Changing Role of Maintenance in Business Organizations: Measurement versus Strategic Orientation

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This is a post-print (ie final draft post-refereeing) of an article published in International Journal of Production Research, available online at: http://dx.doi.org/10.1080/00207543.2015.1106611.

Citation: Simões, Jorge, Gomes, Carlos F. e Yasin, Mahmoud M. (2016) "Changing Role of Maintenance in Business Organizations: Measurement versus Strategic Orientation", International Journal of Production Research, 54(11), pp. 3329-3346. http://dx.doi.org/10.1080/00207543.2015.1106611.

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ABSTRACT

The purpose of this study is to examine the nature of performance measures utilized by the maintenance function in today's business organizations. In the process, the increasing variety and significance of these measures are addressed from operational and strategic perspectives. A survey-based research method was utilized to gather the research data. Several statistical procedures were utilized to analyse the data. The findings of this study point to the multifaceted nature of the maintenance measures and measurement. Multiple categories of maintenance measures were identified. These categories varied from the machine-specific, to measures impacting organizational performance. The relative lack of emphasis placed on the environment and strategic facets of maintenance is noted. The findings of this study have direct implications to organizations, which are attempting to measure the effectiveness of their maintenance efforts. The need to align the maintenance performance efforts with the organizational strategic direction is emphasized. In this context, the integration of the maintenance performance information systems with the overall organizational performance management information system might facilitate the needed alignment. This study utilizes 120 maintenance measures. As such, it represents a comprehensive view of the maintenance effort.

Keywords: Maintenance management**;** Maintenance planning; Operations strategy; Benchmarking; Business information systems; Performance measures.

1. INTRODUCTION

Closed system organizations of the near past either ignored the maintenance function, or incorporated it into the rework aspect of operations. The focus of the closed system organizations with regard to maintenance was on the machine. In this context, keeping the machines running meant more production, leading to higher efficiency. In such operational environment, maintenance was reactive in nature. Maintenance management was not a popular term, as there were not too many dimensions and aspects of maintenance to manage (Simões, Gomes, and Yasin 2011).

The advent of new operational technologies gave more relevance to maintenance (Swanson 1997). Environmental factors, such as increased emphasis on reduction of waste, also gave more importance to the maintenance function of the organizations (Cooke 2003). The increased competitive pressure forced organizations to utilize reliability and dependability, as a competitive weapon. This, in turn, enhanced the role of maintenance in the business organizations. On one hand, daily production activities, such as planning (Fitouhi and Nourelfath 2014), scheduling (Luo, Cheng, and Ji 2015; Lu, Cui, and Han 2014), assigning procedures (Ishizaka and Nemery 2014), and quality control (Chen 2013) have been improved through the effective integration of maintenance activities. On the other hand, production procedures and politics like the quality management approach can contribute to improve maintenance performance (Maletič, Maletič, and Gomišček 2014).

In short, today's open system organizations are finding it necessary not to only manage the different aspects of maintenance, but rather to utilize maintenance management strategically. In this context, well-managed maintenance activities, resources, and different aspects require a carefully-designed strategy. This strategy must be consistent with the organization's overall strategy. In order to enhance organizational competitiveness maintenance managers are being challenged to unify maintenance activities, resources, and procedures in order so support the strategic orientation of their organizations (Al-Najjar 2007; Alsyouf 2007; Lee and Scott 2009; Robson, Trimble, and MacIntyre 2013). Both strategies should work together consistently toward the achievement of the customer-focus, open system strategic-orientation. Such customer orientation is critical to the achievement of strategic competitive advantage.

Given the growing importance of different dimensions of maintenance to the open system manufacturing organizations, this study empirically investigates the research questions below.

1. What is the nature of the different maintenance measures used in today's organizations?
2. Are measures with more relevance to the manager more likely to be used?
3. What is the rate of information availability on the extent of utilization of different maintenance measure by managers?

Exploring these relevant practical questions for 120 maintenance measures has significant practical implications to managers and researchers. As such, this study contributes to the practice and art of utilizing maintenance measures to promote organizational, operational and strategic goods.

This research study is guided by the conceptual framework in Figure 1. The figure is partially based on the available literature (Lee and Scott 2009; Simões, Gomes, and Yasin 2011; Robson, Trimble, and MacIntyre 2013). However, it also emphasizes the growing significance of maintenance in today's business organizations. As such, the importance of performance management of this critical organizational function is systematically explored.

[Insert Figure 1 here]

2. BACKGROUND AND RELEVANT LITERATURE

During the last thirty years, the global market evolution has forced organizations to continuously change their practices and processes in order to maintain and improve their competitiveness. In this context, these organizations have been using several performance measurement and management approaches to support their track to excellence (Gomes, Yasin, and Lisboa 2004a; Franco-Santos, Lucianetti, and Bourne 2012).

The examination of the recent literature reveals certain key themes of performance measurement and management approaches in response to this new century of dramatic environmental and market changes. The first key theme tends to underscore a trend towards emphasizing the dynamic nature of performance measurement and measures (Jakobsen, Nørreklit, and Mitchell 2010; Srimai, Radford, and Wright 2011; Bisbe and Malagueño 2012). The second key theme highlights the importance of information and related systems to the performance measurement process (Nudurupati et al. 2011; Bevanda, Sinkovic, and Currie 2011; Taylor and

Taylor 2013). The third key theme focuses on the need for a strategic approach to the performance measurement effort (Aracıoğlu, Zalluhoğlu, and Candemir 2013; Srimai, Radford, and Wright 2011).

The importance of the human factor to the effectiveness on the measurement process is also stressed in the literature (Tung, Baird, and Schoch 2011; Franco-Santos, Lucianetti, and Bourne 2012; Srimai, Radford, and Wright 2011). Overall, linking performance measurement and measures to continuous improvement efforts appear to be gaining more importance (Arzu Akyuz and Erman Erkan 2010; Ho, Wu, and Wu 2013; Franco-Santos, Lucianetti, and Bourne 2012).

Despite maintenance being an organizational function, its performance measurement aspect seems to be comparatively difficult (Garg and Deshmukh 2012). In the past, maintenance was seen only as a source of cost. Therefore, the maintenance performance measurement was limited to budget reporting (Garg and Deshmukh 2006). More recently, maintenance activities began to be used as a value-adding activity (Sharma, Yadava, and Deshmukh 2011; Kutucuoglu et al. 2001; Goyal and Maheshwari 2012; Kumar et al. 2013). Therefore, a multidimensional performance measurement and management approach needs to be used. However, performance measurement related to maintenance approaches which mainly focus only on cost can be found in literature (Sinkkonen et al. 2013).

