

**A literature review of maintenance performance measurement: A conceptual
framework and directions for future research**

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A literature review of maintenance performance measurement: A conceptual framework and directions for future research

1. Introduction

In the last few decades, manufacturing organizations were forced to shift their business models from closed system-orientations, to more open system-orientations. This shift was brought about by drastic competitive forces, which made the customer the focus of organizational, operational and strategic practices. Today's manufacturing organizations are required to operate as open operational systems. In such systems, advanced operational manufacturing technologies are blended with modern information and communication technologies to integrate and coordinate operational resources, processes, and activities in order to generate a stream of value-added operations aimed at capturing and sustaining a competitive advantage. With the increasing complexity, scope, and organisational role of operational advanced manufacturing technologies, the maintenance of these technologies is becoming very critical to the ability of the organization to compete. In this context, operations management, especially maintenance management, is taking on a broader organizational strategic role.

Traditionally, maintenance, with its multifaceted activities, resources, measurement, and management, has been important to manufacturing organizations. However, in recent years, the need to manage the different facets of maintenance more effectively has gained added importance due to changing operational technologies, and the changing organizational role of maintenance. In today's open system manufacturing organizations, maintenance has a broader perspective. In such organizations, the scope of maintenance has shifted from a narrowly-defined operational perspective, to an organizational strategic perspective. Some authors attribute this shift to the utilization of more advanced technologies (Swanson, 1997), increased emphasis on safety, and new environmental legislations (Cooke, 2003). In such operational environment, the role of the maintenance manager is critical. As such,

maintenance managers are being called upon to integrate and direct the maintenance efforts to meet organizational strategic goals efficiently and effectively (Alsyouf, 2007; Al-Najjar, 2007). Therefore, the need for these managers to receive appropriate formal educational training, which incorporate the different facets of their increasing organizational roles, is becoming more important than ever before (European Round Table, 1999; Shrivastav, 2005).

Motivated by the increasing significance of the different facets of maintenance management in today's open system manufacturing organizations, the objective of this research is to systematically examine the literature dealing with the different aspects of modern maintenance activities, measurements and management. Specifically, this literature review focuses on performance measures, measurement, and management of the different aspects of maintenance. For the purpose of this literature review, several electronic databases were utilized. In the process, articles published in the last thirty years are identified, analysed, and classified. This research effort facilitates tracing the evolution of performance measures and measurement, as related to the important maintenance organizational function, and its resources, activities, and practices. As a result of this detailed examination, directions for future research are identified and articulated.

The next section provides a brief background, which explores the nature of the problem under investigation. Section three of this research deals with the research method utilized. The results section highlights some of the uncovered important themes. A summary of the findings and directions for future research is also presented.

2. Background

Due to the changing organizational role of maintenance, and the increasing complexity of manufacturing technologies, maintenance related costs have been on the increase (Parida and Kumar, 2006). In manufacturing organizations, maintenance related costs are estimated to be twenty five percent of the overall operating cost (Cross, 1988a; Komonen, 2002). In some

industries, such as petrochemical, electrical power, and mining, maintenance related costs may surpass operational cost (Raouf, 1993; De Groote, 1995; Eti *et al.*, 2005; Parida and Kumar, 2006). As such, close attention should be paid to maintenance performance measures, measurement and management in order to utilize the scarce maintenance resources more effectively, and in the process improve overall organizational efficiency and effectiveness.

In order to utilize maintenance performance measurement and management to promote positive and proactive organizational change, the maintenance performance management system should be designed to track and improve the different aspects of the maintenance effort. This process should be guided by the integration of critical success business factors, which are derived from the overall organizational strategy (Tsang *et al.*, 1999).

Despite the overwhelming benefits gained through effective performance measurement and management, and the fact that organizations using integrated balanced performance management systems tend to outperform their counterparts which do not (Parida and Kumar, 2006), studies have shown that 70% of all those systems implementation initiatives have failed (Bourne *et al.*, 2002; Bourne, 2005). Even worst, in a survey of manufacturing organizations conducted by Cholasuke *et al.*, (2004), only one-third of the organizations, with good maintenance management practices tended to realize the full benefits of their maintenance management initiatives. This led some researchers to advocate the utilization of broader and innovative performance management approaches, such as the Balance Scorecard and new organizational improvement instruments (Garg and Deshmukh, 2006).

Overall, effective performance measurement approaches can play an important role in focusing people and resources on a particular aspect of organizational task (Waggoner *et al.*, 1999). According to Parida and Kumar (2006), the following are considered important factors, justifying the implementation of a maintenance performance measurement process:

- Measuring value created by the maintenance;
- Justifying investment;
- Revising resource allocations;
- Health safety and environment issues;
- Focus on knowledge management;
- Adapting to new trends in operation and maintenance strategy;
- Organizational structural changes.

