Evaluation and improvement of maintenance management performance using a maturity model

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Abstract

Purpose – The purpose of this paper is to develop a new maturity model to identify the current state of maintenance area of organizations and drives actions to increase efficiency and effectiveness toward the concept known as world-class.

Design/methodology/approach – The model was developed based on an extensive literature review on maintenance management and maturity assessment, which allowed identifying the relevant factors in maintenance management and the world-class behaviors for each factor. The progressive maturity levels for each of the identified ten factors form the model. To test its effectiveness, it was applied to the maintenance area of three companies.

Findings – The model application showed that, in addition to being a self-assessment tool, it provides knowledge, to those who use it, on behaviors or practices that enable world-class results. For each factor, potential gaps and the desired state were defined focusing on behaviors rather than on indicators values or adopted methodologies, which facilitates the identification of improvement actions that lead to better performance.

Research limitations/implications – Through its use, maturity levels can be identified for all considered maintenance management factors, however, the overall maturity of the maintenance area is not determined. Although this overall evaluation can be done assigning a weight to each factor, it was not considered an added value for the set purpose.

Originality/value – The proposed maturity model contributes to the understanding of the maintenance management process and how to stand out nowadays in an area that has an increasingly important impact on productivity and quality.

Keywords Performance evaluation, Maintenance management, Maturity model

Paper type Research paper

1. Introduction

The identification and characterization of maturity levels have been discussed in various knowledge areas, such as in project management, quality management and systems development, and practical application of findings has led to the achievement of better results. The first maturity model was introduced in the quality management area by Crosby (1979). Maturity models allow an organization to have its methods and processes evaluated in accordance with good management practices and with a set of external parameters.

The industry trend of becoming increasingly technology-intensive as well as to adopt a production paradigm such as Just-in-Time leads maintenance to assume a more and more important role in achieving high productivity and quality. The identification of maturity in maintenance management can highlight weaknesses in this area and boost the implementation of improvements that will strengthen the area's ability to achieve high performance of manufacturing equipment.

Not much-published literature is reported on the development and application of maturity models in physical asset maintenance (Chemweno *et al.*, 2015). Antil (1991) and Wireman (1992) proposed maturity models that are adaptations of the Crosby model to

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maintenance management. However, maintenance management has particularities and important differences from quality management that have to be assessed and improved to achieve better performance. Cholasuke *et al.* (2004) categorized the maturity of the companies that replied to a questionnaire according to their maintenance management practices. Based on this categorization, companies can identify the group to each they belong. However, since the categorization is based on the adoption of certain methodologies and the values of performance indicators, companies cannot easily identify the actions that allows them to reach the next maturity levels, as in Chemweno *et al.* (2015) and in some classes of the model of Campbell and Reyes-Picknell (2006).

For the purpose of both, assessment of maturity and direction indication for improving performance, this paper proposes a maturity model focused on behaviors to allow identifying the next steps that should be taken to reach higher maturity levels. It is not intended that the model specifies the methodologies that should be used or the values of indicators that companies should achieve. Among companies that claim to adopt a certain methodology or use a particular tool, their degree of implementation or use can vary widely as stated in the study of Oliveira *et al.* (2015) and, therefore, it does not guarantee the achievement and sustainability of good results. Regarding performance indicators, indicators with the same designation are often calculated differently from company to company. Furthermore, an indicator value used to define a stage may be suitable for one business sector and too high for another, since it depends on the technological level and maintenance impact.

According to Maier *et al.* (2012), maturity models can be used both as an assessment tool and as an improvement tool. Such as the EFQM model that is used for Excellence awards assignment in Europe, the model proposed in this paper is based on how companies act in the maintenance area and are not prescriptive in terms of methodologies or techniques. The evaluation categories and respective levels or stages of maturity were defined based on an extensive literature review. The world-class practices that define the highest maturity levels were identified taking into account recent works on the literature.

The paper is organized as follows. In Section 2, a literature review about maturity models or grids is presented. Section 3 introduces and describes each category of the model and respective levels. The application of the model to the maintenance area of three companies as well as a discussion on the results is described in Section 4. Finally, the conclusions are presented in Section 5.

2. Literature review: maturity models

Maturity models have been widespread developed in many fields of knowledge to improve organizational performance.

