

A LITERATURE REVIEW OF MAINTENANCE PERFORMANCE MEASUREMENT: DIRECTIONS FOR FUTURE RESEARCH

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ABSTRACT

Motivated by the increasing significance of the different facets of maintenance in today's open system manufacturing organizations, the objective of this research is to systematically examine the literature dealing with the multifacets of maintenance, and their organizational and operational roles. Specifically, this literature review focuses on performance measures, measurement, and management of the different aspects of maintenance in an organizational open system context. In the process, innovative approaches and models utilized to measure and manage maintenance performance in manufacturing operational settings are classified and examined. Based on this investigation, directions for future research are pointed out.

BACKGROUND

Due to the changing organizational role of maintenance, and the increasing complexity of manufacturing technologies, maintenance related costs have been on the increase [39]. In manufacturing organizations, maintenance related costs are estimated to be twenty five percent of overall operating cost [20][31]. In some industries, such as petrochemical, electrical power, and mining, maintenance related costs may surpass operational cost [22][23][39][46]. 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 organizational efficiency and effectiveness.

According to the European Committee for Standardization (CEN), one of the main responsibilities of the maintenance manager is to chart a systematic maintenance strategy, which takes the three main criteria below into account [15].

1. To ensure the availability of the items for the required function, often at optimum costs;
2. To consider the safety requirements associated with the item for both maintenance and user personnel, and, where necessary, any impact on the environment;
3. To uphold the durability of the items and/or the quality of the products or services provided considering, where necessary, costs.

To achieve the overall maintenance objectives, the following strategic approaches are recommended, as either stand-alone, and/or jointly [15].

- Preventive maintenance approach
 - Scheduled maintenance
 - Predetermined maintenance
 - Condition based maintenance

- Predictive maintenance
- Corrective maintenance approach
 - Immediate maintenance
 - Deferred maintenance

These maintenance strategic approaches are usually implemented through a well-designed set of tasks [15][17].

In performing the different tasks related to maintenance performance management, maintenance managers can utilize many tools, approaches, and models. Based on a literature review of maintenance management, Garg and Deshmukh [24] identified forty-nine (49) types of models, techniques, systems and policies. Similar to the performance management process of any other organizational dimensions, maintenance performance measures, measurement, and management should provide evidence of whether, or not, the intended results have been achieved [28].

In order to utilize maintenance performance measurement and management to promote positive 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 organizational strategy [53].

In general, performance measurement can play an important role in focusing people and resources on particular aspects of a business [55]. According to Parida and Kumar [39], 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.

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 [39], studies have shown that 70% of all those systems implementation initiatives have failed [11][12]. Even worst, in a survey of manufacturing organizations conducted by [18], only one-third of the organizations with good maintenance management practices tended to realize the full benefits of their maintenance management initiatives.

One of the earlier studies regarding maintenance performance, which utilized data from organizations in the UK (1976–1987) reported clear productivity improvements in maintenance services [21]. In this study, it was reported that the most significant contributor to the containment of maintenance costs, and overall improvement was the restructuring of jobs and the re-organization of the maintenance function. Although particular attention was devoted to cost, the utilization of other maintenance performance measurement dimensions, such as materials, personnel, safety, workload, reliability, organization, planning and scheduling was also stressed.

The shift from a mere budget reporting-based approach, to more innovative approaches to maintenance performance measures and measurement has been forthcoming in the maintenance literature [1][33][34][37][38]. These innovative approaches include the use of indicators, reference numbers and visual aids, as well as other more elaborated methods [44]. More recently, new performance management approaches, such as the Balance Scorecard, and new organizational improvement instruments, have been advocated to improve the performance of the maintenance management process [24].

METHOD

For the purpose of this research, an exhaustive 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 theses. In total, two hundred and fifty one (251) articles were reviewed, showing a crescent tendency in the articles time distribution.

The reviewed articles were published in sixty seven journals (67) 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. 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 (22%) on the topic investigated in this study during the period under consideration.

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. Five percent (5%) of the retained 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 the focused literature review, three-hundred and forty five (345) different measures emerged, with a total of six hundred and ninety six (696) occurrences. Figure 1 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 key measures,

such as training/learning, skills/competences, work incentives, process performance, resources utilization, maintenance capacity, customer satisfaction, and employee satisfaction.