The study at hand, attempts to shed some light on the important features and characteristics of effective approaches to performance maintenance management. For this purpose, the relevant literature is examined, classified and analyzed.

3. Method

For the purpose of this research, an exhaustive and systematic search of the literature related to maintenance management and maintenance performance measurement was conducted. The time frame for this literature review was from 1979 to 2009. This literature search was conducted using, among others, the following electronic databases: *Emerald*, *ScienceDirect*, *InformaWorld*, and *SpringerLink*. In addition, another search was conducted in an attempt to include related books and other research outlets. In total, two hundred and fifty one (251) articles were reviewed. Figure 1 shows a crescent tendency in the articles time distribution.

[Insert Figure 1]

The reviewed articles were published in sixty seven (67) journals, between the beginning of 1979 and the middle of 2009. Based on this review, only twenty-eight (28) journals published two or more articles during this period (Figure 2). One hundred and twenty one (121) of the articles reviewed, which accounted for forty eight percent (48) of the articles reviewed were published in the following five (5) journals:

Journal of Quality in Maintenance Engineering (55),

International Journal of Quality & Reliability Management (26),
International Journal of Operations & Production Management (16),
International Journal of Production Economics (14)
Reliability Engineering & System Safety (10)

The *Journal of Quality in Maintenance Engineering* is singled out, as providing the most coverage on the topic investigated in this study (22%) during the period under consideration.

[Insert Figure 2]

4. Results

Based on careful and systematic content analysis of the reviewed articles, it was determined that some of these articles contained some redundant information. Therefore, one hundred and fifty six (156) articles were selected for further analysis. Only five percent (5%) of analysed articles did not present measures. On the other hand, seventy percent (70%) of the articles with measures were supported by a model/ framework.

As a result of a focused literature review, three-hundred and forty five (345) different measures emerged, with a total of six hundred and ninety six (696) occurrences. Figure 3 reports the main thirty seven (37) measures, with more than two occurrences. It is to be noted that cost, with forty (55) occurrences, was the most used maintenance performance measure (15% of total occurrences within this group of measures). The most utilized measures represented several dimensions of maintenance performance, namely technical, economic, safety, and human resources. The least utilized measures group included several measures, such as training/learning, skills/competences, work incentives, process performance, resources utilization, maintenance capacity, customer satisfaction, employee satisfaction. While cost is an important measure, future research should also focus on deriving practical

performance measures aimed at capturing the human factor of the maintenance performance effort.

[Insert Figure 3]

The results of the content analysis also showed that most of the reviewed research was derived from practical applications. As it can be seen in Figure 4, hundred and thirty seven (137) case studies related to thirty two (32) different industries were identified. In this context, the automotive, electrical/electronic, and chemical were the most represented industries. Future research should attempt to integrate the findings from the case studies into practical implementations methodologies. The characteristics of the industry should be examined in attempt to conceptualize industry specific factors in relation to effective maintenance performance.

[Insert Figure 4]

Based on further content analysis of the selected articles, three relevant themes related to maintenance performance measures, measurement, and management emerged. These themes represent research areas for future research.

4.1 Effective utilization of maintenance resources

From the perspective of the maintenance manager, maintenance resources are finite, and usually below the level they should be. Production stoppages, breakdowns, power stoppages, shortage in manpower, lack of materials (supply), demand (external) and others business factors directly or indirectly affect the level of production. This tends to make maintenance scheduling a dynamic and challenging process (Paz and Leigh, 1994). As such, the limited capacities and resources have to be shared, rather than competed for (Gits, 1994).

Developing a maintenance planning programme is an iterative process that involves different decision-makers, who may have conflicting objectives. In deriving these objectives, maintenance managers, usually, try to achieve multiple, and sometimes, conflicting objectives, such as maximizing throughput, availability, and quality, subject to the constraints imposed on the production plans (Labib, 1998). The literature points to the existence of tradeoffs among the different aspects of performance (Silveira and Slack, 2001). Performance measures will not have equal importance for an individual operation, thus they tend to be traded-off against each other (Slack and Lewis, 2008). Therefore, in order to solve conflicting objectives, such as system reliability and profit maximization, an organization must establish appropriate maintenance guidelines that regulate (1) costs associated with performing production activities, (2) costs associated with performing maintenance activities, and (3) the various costs associated with equipments failure and the resulting interruptions to the production plan (Weinstein and Chung, 1999).