The adoption of new maintenance strategies has been a strong contributor to slowly shifting away from this cost based approach. According to the literature, the most effective of these strategies is Total Productive Maintenance (TPM). It is presented as a source of organizational improvements with a strong focus on the people (Kulkarni and Dabade 2013), and as a next step to extend the benefits of the Total Quality Management (Brah and Chong 2008). It also has been a fundamental contributor to new maintenance performance measurement approaches such as the Overall Equipment Effectiveness (Garg and Deshmukh 2006), and other related broader performance measurement tools, including overall factory effectiveness (OFE), overall plant effectiveness (OPE), overall throughput effectiveness (OTE), production equipment effectiveness (PEE), overall asset effectiveness (OAE), total equipment effectiveness performance (TEEP), and manufacturing operational effectiveness (MOE)(Gomes, Yasin, and Lisboa 2007; Muchiri and Pintelon 2008)

The implementation of TPM initiatives has been used as a driver for the integration between production and maintenance strategies. In this context, the successful implementation of TPM can facilitate better performance, which lends itself to better organizational competitive advantage (Ahuja and Khamba 2008). However, this is not an easy task. Sometimes, non-successful TPM implementations can have an adverse effect, which becomes a barrier to the process of achieving organizational competitiveness (Belekoukias, Garza-reyes, and Kumar 2014).

Effective maintenance management has been stressed by literature for several reasons. Firstly, maintenance management is stressed due to the rising cost of maintenance in relation to operational costs (Garg and Deshmukh 2006). Secondly, due to the important role it plays in the facilities management (Meng 2011; Mangano and Marco 2014). Lastly, effective maintenance management is sought after due it its direct effect on the safety concerns in health-care organizations (Shohet, Lavy-Leibovich, and Bar-On 2003; Lavy and Shohet 2009).

Despite the efforts of many organizations to align their production and maintenance strategies, it appears that the measurement of maintenance performance still faces a lack of understanding. This gap has led to an under appreciation of the real value of the maintenance function for the organizational competitiveness (Berges, Galar, and Stenström 2013).

Based on an extensive literature review, three relevant themes related to maintenance performance measures, measurement, and management emerged (Simões, Gomes, and Yasin 2011). These themes include effective utilization of maintenance resources, total maintenance and information systems support, measurement, measures, and human factor management. These themes clearly incorporate the critical aspects of an effective maintenance system.

Based on a more recent literature review, it seems that not much progress has been made regarding the process of actually designing and implementing a practical maintenance performance measurement framework (Parida et al. 2015). This leaves maintenance managers with many questions and few answers when it comes to adopting practical maintenance measures and measurement processes. As such, maintenance performance measures and measurement process continues to pose a serious practical challenge to managers (Parida et al. 2015).

The literature also suggests a large number of maintenance performance indicators under various categories to assess maintenance contribution to the business objectives (Muchiri et al. 2010; Simões, Gomes, and Yasin 2011; Garg and Deshmukh 2012). However, it seems to be difficult for maintenance managers to decide the relevant performance measures to use in each situation (Muchiri et al. 2010).

Like in other performance measurement organizational contexts, measuring maintenance performance by considering only financial impacts might help to improve the internal processes of the maintenance function. However, such practice fails to measure the impact of maintenance strategies on other organizational dimensions such as production, logistics, customers, and employees (Kumar et al. 2013). In this context, well-defined maintenance performance measures can help the identification of performance gaps and provide guidance towards closing these gaps (Muchiri et al. 2010).

In order to support maintenance performance measurement approaches, effective information systems are in need. To recognize specificities of the maintenance management and their impact on the organizational performance, the maintenance management information systems began to appear in the 1980s (Garg and Deshmukh 2006). The 1980s was also the decade that marked the major changes in the way companies measured their organizational performance (Gomes, Yasin, and Lisboa 2004b).

Since that period, maintenance information systems have changed in several aspects, following the development of corporate information technologies. These changes helped to view maintenance as an integrated part of the business (Kans 2009). Thus, it is considered a strategic instrument to improve the organizational competitiveness.

In this context, the different facets of maintenance activities, resources, measures, and measurement in business organizations should be examined. The changing role of maintenance in today's organizations calls for closer, practical investigation of current maintenance activities, measures, and measurement. Such research has direct, practical implications to organizations, as they attempt to utilize maintenance competencies to support their customer-orientation strategy.

Despite the abundance of research related to performance measures, measurement, and management this has not been the case for research dealing with performance measures, measurement, and management in the area of maintenance. Such research remains scarce in terms of both theoretical development and applications. Although in recent years, such research has become broader in nature and in the process incorporated the role of information technology, human factor, and some aspects of continuous quality improvements, it still is discreet in nature and lacks an organizational-wide strategic orientation. Despite its importance, impirical research in this area aimed at the development of theory and applications is still slow in forthcoming.

The literature reviewed highlights the evolution of the role of maintenance activities. In this context, closed system organizations focused on machine-specific maintenance activities. As these organizations evolved into open systems the focus with regard to maintenance shifted toward a more integrated function. As such, they tended more to utilize preventive maintenance to increase the quality and reliability of their products. However, the literature regarding the strategic role of maintenance is still lacking. Therefore, the information of the maintenance strategy into the overall organizational strategy is still in need of further research. This leaves more room for research which aims at the practical utility of maintenance to the organization and its strategy. The current study attempts to explore the different facets of maintenance and their practical implications in today's open system organizations.

In the process, the study contributes to the scarce literature through sparking the interest in this important yet relatively neglected field of knowledge. While the aim of this current research is practical in nature, it nevertheless also challenges researchers to develop theoretical frameworks which lend themselves to offering practicing managers useful applications. As organizations move toward the open system mode of operations, such research will be valuable in defining the strategic competitive role of maintenance.

3. METHODOLOGY

3.1 Sample and Procedure

To meet the objective of this study, one thousand six hundred and five (1605) maintenance managers of Portuguese business organizations associated to APMI (Portuguese Association of Industrial Maintenance) were invited to participate on an online questionnaire.

Ninety-five (95) completed responses were received. This resulted in a response rate of approximately 6%. While the response rate is relatively low, it compares favourably with similar operations surveys (Shah and Ward 2002; Scannell, Calantone, and Melnyk 2012; Huan et al. 2008; Wu, Melnyk, and Swink 2012). Given the fact that the survey instrument was quite time-consuming to complete, the response rate is considered reasonable.

According to Table 1, the sample includes business organizations from different industries. These business organizations represent different sizes, both in terms of the number of employees, as well as in terms of the number of machines requiring regular maintenance.

[Insert Table 1 here]

3.2 Instrument

The instrument utilized for the purpose of this study was designed based on an extensive literature review (Simões, Gomes, and Yasin 2011) and interviews with maintenance managers. Initially, the instrument utilized was subject to acclimatization to suit the Portuguese manufacturing practices. Upon completion of the initial stage, the instrument submitted to a group of professionals, consisting of practitioners and academicians. This effort focused on ensuring the utilization of terms that are familiar to the participating managers.