The results of the content analysis also showed that most of the reviewed research was derived from practical applications. This was evident by the fact that there were hundred and thirty seven (137) case studies from thirty two (32) different industries. In this context, the automotive, electrical/electronic, and chemical were the most represented industries.

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

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, shortages in manpower, lack of materials (supply), demand (external) and others business factors, directly or indirectly affect the level of production; thus, making maintenance scheduling a dynamic process [42]. As such, the limited capacities and resources have to be shared, rather than competed for [25]. 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 on production plans [32]. The literature points to the existence of tradeoffs among the different aspects of performance [49]. Performance measures will not have equal importance for an individual operation, thus they tend to be traded-off against each other [50]. 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 [56].

Total maintenance and information systems support

The literature reviewed underscored the relevance of certain tools and techniques in relation to organizational maintenance and its role [10][26]. In the past, reactive maintenance approaches have resulted in consistent, but not necessarily effective performance maintenance results [8]. However, more recently, new maintenance approaches along with business integration at all levels and across all disciplines has been advocated as important factors to manufacturing competitiveness [9]. 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 [35]. Significant support was found for a positive correlation between TPM and business performance. As such, business performance of firms with TPM was reported to be significantly superior to

the non-TPM firms [14]. 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 [48]. 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 [54].

Information technology (IT) can be beneficial in reducing costs, and assisting in providing services, which were infeasible before [19]. IT can also be expensive and wasteful, both in terms of time and money. It is therefore essential that the software design of the maintenance performance management system incorporates the culture and resources of the organization for which it is intended [27][30][43].

Measurement, measures, and human factor management

Maintenance is a logistic organizational function, which typically tends to be integrated into the production process. Therefore, its efficiency and effectiveness tend to be difficult to measure in absolute value. Consequently, performance measures have been defined in relative terms (values), in form of ratios of economic, technical and/or organizational measures [22].

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 specific for on each plant for which they were developed. Specific characteristics for each industry have been identified in the literature as constraints to the development of maintenance management system, namely the information systems support [36], extent of centralization of the maintenance departments [29], technical complexity [51]. Thus, it is difficult to compare ratios of different plants and 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 [40][46][57].

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 human factor in charge of the maintenance system [34]. In this context, factors such as, years of relevant work experience on a particular machine, personal disposition, operator reliability, work environment, motivational management, training and continuing education are all relevant to the effectiveness of the performance of the maintenance system [16].

Operators are in direct contact with maintenance, and are generally able to judge the quality of the service they receive. 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 [6]. As in all quality 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 [5][26].

Maintenance human resources have been playing an increasing role in relation to operational environment safety [41][45]. Maintenance resource management addresses the issues related to organization, communication, problem solving, and decision making [52]. Maintenance and safety are sometimes treated as separate and independent sets of activities, however, part of the accidents in manufacturing environments are caused by poor maintenance [47]. An integrated approach is the appropriate approach for optimizing plant capacity, as safety and maintenance are not mutually exclusive functions [33][47].

CONCLUSION

This literature review examined issues relevant to the different facets of maintenance activities, resources, measures and measurement in manufacturing organizations. Based on this literature review, which examined relevant articles published from 1979 to 2009, a trend toward moving away from a mere budget-reporting based approach, to a complete and integrated system approach with operational and strategic roles was identified.

The historical evolution of maintenance and its organizational role shows a clear path toward the integration of maintenance management, resources, and activities. This evolution has progressed from reactive, preventive, and predictive perspectives to a more holistic/process-oriented total organizational perspective [4]. This path has been marked by several generations of milestones [7].

This literature review underscores the consistency between the organization and its view on maintenance. In this context, closed system organizations tended to view maintenance as a cost of doing business, or a necessary evil. These manufacturing organizations viewed the maintenance as a stand-alone operational function, thus they have tended to have a transactional processing system (TPS) informational perspective. As such, they used internal benchmarking and focused on operational objectives and goals.

Open system organizations tend to view maintenance as a strategic competitive resource. This view is consistent with maintenance measures used and information systems utilized to gather needed data. The changing complexity of manufacturing technologies is also evident in the evolution of the maintenance function and its role in today's manufacturing organizations. These manufacturing organizations view the maintenance, as integrated strategic organizational system. They tend to utilize DSS/Database informational perspective. They also tend to use competitive benchmarking. Such organizations tend to focus on strategic and value-added objectives and goals. Finally, they tend to utilize integrated advanced manufacturing technologies.

References available upon request from Mahmoud M. Yasin