When manufacturing organizations choose to compete in the global market, they usually use several competitive priorities, such as cost, quality, flexibility, and other competitive methods contingent on their manufacturing processes capabilities. Therefore, the readiness and availability of manufacturing equipments becomes critical, thus making maintenance an integral part of the manufacturing management process. This in turn can influence competitive priorities, and hence the achievement of the business strategy (Pinjala *et al.*, 2006). Therefore, it is fundamental for maintenance managers to be aware of the organizational business strategy, as they manage their maintenance resources. The business strategy should drive the selected maintenance approach, models and strategies utilized. For instance, a JIT operational approach requires high machine availability. Therefore, such operational environment should stress the importance of preventive maintenance. On the other hand, total quality management (TQM) requires machines to be in an excellent working condition (Chen, 1994). Therefore, scheduled maintenance is needed to promote and support

a TQM/CI operational orientation. Overall, it is important to have an organizational systematic maintenance strategy to guide the strategic use of maintenance resources, models and techniques (Jonsson, 1997).

There are many models, techniques, systems and approaches available to facilitate and support maintenance management of activities, resources, and decisions (Garg and Deshmukh, 2006). In this context, several new approaches and strategies/tactics/technologies can be utilized. These include among others, self-maintenance, web-based maintenance, integration of product and maintenance design, proactive maintenance based on intelligent units, life cycle simulation for maintenance strategy planning, model-based maintenance, total productive maintenance (TPM), Reliability Centered Maintenance (RCM), Preventive Maintenance (PM), Condition Based Maintenance (CBM), and Continuous Maintenance (CM) (Takata et al., 2004). Therefore, approaching maintenance management strategically and systematically has become essential to make the right choices, especially in capital-intensive industries.

The literature points to strong linkages between business strategy and manufacturing maintenance strategies (Madu, 2000; Pinjala *et al.*, 2006; Rosqvist *et al.*, 2009). As such, there is a need for a well designed and implemented organizational system to manage maintenance and related performance aspects from a strategic perspective. According to Alsayouf (2006), such system should have the following characteristics and abilities:

- Assess the contribution of the maintenance function to the strategic business objectives;
- Identify the weaknesses and strengths of the implemented maintenance strategy;
- Establish a sound foundation for a comprehensive maintenance improvement strategy using quantitative and qualitative data;
- Re-evaluate benchmarking maintenance practice and performance with the best practice within and outside the same industry;
- Track maintenance impact and showing the linkages between operational and financial measures, holistically.

Some of the important factors, which need to be considered in the road toward effective performance maintenance management, as identified from the literature (Tsang, 1998; Kumar, 2006; Parida and Kumar, 2006) are highlighted below:

- Measuring value created by the maintenance;
- Justifying investment and maximize asset utilization;
- Revising resource allocations, improving responsiveness;
- Health safety and environmental issues;
- Focus on knowledge management and developing core competences;
- Adapting to new trends in operation and maintenance strategy;
- Organizational structural changes.

In this context the following research questions are relevant.

- Does business strategy and maintenance strategy need be consistent and linked with each other?
- Does maintenance need to maximize equipment/resources availability in order to allow strategy flexibility?
- Does the links between business strategy and maintenance need to be well established and to be clear to relevant members of the organization?
- Is it necessary to have a clear maintenance vision statement specifying what goals to accomplish and how such goals can be measured?

4.2 Total maintenance and information systems support

The literature reviewed tended to underscore the relevance of certain tools and techniques in relation to organizational maintenance and its role (Goh and Guan-How, 1995; Ben-Daya and Duffuaa, 1995). In the past, reactive maintenance approaches have resulted in consistent, but not necessarily effective performance maintenance results (Azadivar and Shu, 1999). Innovative maintenance approaches, along with business integration efforts at all levels and across all function/departments, have been advocated as important factors to improving manufacturing competitiveness (Bamber *et al.*, 2004). As such, total productive maintenance (TPM) can drive and facilitate an integrated manufacturing management system capable of supporting the different operational sub-systems. This integrated maintenance

management approach within a manufacturing environment places the maintenance function at the heart of the manufacturing system.

Integration can be facilitated by overlapping practices related to manufacturing initiatives, such as JIT and TQM with TPM (Miyake *et al.*, 1995; Cua, Mckone, and Schroeder, 2001). Significant support was found for a positive correlation between TPM and business performance, thus showing that business performance of firms with TPM was significantly superior to the non-TPM firms (Brah and Chong, 2004). In this context, the role of an integrated information system is critical in order to ensure the availability of data needed for true reliability-based maintenance schedule optimization (Sherwin and Jonsson, 1995). Information sharing practices, information attributes, information technology use, collaborative foundation, time-related issues, processes and activities are all considered as critical elements of information integration (Uusipaavaniemi and Juga, 2009).