The final version of the research instrument was composed of one hundred and twenty-four (124) maintenance performance measures. However, four measures were dropped during the data validation process. Therefore, only 120 performance measures were used in this study (Appendix). The measures utilized in this study are grouped into eight classifications. The respondents were asked to evaluate the characteristics of the different measures on a scale ranging from 1-5.

3.3 Models, Variables, and Data Analysis

The data obtained from the participants was analysed using several statistical methods in order to assess the profiles of maintenance managers with regard to the different maintenance measures utilized. Although simple in nature, these methodologies are effective and have been used in some studies related to performance measurement and management (Foster and Gupta 1994; Dempsey et al. 1997; Gomes, Yasin, and Lisboa 2004a; Gomes, Yasin, and Lisboa 2006; Gomes, Yasin, and Lisboa 2011).

Firstly, cluster analyses were performed on the predicated values (relevance, extent of use, and availability of information) pertaining to the 120 maintenance performance measures. The number of clusters was set to five in order to be consistent with scale used in the questionnaire (Dempsey et al. 1997; Gomes, Yasin, and Lisboa 2004a; Gomes, Yasin, and Lisboa 2006; Gomes, Yasin, and Lisboa 2011).

Secondly, multiple regression was applied to test the linear relationship between frequency of use (FU) as a dependent variable, and both predicted value (PV) and information availability (EA) as independent variables. The model tested is shown below.

$$\mathbf{FU = f\ (PV, EA)}$$

The linear function to be estimated is:

$$\overline{\mathbf{FU}_i} = \alpha_0 + \alpha_1 \overline{\mathbf{PV}_i} + \alpha_2 \overline{\mathbf{EA}_i} + \mathbf{e}_i$$

$\overline{FU_i}$ - The mean frequency of use score on the ith measure,

$\overline{PV_i}$ - The mean predictive value score on the ith measure,

$\overline{EA_i}$ - The mean ease of acquisition score on the ith measure,

e_i - Variable that represents the residual

α_0, α_1 e α_2 - Linear parameters

The use of the linear function is appropriate and predictive, as there was no evidence of a nonlinear relationship in the literature. The managers interviewed deemed the linear function appealing and realistic.

The observation unit used for this model is the average of the responses of all maintenance managers for each measure. The use of regression analyses in this manner is consistent with the literature (Hair, Black, Babin, & Anderson, 2009). The data gathered was analysed to verify the assumptions relevant to this model.

Thirdly, GAP analysis was employed to assess the relative significance of each performance measure. Based on the following equation, a larger GAP value indicates greater disparity between the relevance and the information availability for each performance measure.

$$GAP_i = (PV_i - EA_i)PV_i$$

4. RESULTS AND DISCUSSION

4.1 Cluster Analysis Results

Results of cluster analysis related to frequency of use of maintenance performance measures are presented in Table 2. Based on these results, nineteen performance measures from six categories were selected as the most used (Cluster 1). Two observations stand out in terms of the utilization of the maintenance performance measures. The first observation relates to the lack of measures from two categories, namely D-Maintenance strategies, and H-Environment.

As organizations are more and more open to their environment, the need to initiate, monitor, and improve performance aspects related to the environment will become more critical. In this context, the role of maintenance activities in bridging the gap between the organization and the different stakeholders in the environment will gain more relevance. Therefore, the strategic role of maintenance will take on an organizational wide importance. As such, a discrete and piece-approach to maintenance performance measures and measurements will no longer be sufficient to support the customer orientation strategic approach of the environmentally sensitive organization.

[Insert Table 2 here]

The second observation relates to the preponderance of measures from category B (Machines and equipment), leading with six measures, category A (Maintenance team), and category E (Maintenance monetary efficiency), assuring 74% of the performance measures selected as the most used. This focus on operational maintenance is not surprising. However, the non-inclusion of OEE, one of the most cited maintenance operational measures (Muchiri and Pintelon 2008), is noted. Perhaps, this could be attributed to the integrated nature of this performance measure, which includes information of different organizational sources.

Based on the cluster analysis, the least used measures were also identified, including five measures from category C (Production vs. Maintenance), two measures from G category (Maintenance organization), one measure from category E (Maintenance monetary environment), and one measure from category F (Maintenance tasks and actions).

The cluster analysis results related to the maintenance managers' perceptions of the PV are found in Table 3. In the first cluster, which include the measures with the highest predictive value, there appears to be a uniform distribution in terms of the categories of measures (i. e. A(3), B(4), C(2), D(1), E(1), and G(1)). The absence of categories F (Maintenance tasks and actions) and H (Environment) from the first cluster, with the highest predictive values is noted. Nine of the measures included in the first cluster are the same measures as in the case of the Frequency of Use. Moreover, three other performance measures were included, (B29-Reliability for each machine, A16-Trainning maintenance personnel, and D71-Preventive maintenance cost ÷ Total maintenance cost) reflecting a special concern on maintenance effectiveness. The two performance measures most used by maintenance managers are also the two with the highest predictive values.

[Insert Table 3 here]

Finally, it is to be noted that the group of measures located at the bottom of Table 3 due to having lower predictive values tended to include the same measures found in the same position in Table 2 (frequency of utilization). It also includes five more measures, which were located in cluster, four of the FU, also classified as less used measures.

Table 4 presents the results related to ease of acquisition of information of maintenance performance measures. Analysing the measures included in the first cluster reveals that A category (Maintenance team) leads with nine measures, followed by category B (Machines and equipment) with five measures, the C category (Production vs. maintenance) with three measures, the E category (Maintenance monetary independency) with two measures, and finally the F and G categories each with one measure. The D (Maintenance strategies) and H (Environment) categories are not represented in the first cluster.

The above findings have direct implications to managers and their organizations. In this context, these organizations need to consider modern information systems and related technologies in order to be able to track and improve maintenance performance measures pertaining to the environment and the strategic role of maintenance. Furthermore, these organizations stand to benefit from the training and development of their managers in order to better recognize the relevance of these measures. Such training should introduce the maintenance managers to the organizational value of these overlooked measures.

[Insert Table 4 here]

Although most of the information needed to use these maintenance performance measures is mandatory by law and by accounting regulatory procedures, two observations stand out in terms of the these measures. The first observation relates to the existence of few measures, which show a concern of maintenance managers to the organizational effectiveness. The availability of information regarding the flexibility of the maintenance team, related to the balance between types of maintenance for each machine, and to the total cost of spare cost show that maintenance managers are beginning to have an open-system approach to maintenance management.

The second observation relates the lack of measures of categories F and G, which should be a concern for Portuguese companies. Although these measures require an extra effort in the relationship between different organizational departments they can be drivers for improving and maintaining production effectiveness.