2.1 Maturity models in different knowledge area

The maturity models stem from the work developed by Crosby (1979), that structured a model based on five incremental levels of maturity for quality management in an organization, called Quality Management Maturity Grid. Also in quality management area, more recently, Bessant *et al.* (2001) defined five maturity levels for the development of continuous improvement skills, allowing companies to develop a plan to expand their continuous improvement skills, plan and develop the quality of organizational processes. The ISO 9004:2009 (2009) standard also presents a maturity model for quality management.

In the area of information technology (IT), there is a well-known maturity model designated by Capability Maturity Model (CMM) that was developed by the Software Engineering Institute of Carnegie Mellon University between 1986 and 1993. The CMM proposes a structure with five levels that allows stratifying the position occupied by the software development companies with respect to the maturity of their project management processes.

Another important contribution to the development of maturity models is the *Organizational Project Management Maturity Model* (*OPM3 model*) (PMI, 2005) published by the Project Management Institute. *OPM3* enables companies to produce and reproduce successfully and consistently over time, a high-performance project management.

Regarding people management in organizations, two maturity models can be identified: Human Factors Integration CMM (Earthy *et al.*, 1999), which seeks to guarantee the quality in industrial processes providing the means to eradicate safety hazards at work, and People CMM (Curtis *et al.*, 2001), which establishes the basis for continuous improvement of individual skills and for developing work teams.

Other models can be found in literature such as: Risk Maturity Model (Hillson, 1997); Best Practice Model for Change Management (Clarke and Garside, 1997); Information Process Maturity Model (Hackos, 2004); Assessment of purchasing maturity in spare parts supply chain (Asikainen, 2013). A comprehensive overview of 24 maturity grids built on the ideas of Crosby's quality grid is presented by Maier *et al.* (2012). In the last years, several other models have been proposed in literature to assess the maturity of: Lean management (Urban, 2015); demand-driven supply chain (Mendes *et al.*, 2016); risk management (Oliva, 2016); portfolio management (Nikkhou *et al.*, 2016); energy management (Finnerty *et al.*, 2017); sustainability (Meza-Ruiz *et al.*, 2017; Machado *et al.*, 2017); production management (Kosieradzka, 2017).

As in the several areas mentioned, maturity models have also emerged in the area of maintenance and, in the literature, a few may be found. These models are discussed below.

2.2 Maintenance maturity models

Antil (1991) proposed a model inspired and based heavily on the maturity model developed by Crosby (1979) to the area of quality. This model was subsequently adopted and used by Fernandez *et al.* (2003) to identify the position of companies in terms of maintenance in order to define and implement a computerized maintenance management system (CMMS) that suits their needs. The model considers that maintenance evolves from a predominantly reactive state, in the early stages, for a preventive and a predictive state in the latter stages. With its four classes of evaluation, it covers some aspects related to maintenance management, namely, problem-solving strategies, the use of a software tool to support the management of maintenance activities and issues related to posture in maintaining organizations' equipment.

Wireman (1992) also proposed a maturity model to maintenance management that follows the structure of the model formulated by Crosby for quality and converts, in several cases, the terms related to quality to those associated with maintenance. The classes address issues related to: the maintenance posture of the organization; maintenance resources; maintenance organization and improvement actions, system information and qualification. The class related to maintenance resources adopts goals, defining the percentage of resources wasted, to define each maturity stage. Considering the application of the model to different companies and activities segments, this approach of defining stage by fixed goals may mean inaccessible stages and unequal difficulties for reaching the same level in different companies. The class related to workers qualification makes use of intangible issues when it refers to how good is a certain activity performed. Furthermore, the model joins in the same class two important factors in maintenance: maintenance information and improvement actions.

Cholasuke *et al.* (2004) performed a pilot survey in the UK to identify the factors or key ingredients for effective maintenance management and success. Based on the survey results, the respondent's companies were categorized into four maturity levels, defined by the combination of two criteria: the employment of good maintenance practices and the benefits gained from maintenance. Besides, a categorization was also defined for each considered factor in three maturity levels that among other includes: the effectiveness of maintenance, using targets for the overall equipment effectiveness (OEE) indicator to define the groups; policy and organization, differentiating the groups by the hierarchical structure of the area; planning and scheduling activity, using an overtime level limit for defining each group; continuous improvement, considering the type of methodologies adopted in maintenance management, such as reliability-centered maintenance and total productive maintenance (TPM) to define the groups; spare parts management, pointing out the use of Pareto diagram, in the excellence level, to control inventory requirements.