Information technology (IT) can be beneficial in reducing costs, and assisting in providing services, which were infeasible before (Concetti *et al.*, 2009). IT can also be expensive and wasteful both in terms of time and money (Ross, 2009). Therefore, it is essential that the software design of the maintenance performance management system incorporates the culture and resources of the organization for which it is intended (Davies, 1990; Pinjala, Pintelon, and Vereecke, 2006; Hwang, Tien, and Shu, 2007; Kans, 2008).

The literature reviewed presented computerized maintenance management systems that included many of the features needed to support the maintenance management and performance measurement system (Labib, 1998; Labib, 2004). However, typical software, usually, does not support important features, such as failure reports, which are specific to production functions. Also, the suitable maintenance management software support tends to depend on the maintenance strategy used (Kans and Ingwald, 2008). Manufacturing organizations, especially small and medium-sized enterprises would benefit from having easy-to-use tools and methods for determining their maintenance management information

technologies needs in order to be able to choose the best solution available from off-the-shelf options (Kans, 2008). This may lead to system design and development significant savings.

A common database can be an important instrument for decision-making in relation to maintenance management (Kans and Ingwald, 2008). Such database should include data from several relevant operational organizational areas. Therefore, it can form a good basis for quick overview of the current problematic areas and needed actions. Applying the common database methodology makes it possible to gage current activities and potential areas of improvements (Uusipaavalniemi and Juga, 2009). Furthermore, since such database provides easy access to relevant real-time and on-demand data, it facilitates the detection of deviations at an early stage, thereby avoiding unnecessary costs in the future. The backward data identification process ensures that the data-set supports relevant performance measures for maintenance monitoring and follow-up (Kans and Ingwald, 2008).

In this context the following research questions are relevant:

- Does maintenance performance measurement systems should be integrated in the organizational performance measurement system?
- Does maintenance information systems should be tailored to manufacturing processes?

4.3 Measurement, measures, and human factor management

Maintenance is a logistic organizational function, which is typically integrated into a production process. Therefore, its efficiency and effectiveness tend to be difficult to measure in absolute terms. Consequently, performance measures have been defined in relative terms (values), in form of ratios of economic, technical or organizational measures (De Groote, 1995).

In the past, operating ratios were considered to be adequate indicators of maintenance performance. In this context, most commonly used ratios included maintenance cost ratio to the plant area, maintenance cost ratio to the number of people directly employed, and maintenance cost ratio to the number of units produced. The limitation of these ratios is that

they were dependent on each specific plant for which they were developed. In this context, specific characteristics for each industry have been identified in the literature as constraints to the development of maintenance management systems. These constraints include: information systems support (Oelsner, 1979), extent of centralization of the maintenance departments (Ikhwan and Burney, 1994), technical complexity (Swanson, 1997). Thus, it is difficult to compare ratios of different plants or, for that matter, different organizations. In this context, meaningful comparisons of maintenance performance efficiency between various plants cannot be carried out in the absence of maintenance performance efficiency standards (Raouf, 1993; Yam *et al.*, 2000; Ahrén and Parida, 2009).

Benchmarking is critical toward achieving world-class maintenance performance levels (Chen, 1994; Raouf and Ben-Daya, 1995; Madu, 2000). It is to be noted that although benchmarking is one of the key elements for the continuous improvement process (Ahrén and Parida, 2009), only seventeen of the analyzed papers (11%), presented, or even referred to benchmarking techniques in associations with maintenance performance measurement.

The implementation of quality improvement programs, modern information systems, continuous improvement programs, and the evolution of performance measurement systems, tended to promote the proliferation of maintenance performance measures and measurement (Cua *et al.*, 2001; Bamber, Sharp, and Castka, 2004; Seth and Tripathi, 2006). Due to the increase in the number and type of measures, new approaches for maintenance performance measures and measurement are needed (Kumar, 2006).

The literature has presented several approaches to a better systematization and utilization of maintenance performance measures. Traditional approaches tended to establish a hierarchy with two sets of indicators, namely (i) key indicators, to be evaluated periodically, and (ii) detailed indicators, which are only used for searching for the causes of deviations observed in the key indicators (Martorell *et al.*, 1999). However, new innovative approaches tends to emphasize a more balanced view of maintenance performance measures, namely,

equipment related performance, task related performance, cost related performance, immediate customer impact related performance, and learning and growth related performance (Kutucuoglu *et al.*, 2001).

The CEN (2007), through the framework of the EN 15341 standard, presented the maintenance performance measures' classification in terms of economic, technical, and organizational indicators. More recently, Cabral (2009) classified economical and technical measures in four groups, namely time related factors, human effort related factors, number of events, and cost related factors.

