5
Helping improve the production process	0	1	2	3	4	5
Helping design the production process	0	1	2	3	4	5
Helping the purchasing department in original equipment manufacturer (OEM) selection	0	1	2	3	4	5

Performance

	Less than 20% of performance improvement was the result of maintenance efforts		About 50% of performance improvement was the result of maintenance efforts		More than 80% of performance improvement was the result of maintenance efforts
Over the past two years, how much has maintenance contributed to the *improvement of product quality*?	1	2	3	4	5
Over the past two years, how much has maintenance contributed to the *improvement of equipment availability*?	1	2	3	4	5
Over the past two years, how much has maintenance contributed to the *reduction of production costs*?	1	2	3	4	5

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