Campbell and Reyes-Picknell (2006) proposed a model, defined with the support of a survey, using the concept of Pyramid of Excellence. Indicators and goals are used to define some maturity levels such as for the material management class. The use of methodologies such as balanced scorecard and reliability-centered maintenance is a considered aspect to define the highest levels of maturity. The model includes a class designated by management support that refers to the degree of use of a management system but there is no explicit reference to the use of a computer system to support maintenance management. Human resource is addressed but qualification and training are not mentioned. Some aspects are considered in more than one class, such as preventive maintenance and condition-based maintenance, the autonomy of the teams and the participation of the operators.

The maintenance maturity models previously mentioned are over ten years old and therefore do not consider the latest maintenance management developments. In a more recent study, Chemweno *et al.* (2015) proposed a generic framework denominated as asset maintenance maturity model (AMMM) that consists of a structured guide to assess and improve maturity in asset management that involves three phases: performance assessment, continual improvement, benchmarking and standardization. This work is an extension of the maintenance performance measurement framework proposed by Van Horenbeek and Pintelon (2014), aimed at disciplining the process of choosing and managing performance indicators. Such a framework enumerates maintenance objectives and respective maintenance performance indicators. The AMMM is based on a quantitative analysis which includes a weighted performance assessment score for benchmarking and risk assessment to boost improvements actions. Five levels of maturity are defined based on the score value. According to the authors, the improvement process is focused on the definition of the more adequate maintenance strategy for a given failure, analyzing failure risks. The main difficulty in using this methodology is the manipulation and understanding of the mathematical formulation of the weighted performance assessment score to determine the maturity level. This model allows assessing the maturity level but does not indicate or assist in the identification of actions that must be pursued to reach the highest level.

A summary of the published works in maintenance maturity assessment is shown in Table I.

In a more comprehensive area than maintenance management, that is physical asset management, assessment of maturity also arose. The Institute of Asset Management (IAM) in association with the British Standards Institution (BSI) issued a document in 2004, revised in 2008, and called BSI PAS 55:2008, which seeks to establish a standard for asset management. The IAM in conjunction with a number of sponsoring organizations developed an Assessment Methodology, the PAS 55 Assessment Methodology (PAM), to measure their conformance with BSI PAS 55:2008. The specifications of the PAS 55 requirements were transformed into ISO standards, released in 2014. The PAM Maturity Scale has since been revised and renamed as the IAM Asset Management Maturity Scale.

Proposed by	Measurement classes	Level/stage
Antil (1991)	1. Management understanding and Attitude 2. Problem handling 3. Company maintenance posture 4. CMMS	1. Uncertainty 2. Awakening 3. Enlightenment 4. Wisdom 5. Certainty
Wireman (1992)	1. Corporate/plant management attitude 2. Maintenance organization status 3. Percentage (%) of maintenance resources wasted 4. Maintenance problem solving 5. Maintenance workers, qualification and training 6. Maintenance information and improvement actions 7. Summation of company maintenance position	1. Uncertainty 2. Awakening 3. Enlightenment 4. Wisdom 5. Certainty
Cholasuke *et al.* (2004)	1. Maintenance effectiveness (output) 2. Policy deployment and organization 3. Maintenance approach 4. Task planning and scheduling 5. Information management and CMMs 6. Contracting out maintenance 7. Continuous improvement 8. Financial aspects 9. Human resource management 10. Spare part management	1. Innocence 2. Understanding 3. Excellence
Campbell and Reyes-Picknell (2006)	1. Strategy 2. People 3. Work management 4. Materials management 5. Basic care 6. Performance management 7. Support systems 8. Asset reliability 9. Teamwork 10. Processes	1. Innocence 2. Awareness 3. Understanding 4. Competence 5. Excellence
Chemweno *et al.* (2015)	A. Strategic: 1. People and environment; 2. Functional and technical aspects; 3. Plant design life; 4. Support; 5. Maintenance budget B. Tactical: 1. Safety/risk/health; 2. Output quality; 3. Reliability; 4. Availability; 5. Inventory of spare parts; 6. Capital replacement decision; 7. Maintenance cost; 8. Overall equipment effectiveness; 9. Environmental impact; 10. Logistics; 11. Maintenance quality; 12. Personnel management; 13. Productivity; 14. Life cycle optimization; 15. Maintainability	1. Level 1 2. Level 2 3. Level 3 4. Level 4 5. Level 5