Qualified and well-trained machine operators and maintenance technicians are the driving force behind any effective maintenance measurement system. They collect the information (especially in small extent automated factories with no automatic data collection), and they report occurrences (Nakajima, 1988). Most of the maintenance tasks are handled directly by operators instead of the on-site maintenance team. Thus, flexible, co-operative and a shared responsibility approach among production and maintenance personnel is required to promote operator ownership and free up maintenance personnel to perform more technically challenging maintenance works (Yam *et al.*, 2000).

The human factor represented by maintenance technicians and other related staff is the backbone of the maintenance system in any organization. As such, the effectiveness of the different facets of the performance system is very much dependent on the competency, training, and motivation of the overall human factor in charge of the maintenance system (Ljungberg, 1998). In this context, factors such as, years of relevant work experience on a specific machine, personal disposition, operator reliability, work environment, motivational management, training and continuing education, are all relevant factors which tend to impact the effectiveness of the performance of the maintenance system (Cabahug *et al.*, 2004). Operators are in direct contact with the maintenance activities and efforts. Therefore, they are

able to judge the quality of the service they receive. In this context, their regular feedback should be incorporated into the evaluation of the maintenance system.

The close cooperation and coordination between the maintenance technicians and machine operators is very critical, as it influences service quality and, in turn, the extent of satisfaction with the rendered services. In this context, repeated visits to repair equipment for the same problem result in operator dissatisfaction (Ardalan *et al.*, 1992). As in all quality oriented management programmes, employee participation is critical for success. The attitude, conduct and personality of maintenance personnel are critical to the effectiveness of the maintenance effort (Goh and Guan-How, 1995; Arca and Prado, 2008).

The human resources aspect of maintenance has been playing an increasing role in relation to operational environment safety (Rankin *et al.*, 2000; Patankar and Taylor, 2000). Maintenance resource management addresses the issues related to organization, communication, problem solving, and decision making (Taylor, 2000). Maintenance and safety, are sometimes, treated as separate and independent sets of activities (Raouf, 2004). However, part of the accidents in manufacturing environments is caused by poor maintenance (Raouf, 2004). An integrated approach is the appropriate approach for optimizing plant capacity, as safety and maintenance are not mutually exclusive functions (Raouf, 2004; Liyanage, 2007).

If an organization stresses teamwork (like in the case of those who use TPM), the remuneration structure should promote cooperation rather than undermine it (Bullinger and Menral, 2002). A wide variety of remuneration programmes, which take into account factors, other than rank, experience and length-of-service exist. These programmes are been used in modern, innovative organizations. Some organizations use pay-for-skill programmes to develop multi-skilled employees, pay-for-performance, promote goal-sharing programmes, and provide bonuses that are linked to group performance (Bullinger and Menral, 2002; Eti, Ogaji, and Probert, 2006). However, offering the “right” rewards alone is unlikely to

produce sustained empowerment. The power of such methods to maintain commitment declines with use (Eti *et al.*, 2006). Today's privileges become tomorrow's rights. Involvement and autonomy are the main motivations that activate the human mind and drive human effort (Eti *et al.*, 2006).

In this context the following research questions are relevant:

- Should the operators training process include maintenance techniques?
- Should maintenance technicians training include manufacturing process know-how?
- Should the maintenance technicians' compensation system be based on organizational strategic objectives?

5. Conclusion

This literature review examined issues relevant to the different facets of maintenance activities, resources, measures, and measurement in manufacturing organizations. Articles published from 1979 to 2009 were classified and analyzed. Based on the findings of this study, it is concluded that the area of maintenance performance and management is in need of more future systematic research efforts aimed at solidifying theoretical constructs and promoting the implementation of more practical approaches.

There appears to be a shift away from viewing the maintenance performance measurement effort based on a mere budget reporting perspective, to viewing it based on a systematic, organizational perspective. The evolution of the organizational role of the maintenance function shows a clear path toward the integration of maintenance resources and activities into a total management system. This change appears to have evolved from a reactive, preventive, and predictive mode to a more holistic/process-oriented, complete, systematic organizational mode (Alsyouf, 2007). Such evolution path was marked by different generations of maintenance milestones (Arunraj and Maiti, 2007).

The framework in Figure 5 attempts to provide an organizational context for the evolving role of the maintenance function in manufacturing organizations. It underscores the consistency between the organization and its perspective on the role of maintenance.

[Insert Figure 5]

In this context, closed system manufacturing organizations tended to view maintenance as a cost of doing business, or a necessary evil. These manufacturing organizations approached maintenance as a stand-alone operational function. This functional perspective utilized a transactional processing systems (TPS) informational approach. This information approach was supplement with the utilization of mainly internal benchmarking practices. Under this approach, organizational performance tended to focus on operational objectives and goals. In this context, stand-alone technologies were utilized to perform required operations.