Table 4 also includes the measures with highest cost of information acquisition (Cluster 5). It seems that these maintenance performance measures are consistent with the measures that were found to have the lowest predictive value and the lowest frequency of utilization.

4.2 Regression Analysis Results

As was shown in Table 1, the organizations surveyed present different sizes as measured by the number of machines with regular maintenance. Therefore, the way maintenance performance is gauged in those different organizations should be analysed. For that purpose, the model below is used.

$$\overline{FU_i} = \alpha_0 + \alpha_1 \overline{PV_i} + \alpha_2 \overline{EA_i} + \alpha_3 DIM_i + e_i$$

In this model, DIM_i is the binary variable which assumes the value of 1, if a maintenance manager represents an organization with more than 249 machines. On the other hand, it assumes the value of 0 if a maintenance manager represents an organization with less than 150 machines.

The regression results show that the model explained 92.5% of the variations in the frequency of use (Table 5), without statistical significance ($\alpha<0.05$) for the variable DIM.

[Insert Table 5 here]

Therefore, it is concluded that no significant differences exist between organizations with a small number of machines and their counterparts with a larger number of machines with respect to their profile of maintenance performance measures utilization.

Based on the results of this analysis, the above model was abandoned in favour of the general model initially proposed in the methodology section. Therefore, the linear function to be estimated is:

$$\overline{FU}_i = \alpha_0 + \alpha_1 \overline{PV}_i + \alpha_2 \overline{EA}_i + e_i$$

Based on the results, it seems that 94.2% of the variability of the Frequency of Use of maintenance performance measures can be explained by the Predictive Value and Ease of information Acquisition (Table 6). This means that once managers have the needed information pertaining to relevant measures, they are more likely to use such measures. This provides additional justification for the organizational investment in integrated information systems which are designed to make information on relevant measures readily available.

[Insert Table 6 here]

In order to analyse the deviation of performance measures from the behaviour profile identified by the regression model, the residual errors from the estimated profile were analysed (Table 7).

[Insert Table 7 here]

Seven of the nine most commonly used measures belong to *Maintenance tasks and actions* category, while the other two belong to *Maintenance team* category and *Production vs maintenance*. On the other hand, five of the thirteen of the least commonly used measures belong to *Production vs. maintenance* category, four belong to the *Maintenance strategies* category, two belong to *Machines and equipment* category, one belongs to the *Maintenance tasks and actions* category, and one belongs to the *Maintenance organization* category.

4.3 Gap Analysis results

In order to better analyse the disparity between the usefulness of the measure and its information availability from the perspective of the maintenance managers, two groups were identified. The first group includes the measures with negative values for the gap indicator (Table 8a). In relation to these measures, it is confirmed that available information exits in excess, since most of the measures can be extracted directly or indirectly from existing documents of business organizations. However, the inclusion of measures of categories H-Environment and D-Maintenance strategies is to be noted. These measures were not selected for the first cluster of Table 2. This means that, although they are the measures with more excess of information related to their predictive value, they are not the most used measures. Due to the nature of these measures, this should be an important concern for executives of business organizations.

[Insert Table 8a here]

The second group includes the measures with positive values above the average (0.0577) for the GAP (Table 8b). The inclusion of Overall Equipment Effectiveness (OEE) confirms the observation made earlier concerning the importance of this performance measure.

[Insert Table 8b here]

Based on the cluster analysis, it is obvious that some measures are used more so than other measures. Based on the regression analysis, it appears that the predicted value of the given measure is the greatest predictor of the frequency of the utilization of that measure.

Therefore, organizations should train their managers in identifying and using measures with high predictive values. In addition, organizations should make information about relevant measures measures with high predictive values) more readily available, as the ease of acquiring information was also found to be a predictor of the frequency of use of a given measure.

5. CONCLUSION AND IMPLICATIONS

This study sought to further our understanding of the current maintenance practices and their implications to Portuguese organizations. Data related to one-hundred and twenty (120) maintenance measures was collected from ninety-five (95) Portuguese maintenance managers. Cluster analysis, regression analysis, and GAP analysis were utilized for the purpose of this study. Based on the obtained results the following conclusions and implications are in order.

First, for the most part, the results appear to indicate consistency among usage, implementation, and accessibility of information with regards to measures that were analysed. Their rationale for using most of the studied measures seems to be attributed to the managers' perceptions of the measures' predictive values. The results show that maintenance managers, for the most part, are using measures which have relevance to the different facets of the maintenance process. Overall, information related to the most used measures appears to be readily available. In this context, the underutilization of measures of the environmental category, and the strategic category requires closer attention and actions from management. While such measures are gaining relevance in today's open system organizational environment, they are not being sufficiently used due to lack of information on such measures. As such, most organizational cultures of the studied organizations need to be modified in order to emphasize more the value placed on such measures. In addition, organizational investments in information systems to gather, organize, and utilize information related to such measures must be given priority. The lack of information in relation to such emerging measures might lead to negative strategic competitive implications.

Second, maintenance managers, in some cases, are utilizing some measures simply because information on such measures is readily and routinely available. This leads to overemphasizing the utilization of such measures despite their relative lack of relevance (predictive value). The end result, therefore, is unjustified utilization of unimportant measures. Modifying the existing information systems might result in shifting the focus of the utilization of the maintenance measures more toward the relevant rather than the mere availability of information.

Third, there are some measures with high predictive value, which are not being used extensively. These measures include important performance-oriented measures such as training of maintenance personnel, reliability for machines, and cost of preventive maintenance. The maintenance performance implications of these measures require a close examination of their relative lack of use. The relative use of such important measures might be attributed to lack of information, or organizational cultural elements. In either case, management should have a well-designed plan of action to rectify this problem.

Finally, despite the increasing number of maintenance measures in the studied business organizations, management of these organizations should be concerned about the apparent lack of depth and scope of the utilization of some of these measures. The majority of the study's measures tended to focus on single and machine-specific measures. These measures are efficiency based, rather than system-wide effectiveness based. Therefore, although the number of maintenance measures appears to be increasing, the emphasis of the maintenance function and its efficiency appears to still be operational with a closed system orientation. Measures linked to the strategic and open system orientation of today's business organizations are still being underutilized. Therefore, managerial action is needed in order to incorporate the strategic element into the maintenance function. This should help toward aligning the maintenance strategy with the overall organizational open system strategic orientation. This in turn might lead to improvement in organizational performance, through the enhancement of customer orientation.