Table I.
Maintenance maturity classifications

3. The model development

The model to be developed is a grid with different classes for maturity evaluation, presented in the rows, and for each class, the progressive levels of maturity, from the worst to the desired level, presented in the columns. The first step in developing the maturity model is the identification of the significant factors that contribute to the performance of the area. These factors are considered the classes of the model.

For the proposed model, ten evaluation classes were considered as follows: (1) organizational culture, (2) maintenance policy, (3) performance management, (4) failure analysis, (5) planning and programming of preventive maintenance activities, (6) CMMS, (7) spare parts inventory management, (8) standardization and document control, (9) human resource management and (10) results management (maintenance costs and quality).

The identification of the significant factors was made considering the enablers that cover the entire maintenance management chain. These enablers were identified in the literature.

According to Marquez and Gupta (2006), three main pillars support maintenance, namely, IT, maintenance engineering (ME) and organizational (or behavioral) pillar (BE). The considered classes were defined to involve these three pillars (IT – CMMS; ME – failure analysis, planning and programming of preventive maintenance activities; BE – organizational culture, maintenance policy, human resources management) but also to cover all the maintenance management activities. The standard EN 13306:2010 (2010) defines maintenance management as all the activities of the management that determine the maintenance objectives or priorities, strategies and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organization including economical aspects. Historical records (made through CMMS – Class 6) and failure analysis (Class 4) are important to provide information for the planning and programming of maintenance activities (Class 5). And, in its turn, the effectiveness and efficiency in the execution of the maintenance plan depend on spare parts inventory management (Class 7), on the availability of standards and documentation (Class 8) and on human resources management (Class 9). The use of performance indicators (Class 3) allows converting data into information that supports decision making to improve maintenance results (Class 10). In addition to involving, through the ten defined classes, the factors that influence all maintenance activities, the model, covers the strategic, operational and tactical levels of maintenance management.

Comparing to previous works, the considered classes cover the key ingredients or factors for effective maintenance identified by Cholasuke *et al.* (2004), except the contracting out maintenance factor since the model is focused on the internal management.

The proposed maturity model is focused on behavior and not on results since the latter may have different magnitudes depending on the industry sector. The behaviors that lead to good results for each class of the model have been identified by an extensive literature review, and the levels established supported by the authors' experience in maintenance management.

Five levels of progression, as most of the maturity models previously proposed, were considered. The model is presented in Table II. In each cell of the grid, statements aim at defining the behavior or practices adopted in the maintenance area.

Each class is explained below justifying its influence on maintenance operation and performance, and identifying the associated relevant elements (or aspects) and world-class behaviors that supported the maturity levels definition.

3.1 Organizational culture (1)

According to Gulati and Smith (2009), culture refers to the values, beliefs and behaviors of an organization and, in general, these beliefs and values define how people interpret experiences and behave individually and in groups.

Some authors believe that organizational culture is a determining factor in achieving results in maintenance (Fernandez *et al.*, 2003; Garg and Deshmukh, 2006; Marquez and Gupta, 2006) and sustain that the application of methodologies, training strategies, among others is affected by company's culture (Bortolotti *et al.*, 2015; Panneerselvam, 2012; Valmohammadi and Roshanzamir, 2015).

Clarke and Garside (1997) propose a model for change management, in which organizational culture is addressed showing the existence of organizations with a reactive culture, i.e. organizations where people do not accept change easily, as well as the existence of organizations with proactive culture, i.e., organizations where people are fully committed to change.