On the other hand, today's open system manufacturing organizations tend to view maintenance as a strategic competitive resource. This view is consistent with the maintenance performance measures used, and the information systems utilized to gather data. These manufacturing organizations tend to view the maintenance effort as integrated, strategic organizational system. In the process, these organizations tend to approach needed information based on an integrated DSS/Database informational perspective. This organizational informational approach is supplemented through the effective utilization of broader benchmarking practices. In this context, organizational performance focus is on operational, strategic and value-added objectives and goals. The operational technologies used in these organizations are based on the automation and integration of different operational capabilities.

From an implementation perspective, manufacturing organizations are in need of systematic, dynamic performance management approaches. Such approaches should be able to measure, monitor, track, and continuously improve the different aspects of organizational performance. In this context, it is critical for these organizations to integrate their maintenance related performance aspects into the overall organization performance systematic approach (Gomes and Yasin, 2011). As organizations attempt to implement such organizational performance improvement approaches, they must understand the relevant performance issues and concerns related to the growing organizational role of maintenance effort. This study contributes toward such understanding.

Based on the findings of this study, it is concluded that the area of maintenance performance and management is in need of more future systematic research efforts aimed at solidifying theoretical constructs and promoting the utilization of more practical applications.

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Figure 1 – Article time distribution 1979-2009