The conceptual framework in Figure 2 is designed to assist the maintenance managers in their effort to coordinate and manage the different facets of the important maintenance function. The framework also offers a systematic approach, which could be utilized toward a more effective utilization of the different maintenance performance measures. In the process, this might facilitate the alignment of the maintenance efficiency with the organizational open system strategic orientation. Future research is called for in this practical and organizational critical area. The framework offered in Figure 2 also might be used as a first step in that direction. Figure 2 is consistent with the main contribution of this study, which is to spark interest among researchers in this important, yet relatively neglected area.

In this context researchers are encouraged to test the approach advocated in Figure 2 in different cultural settings and research methodologies. The methodology utilized in this study is simple, yet practical. The maintenance body of knowledge stands to benefit from utilizing different methodologies. A stream of future research with different samples, methodologies and conceptual frameworks is needed in order to refine the theory and practice of organizational role of the maintenance activities and resources.

[Insert Figure 2 here]

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APPENDIX

Exhibit 1a – Measures used on questionnaire

A.	**MAINTENANCE TEAM**
1	Technicians seniority
2	No. of apprentices ÷ No. of senior technicians
3	Turnover of maintenance technicians
4	Rate of absentees for the maintenance team
5	Flexibility of the maintenance team
6	Cost of maintenance personnel ÷ total personnel cost
7	Labour costs of maintenance team (€/hour)
8	No. of overtime hours worked by the maintenance team
9	Equal employment opportunity for maintenance positions (gender, race or religion)
10	Available maintenance capacity (hours)
11	Rate of utilization of the maintenance capacity (persons)
12	Percentage of factory space allocated to the maintenance team
13	Level of satisfaction of the maintenance technicians
14	Relations between managers and maintenance technicians
15	No. of hours spent on operational maintenance ÷ total no. of hours of maintenance performed (operational+management+engineering)
16	Training of maintenance personnel (hours)
17	Maintenance training hours per person, during working hours.
18	Maintenance training hours ÷ maintenance planned training hours
19	No. of actual maintenance training hours ÷ no. of actual maintenance hours
20	Percentage of maintenance budget allocated to salary
21	Operational maintenance costs per technician
22	Insurance plans (life, health, and education)
23	Safety record
24	Incentive plans (e.g. profit sharing)
B.	**MACHINES AND EQUIPMENT**
25	Energy consumption per machine
26	Age of plant(s) and Machine(s)
27	Machine age
28	Failure rate for each machine
29	Reliability for each machine
30	Percentage of machine downtime
31	Utilization rate of each machine
32	Machine speed loss
33	Percentage of availability of each machine
34	Machine availability ÷ Planned production time for that machine
35	Production quantity (output) for each machine
36	Repair cost for each machine
37	Percentage of unavailable machines due to waiting for maintenance
38	Percentage of downtime for machine due maintenance
39	Percentage of machines with a documented functional diagnostic checklist
40	Percentage of documented maintenance procedures
41	Percentage of machines with full documented technical specifications
42	Percentage of conform products produced by each machine
43	Mean time to failure (MTTF) for each machine
44	Mean time to repair (MTTR) for each machine
45	Mean time between failure (MTBF) for each machine
46	Mean time between repairs (MTBR) for each machine
47	Mean time to first failure for each machine

Exhibit 1b – Measures used on questionnaire

48	Minimum time for repair machine
49	Minimum time expected for machine repair
50	Overall Equipment Effectiveness (OEE)
C.	**PRODUCTION VS MAINTENANCE**
51	Delays in communicating machine breakdowns
52	Percentage of delays in the delivery of maintenance services
53	Complaints about repairs within one week period
54	No. of complaints from machine operators
55	No. of breakdowns with negative impact on customer satisfaction
56	Percentage of maintenance services rejected by operators
57	Surveys of machine operators regarding maintenance services
58	Disputes between machine operators and maintenance technicians
59	No. of customer complaints attribute to machine breakdowns
60	No. of senior maintenance technicians ÷ no. of production operational managers
61	Machine Adjustments and setup time ÷ total time maintenance
62	Percentage of downtime of the entire production system
63	No. of products not produced due to maintenance stoppages
64	Units produced ÷ given time unit
65	Percentage of maintenance type for each machine
66	Preventive maintenance ÷ corrective maintenance (machine)
67	Maintenance planned ÷ unplanned maintenance (machine)
D.	**MAINTENANCE STRATEGIES**
68	Preventive maintenance hours ÷ Corrective maintenance hours
69	Immediate corrective maintenance hours÷ total maintenance hours
70	Planned maintenance hours ÷ total maintenance hours
71	Preventive maintenance cost ÷ total maintenance cost
72	Preventive maintenance cost ÷ reactive maintenance cost
73	Unplanned maintenance cost
74	Percentage of maintenance budget allocated for external services
75	Cost of outsourcing maintenance ÷ total maintenance operational costs
76	Cost of outsourced repairs ÷ total maintenance cost
77	Cost of maintenance subcontracts ÷ total maintenance cost
78	No. of external maintenance services performed
79	Rate of maintenance services subcontracted
E.	**MAINTENANCE MONETARY EFFICIENCY**
80	Scrap management cost
81	Total cost of spare parts in stock ÷ replacement cost of the machines
82	Total cost of spare parts in stock
83	Maintenance budget
84	Maintenance budget ÷ replacement cost of the entire plant
85	Replacement cost of all machines
86	Rate of utilization of maintenance budget
87	Total cost of spare parts
88	Maintenance total cost ÷ total cost of goods sold
89	Maintenance cost per aggregate unit sold
90	Maintenance cost ÷ production cost
91	Future investment needs for maintenance
92	Percentage of critical machines
93	Percentage of machine subject to regular analysis of condition based maintenance and to inspections

Exhibit 1c – Measures used on questionnaire

94	No. of problems found by analysis of condition based maintenance and by inspections
95	Maintenance budget ÷ total net sales
96	Percentage of maintenance budget allocated to buildings
97	Process maintenance budget ÷ total maintenance budget
98	Percentage of maintenance budget for spare parts and materials
99	Acquisition cost of machines.
F.	**MAINTENANCE TASKS AND ACTIONS**
100	Cost of spare parts damaged during repair process
101	Average cost per repair order
102	No. of maintenance occurrences
103	No. of efficiency/quality/safety improvements undertaken by the maintenance team
104	Delays in providing maintenance service
106	Percentage of repairs that were initiated but delayed
106	Time elapsed between the request and the completion of maintenance service
107	Percentage of repeated repairs within the first 24 hours after completing the service
G.	**MAINTENANCE ORGANIZATION**
108	No. of delays due to lack of repair tools
109	No. of delays in repair due to lack of spare parts
110	Average no. of repairs on the waiting list
111	No. of maintenance work orders completed per day
112	Percentage of spare parts not found when needed
113	Actual services performed ÷ services planned
114	Rate maintenance plan execution
115	Maintenance procedure quality
116	Average response time of the maintenance team
117	Variance response time of the maintenance team
H.	**ENVIRONMENT**
118	Pollution level (noise/water/air)
119	Actual environmental policy implemented ÷ targeted environmental policy
120	Energy consumption per unit produced