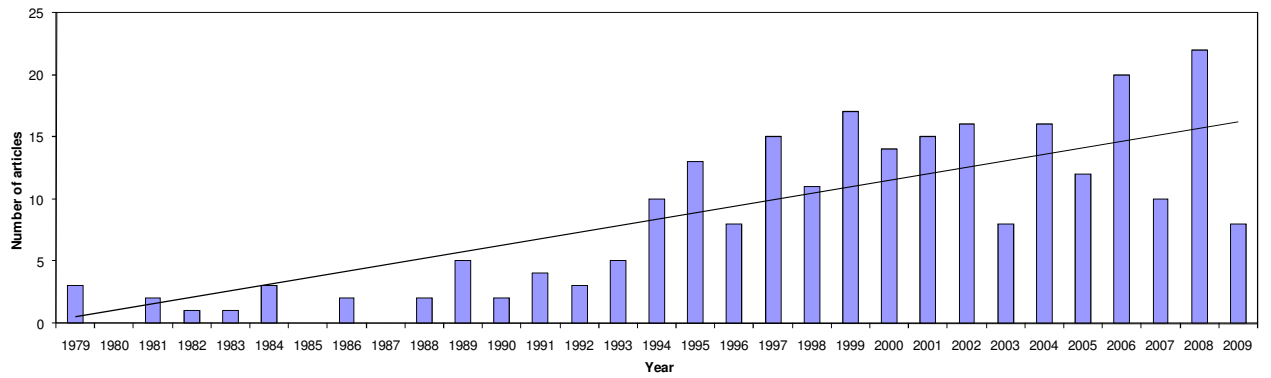


Figure 2 – Number de papers per Journal

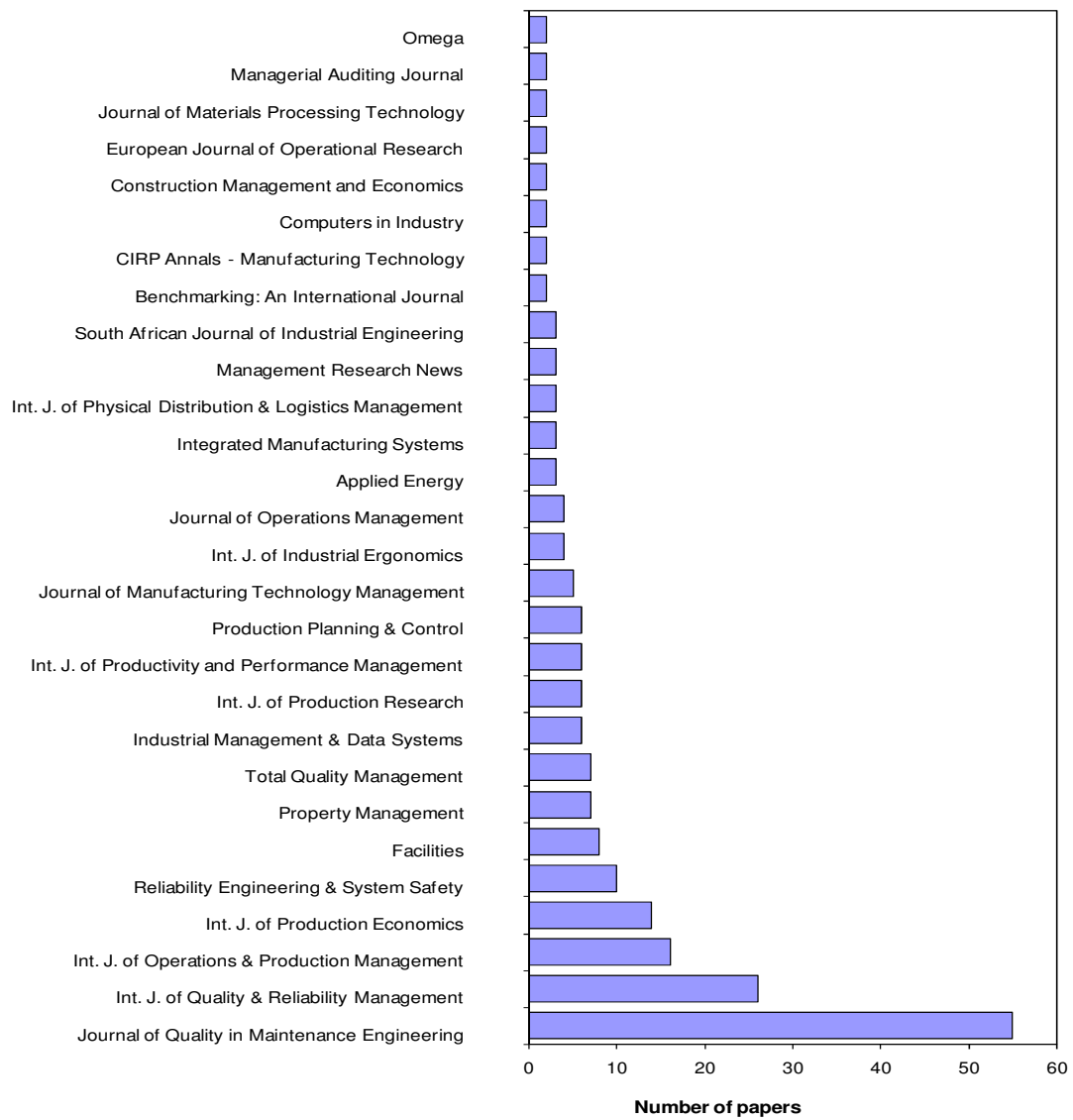


Figure 3 – Type and occurrences of maintenance performance measures