Table 1 – Sample Profile

Item	Frequency	Percentage
Number of employers		
Less than 10	5	5.26
From 10 to 49	11	11.58
From 50 to 250	40	42.11
More than 250	39	41.05
Total:	95	100.00
Machines with regular maintenance		
Less than 10	9	9.47
From 10 to 49	28	29.47
From 50 to 149	17	17.90
From 150 to 249	9	9.47
From 250 to 499	11	11.58
More than 500	10	10.53
No response	11	11.58
Total:	95	100.00
Industry		
Basic metals, and metal products	13	13.68
Electricity, gas and water supply	13	13.68
Food products, beverages and tobacco	10	10.52
Pulp, paper, and paper products	6	6.32
Chemical products	6	6.32
Car vehicles, and motorcycles	5	5.26
Ceramic products	5	5.26
Construction	3	3.16
Electronic products, and semiconductors	3	3.16
Logistics	3	3.16
Mining / Extraction and processing stone	3	3.16
Plastic products	3	3.16
Transportation	3	3.16
Miscellaneous (with less than three occurrences)	19	20.00
Total:	95	100.00

Table 2 – Cluster Analysis Results Relative to Frequency of Use Measures

Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
1	Maintenance budget	E83	3.83	1.22	0.32
	Repair cost for each machine	B36	3.74	1.18	0.32
	Utilization rate of each machine	B31	3.69	1.28	0.35
	Safety record	A23	3.62	1.52	0.42
	Rate maintenance plan execution	G114	3.60	1.25	0.35
	Labour costs of maintenance team (€/hour)	A07	3.56	1.27	0.36
	Flexibility of the maintenance team	A05	3.52	1.33	0.38
	Production quantity (output) for each machine	B35	3.52	1.40	0.40
	Percentage of maintenance type for each machine	C65	3.51	1.26	0.36
	Total cost of spare parts	E87	3.51	1.37	0.39
	No. of maintenance occurrences	F102	3.46	1.23	0.36
	Number of overtime hours worked by the maintenance team	A08	3.45	1.40	0.41
	Acquisition cost of machines.	E99	3.43	1.38	0.40
	Percentage of machine downtime	B30	3.41	1.40	0.41
	Units produced ÷ given time unit	C64	3.41	1.39	0.41
	Preventive maintenance ÷ corrective maintenance (machine)	C66	3.41	1.34	0.39
	Percentage of availability of each machine	B33	3.40	1.34	0.39
	Future investment needs for maintenance	E91	3.40	1.17	0.34
	Machine availability ÷ planned production time for that machine	B34	3.36	1.36	0.40
Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
5	Complaints about repairs within one week period	C53	2.23	1.39	0.62
	No. of senior maintenance technicians ÷ no. of production operational managers	C60	2.20	1.15	0.52
	Scrap management cost	E80	2.20	1.34	0.61
	Surveys of machine operators regarding maintenance services	C57	2.12	1.29	0.61
	Percentage of spare parts not found when needed	G112	2.09	1.15	0.55
	Percentage of maintenance services rejected by operators	C56	2.06	1.20	0.58
	Percentage of repeated repairs within the first 24 hours after completing the service	F107	2.03	1.18	0.58
	Disputes between machine operators and maintenance technicians	C58	1.91	1.12	0.59
	No. of delays due to lack of repair tools	G108	1.89	1.09	0.58

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 3 – Cluster Analysis Results Relative to Predictive Value Measures

Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
1	Maintenance budget	E83	3.88	1.04	0.27
	Repair cost for each machine	B36	3.87	1.01	0.26
	Production quantity (output) for each machine	B35	3.80	1.17	0.31
	Percentage of maintenance type for each machine	C65	3.80	1.15	0.30
	Utilization rate of each machine	B31	3.79	1.17	0.31
	Rate maintenance plan execution	G114	3.79	1.19	0.31
	Flexibility of the maintenance team	A05	3.69	1.16	0.31
	Preventive maintenance ÷ corrective maintenance (machine)	C66	3.69	1.20	0.33
	Reliability for each machine	B29	3.68	1.11	0.30
	Training of maintenance personnel (hours)	A16	3.67	1.09	0.30
	Preventive maintenance cost ÷ total maintenance cost	D71	3.67	1.09	0.30
	Labour costs of maintenance team (€/hour)	A07	3.66	1.21	0.33
Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
5	Cost of spare parts damaged during repair process	F100	2.64	1.19	0.45
	Percentage of repeated repairs within the first 24 hours after completing the service	F107	2.64	1.36	0.52
	Percentage of factory space allocated to the maintenance team	A12	2.63	1.21	0.46
	Maintenance cost per aggregate unit sold	E89	2.63	1.40	0.53
	Complaints about repairs within one week period	C53	2.60	1.40	0.54
	Percentage of spare parts not found when needed	G112	2.60	1.26	0.48
	Equal employment opportunity for maintenance positions	A09	2.56	1.43	0.56
	Incentive plans (e.g. profit sharing)	A24	2.52	1.37	0.54
	Surveys of machine operators regarding maintenance services	C57	2.50	1.31	0.52
	No. of delays due to lack of repair tools	G108	2.48	1.33	0.54
	No. of senior maintenance technicians ÷ no. of production operational managers	C60	2.47	1.21	0.49
	Percentage of maintenance services rejected by operators	C56	2.46	1.26	0.51
	Scrap management cost	E80	2.38	1.34	0.56
	Disputes between machine operators and maintenance technicians	C58	2.27	1.25	0.55

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 4 – Cluster Analysis Results Relative to Ease of Information Acquisition Measures

Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
1	Labour costs of maintenance team (€/hour)	A07	3.84	1.15	0.30
	Technicians seniority	A01	3.82	0.99	0.26
	Safety record	A23	3.80	1.41	0.37
	Production quantity (output) for each machine	B35	3.71	1.30	0.35
	Training of maintenance personnel (hours)	A16	3.70	1.14	0.31
	Utilization rate of each machine	B31	3.70	1.33	0.36
	Flexibility of the maintenance team	A05	3.69	1.16	0.31
	No. of overtime hours worked by the maintenance team	A08	3.69	1.30	0.35
	Rate maintenance plan execution	G114	3.69	1.27	0.34
	Maintenance budget	E83	3.68	1.20	0.33
	Repair cost for each machine	B36	3.66	1.12	0.31
	Available maintenance capacity (hours)	A10	3.63	1.10	0.30
	Rate of absentees for the maintenance team	A04	3.61	1.39	0.39
	Percentage of maintenance type for each machine	C65	3.61	1.26	0.35
	Total cost of spare parts	E87	3.60	1.24	0.34
	Cost of maintenance personnel ÷ total personnel cost	A06	3.56	1.25	0.35
	Units produced ÷ given time unit	C64	3.56	1.38	0.39
	Age of plant(s) and machine(s)	B26	3.55	1.22	0.34
	Machine age	B27	3.55	1.17	0.33
	Preventive maintenance ÷ corrective maintenance (machine)	C66	3.52	1.27	0.36
	No. of maintenance occurrences	F102	3.52	1.28	0.36
Cluster	Measure	Cat.	Mean	Stand. Devia.	Coeffic. Variat.
5	Complaints about repairs within one week period	C53	2.45	1.46	0.60
	Scrap management cost	E80	2.43	1.42	0.58
	Percentage of maintenance services rejected by operators	C56	2.29	1.32	0.58
	Percentage of spare parts not found when needed	G112	2.27	1.21	0.53
	Surveys of machine operators regarding maintenance services	C57	2.23	1.32	0.59
	No. of delays due to lack of repair tools	G108	2.17	1.24	0.57
	Disputes between machine operators and maintenance technicians	C58	2.05	1.18	0.58

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 5 – Regression Results Based on Dimension (No. of machines)

	R	R^2	Adjusted R^2	Std. Error of the Estimate	
	0.962	0.925	0.924	0.128	
	Unstandard. Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	-0.649	0.068	-----	-9.492	0.000
PV	0.741	0.038	0.658	19.487	0.000
EA	0.387	0.039	0.340	10.017	0.000
DIM	0.024	0.017	0.026	1.434	0.153

Table 6 – Regression Results Based on all sample

	R	R^2	Adjusted R^2	Std. Error of the Estimate	
	0.971	0.942	0.941	0.1046	

	Unstandard. Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	-0.702	0.121	-----	-8.447	0.000
PV	0.711	0.051	0.617	13.966	0.000
EA	0.426	0.049	0.386	8.729	0.000

Table 7 –Departure of Residual Errors from the Estimated Profile

Measure	Category	Standardized Residual
Significant positive residuals (more use)		
Acquisition cost of machines.	E99	2.42
Safety record	A23	2.11
Maintenance budget	E83	1.95
No. of complaints from machine operators	C54	1.95
Scrap management cost	E80	1.66
Rate of utilization of maintenance budget	E86	1.64
Percentage of maintenance budget allocated to buildings	E96	1.56
Total cost of spare parts	E87	1.53
Percentage of critical machines	E92	1.30
Significant negative residuals (less use)		
No. of apprentices ÷ No. of senior technicians	A02	-2.92
Turnover of maintenance technicians	A03	-2.46
Percentage of repeated repairs within the first 24 hours after completing the service	F107	-2.02
Preventive maintenance cost ÷ reactive maintenance cost	D72	-1.82
No. of external maintenance services performed	D78	-1.75
No. of actual maintenance training hours ÷ No. of actual maintenance hours	A19	-1.58
Age of plant(s) and equipment(s)	B26	-1.52
Training of maintenance personnel (hours)	A16	-1.48
Technicians seniority	A01	-1.48
Cost of outsourced repairs ÷ total maintenance cost	D76	-1.48
Cost of maintenance subcontracts ÷ total maintenance cost	D77	-1.47
No. of delays in repair due to lack of spare parts	G109	-1.34
Reliability for each machine	B29	-1.31

Note: Measures with significant standardized residuals (α=.1)

Table 8a – Measures with a Negative Gap Indicator

Rank	Measure	Cat	PV	EA	GAP
90	Actual environmental policy implemented ÷ targeted environmental policy	H119	3.47	3.48	-0.03
91	Maintenance training hours per person, during working hours.	A17	2.94	2.96	-0.06
92	Maintenance total cost ÷ total cost of goods sold	E88	3.09	3.11	-0.06
93	Total cost of spare parts in stock ÷ replacement cost of the machines	E81	2.90	2.93	-0.09
94	Training of maintenance personnel (hours)	A16	3.67	3.70	-0.11
95	Scrap management cost	E80	2.38	2.43	-0.12
96	Cost of outsourced repairs ÷ total maintenance cost	D76	3.20	3.24	-0.13
97	Cost of maintenance subcontracts ÷ total maintenance cost	D77	3.19	3.23	-0.13
98	Pollution level (noise/water/air)	H118	2.91	2.96	-0.15
99	Available maintenance capacity (hours)	A10	3.57	3.63	-0.21
100	Total cost of spare parts	E87	3.54	3.60	-0.21
101	Rate of maintenance services subcontracted	D79	2.90	2.99	-0.26
102	Acquisition cost of machines.	E99	3.38	3.46	-0.27
103	Age of plant(s) and equipment(s)	B26	3.47	3.55	-0.28
104	Machine age	B27	3.47	3.55	-0.28
105	No. of maintenance work orders completed per day	G111	3.28	3.39	-0.36
106	No. of external maintenance services performed	D78	3.05	3.18	-0.4
107	Insurance plans (life, health, and education)	A22	2.72	2.87	-0.41
108	Percentage of factory space allocated to the maintenance team	A12	2.63	2.84	-0.55
109	No. of actual maintenance training hours ÷ no. of actual maintenance hours	A19	2.82	3.03	-0.59
110	Cost of maintenance personnel ÷ total personnel cost	A06	3.37	3.56	-0.64
111	No. of senior maintenance technicians ÷ no. of production operational managers	C60	2.47	2.73	-0.64
112	Labour costs of maintenance team (€/hour)	A07	3.66	3.84	-0.66
113	No. of overtime hours worked by the maintenance team	A08	3.44	3.69	-0.86
114	Maintenance training hours ÷ maintenance Planned training hours	A18	3.03	3.32	-0.88
115	Turnover of maintenance technicians	A03	2.73	3.09	-0.98
116	Safety record	A23	3.49	3.80	-1.08
117	Equal employment opportunity for maintenance positions (gender, race or religion)	A09	2.56	2.99	-1.1
118	No. of apprentices ÷ No. of senior technicians	A02	2.86	3.48	-1.77
119	Rate of absentees for the maintenance team	A04	3.00	3.61	-1.83
120	Technicians seniority	A01	3.19	3.82	-2.01

Table 8b – Measures with Gap Indicators above Average of the Positive Values

Ord	Measure	Cat	PV	EA	Gap
1	Energy consumption per machine	B25	3.50	3.07	1.51
2	Unplanned maintenance cost	D73	3.57	3.20	1.32
3	Machine speed loss	B32	3.04	2.64	1.22
4	Preventive maintenance cost ÷ total maintenance cost	D71	3.67	3.34	1.21
5	Level of satisfaction of the maintenance technicians	A13	3.49	3.15	1.19
6	Overall Equipment Effectiveness (OEE)	B50	3.49	3.15	1.19
7	Reliability for each machine	B29	3.68	3.36	1.18
8	Planned maintenance hours ÷ total maintenance hours	D70	3.56	3.24	1.14
9	Average response time of the maintenance team	G116	3.38	3.05	1.12
10	Future investment needs for maintenance	E91	3.61	3.33	1.01
11	Preventive maintenance cost ÷ reactive maintenance cost	D72	3.39	3.10	0.98
12	Maintenance procedure quality	G115	3.39	3.10	0.98
13	Mean time to failure (MTTF) for each machine	B43	3.34	3.06	0.94
14	No. of delays in repair due to lack of spare parts	G109	3.10	2.81	0.9
15	Maintenance planned ÷ unplanned maintenance (machine)	C67	3.57	3.33	0.86
16	Percentage of spare parts not found when needed	G112	2.60	2.27	0.86
17	Repair cost for each machine	B36	3.87	3.66	0.81
18	No. of breakdowns with negative impact on customer satisfaction	C55	3.00	2.73	0.81
19	Rate of utilization of the maintenance capacity (persons)	A11	3.60	3.38	0.79
20	Maintenance budget	E83	3.88	3.68	0.78
21	No. of efficiency/quality/safety improvements undertaken by the maintenance team	F103	3.36	3.13	0.77
22	No. of delays due to lack of repair tools	G108	2.48	2.17	0.77
23	No. of customer complaints attribute to machine breakdowns	C59	2.87	2.61	0.75
24	Variance response time of the maintenance team	G117	2.88	2.62	0.75
25	Energy consumption per unit produced	H120	3.48	3.27	0.73
26	Percentage of maintenance type for each machine	C65	3.80	3.61	0.72
27	Percentage of repairs that were initiated but delayed	F105	2.97	2.73	0.71
28	Surveys of machine operators regarding maintenance services	C57	2.50	2.23	0.68
29	Mean time between failure (MTBF) for each machine	B45	3.46	3.27	0.66
30	Delays in communicating machine breakdowns	C51	2.98	2.76	0.66
31	Machine adjustments and setup time ÷ total time maintenance	C61	3.01	2.79	0.66
32	Mean time between repairs (MTBR) for each machine	B46	3.24	3.04	0.65
33	Preventive maintenance ÷ corrective maintenance (machine)	C66	3.69	3.52	0.63
34	Percentage of delays in the delivery of maintenance services	C52	3.03	2.83	0.61
35	Preventive maintenance hours ÷ corrective maintenance hours	D68	3.55	3.38	0.6
36	Immediate corrective maintenance hours÷ total maintenance hours	D69	3.12	2.93	0.59
37	Relations between managers and maintenance technicians	A14	3.43	3.26	0.58

Figure 1 – The changing role of the maintenance function in manufacturing organizations

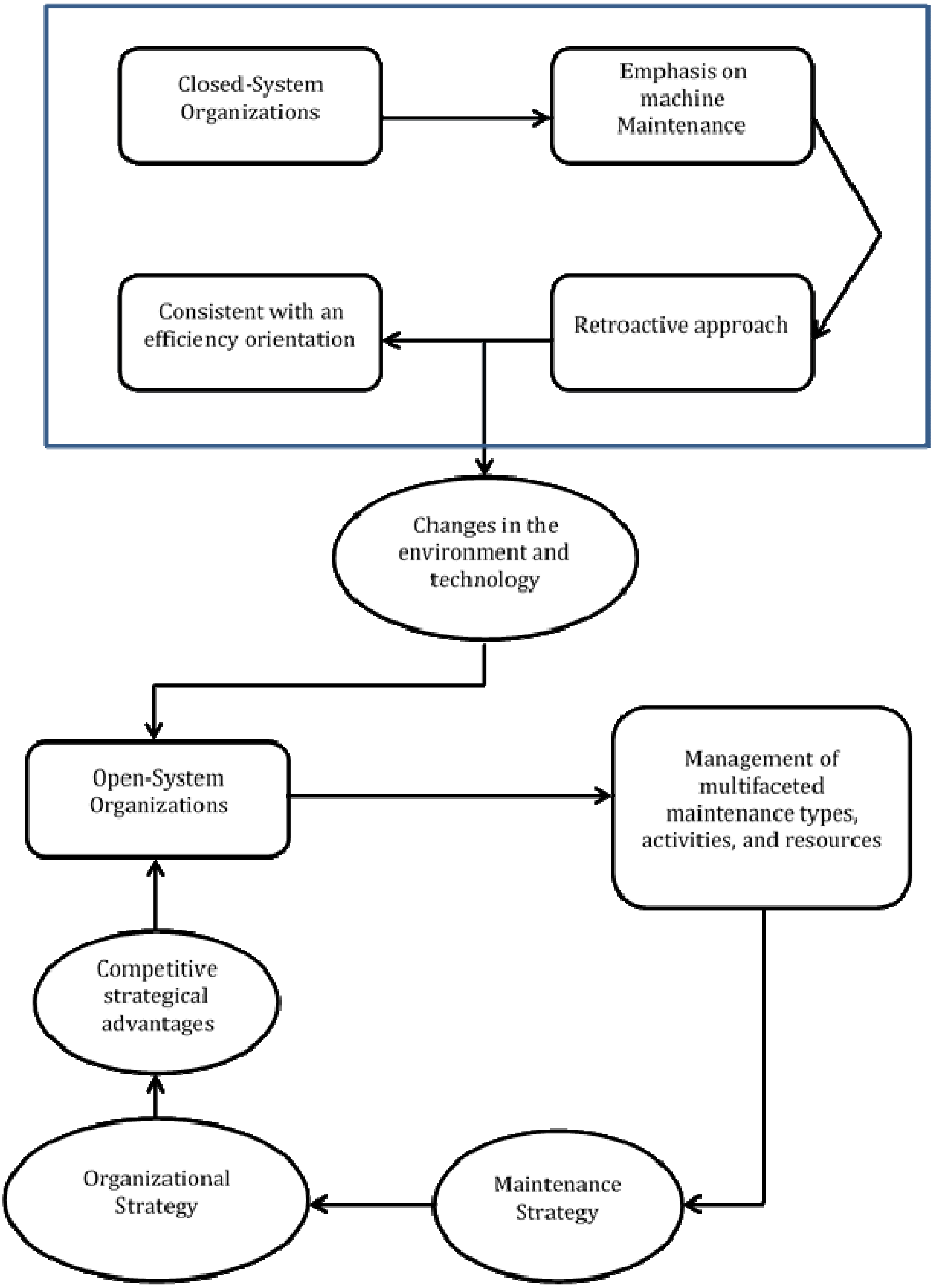

Figure 2 – Toward improving the management of the performance of the maintenance function