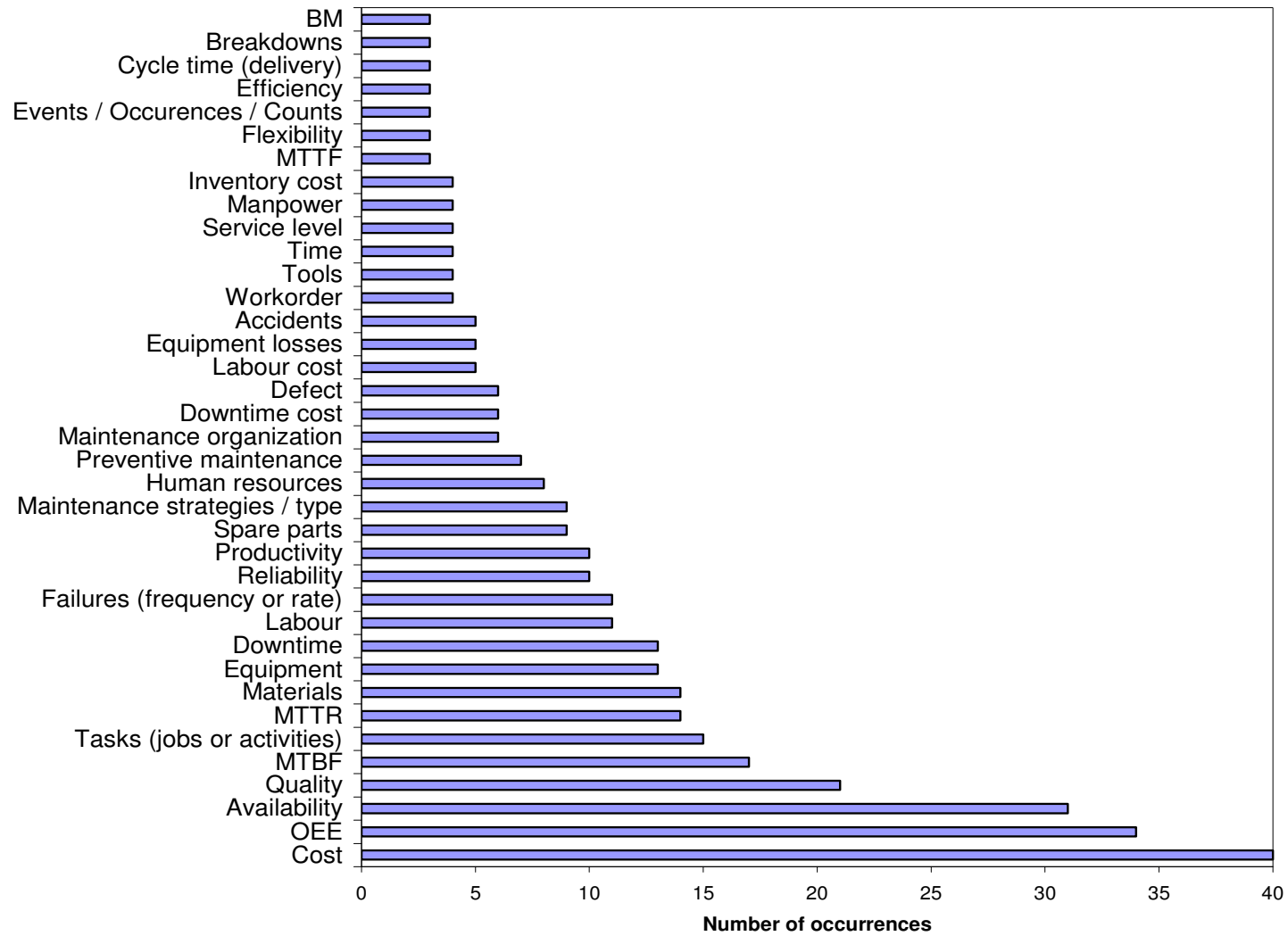


Figure 4 – Distribution of case studies per industry

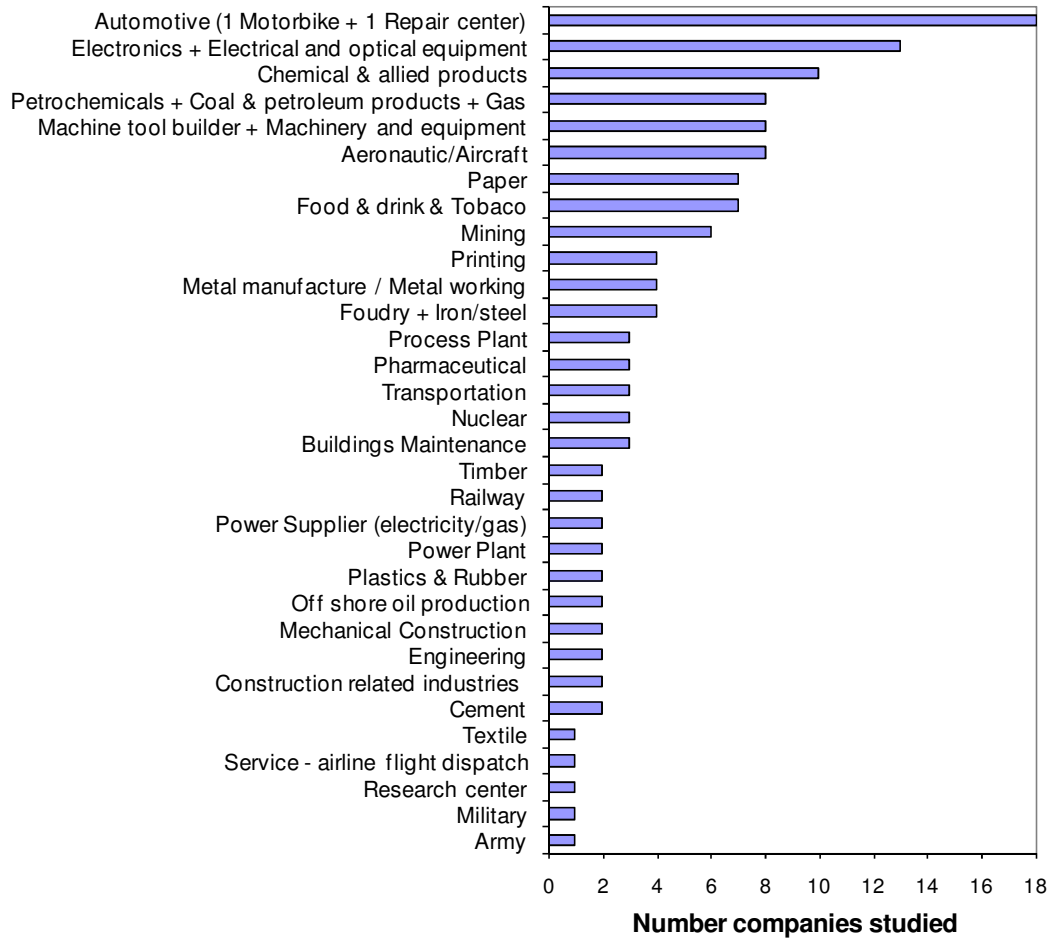


Figure 5 – The evolution of maintenance activities and organizational role