To improve the maintenance area performance, a proactive culture must be established. Bearing in mind that a thorough approach to organizational culture can be complex, three

Table II. Maintenance maturity grid

Measurement class	Level 1	Level 2	Level 3	Level 4	Level 5
Organizational culture	Changes are not well accepted. There is no guidance for continuous improvement and teamwork	Changes are accepted reluctantly. The need for continuous improvement was Identified, but not yet adopted. Limited teamwork	Changes are accepted and considered important. Implementation of actions for continuous improvement. Teamwork	Changes are accepted and considered important. Actions for continuous improvement with defined methodologies. Teamwork. Team spirit	There is commitment to the change, adapting to the new strategic priorities. Actions for continuous improvement with defined methodologies. Teamwork. Team spirit
Maintenance policy	Maintenance is considered a necessary evil, being focused on the resolution of faults in the shortest possible time	Maintenance is considered a necessary evil, but the need to act preventively is recognized	Maintenance is considered important in achieving the organization's objectives. Preventive maintenance in order to increase productivity and reduce costs	Maintenance is considered important in achieving the organization's objectives. Acting proactively (including improving equipment) in order to increase productivity, reduce costs and improve quality	Maintenance is considered a strategic function. Acting proactively (including improving equipment) and efficiently in order to increase productivity, reduce costs, improve quality and reduce accidents and environmental impact
Performance management	There are no defined indicators	Performance indicators calculated sporadically, with a focus on technical indicators determined for the all factory and/or at the production line level	Performance indicators calculated periodically, with a focus on technical and economic indicators, determined for the all factory, at the line and equipment level	Technical, economic and organizational indicators calculated and analyzed periodically, supporting decision making and giving rise sporadically to improvement projects; reliable data	Technical, economic and organizational indicators aligned with the strategic objectives of the organization, calculated and analyzed periodically, supporting decision making and giving rise to improvement projects; reliable data
Failure analysis	Failures analysis without a defined method, performed when failures with significant impact occur	Failures analysis without a defined method, performed sporadically and when failures with significant impact occur	Periodic failures analysis based on a defined method	Identification of critical equipment and critical failures sporadically and implementation of measures based on a methodical analysis of failures that causes a low recurrence of failures	Updated information of critical equipment and critical failures, and implementation of measures based on a methodical analysis of failures, which leads to the absence of fault recurrence
Planning and scheduling of preventive maintenance activities	Preventive activities defined following the occurrence of critical events	Planning carried out based on the manufacturer's manuals covering some equipment. Delays and programmed actions not completed	Planning carried out based on the manufacturer's manuals covering all equipment. Delays and programmed actions not completed	Revised activity planning based on failure rate and equipment monitoring. Occasional deviations in plans fulfillment	Revised activity planning based on failure rate and equipment monitoring. Programming defined based on planned production

(*continued*)

Table II.

Measurement class	Level 1	Level 2	Level 3	Level 4	Level 5
CMMS	No electronic records of maintenance data	Use of computer applications for maintenance management, not integrated with other computer systems of the company	Computerized system for planning and control of maintenance, with some unused functions, not integrated with other computer systems of the company	CMMS where not all functions available are widely and properly used, not integrated with other systems of the company	CMMS to support all functions of maintenance management, with a high degree of automation, whose functions available are effectively used, integrated with other systems of the company
Spare parts inventory management	Spare parts are not classified. There is no forecast of future demand	Classification of spare parts based on only one criterion (e.g. price or consumption pattern). Demand forecasts based on historical consumption	Classification of spare parts based on only one criterion (e.g. price or consumption pattern). Demand forecasts defined empirically and based on historical consumption	Classification of spare parts based on more than one criterion related to spare parts supply characteristics (e.g. lead time, suppliers) and/or inventory characteristics (e.g. price, obsolescence). Demand forecasts based on historical consumption, spare parts lifetime and maintenance strategy	Classification of spare parts based on their functionalities (impact of stock out), supply characteristics and inventory characteristics. Inventory management strategy defined for each group of the classification. Inventory levels regularly reviewed based on forecast demand, defined based on spare parts lifetime and maintenance strategy
Standardization and document control	Documentation of equipment unavailable or outdated. Non-standardized processes and activities	Documentation of equipment and processes are unorganized. Some processes and activities are standardized, but not revised	Documentation of equipment and processes are organized. Most processes and activities are standardized, but not revised	Documentation of equipment and processes are organized, with quick and easy access. Processes and activities are standardized and revised	Documentation of equipment and processes are systematically updated with quick and easy access. Processes and activities are standardized and systematically revised
Human resource management	Punctual training motivated by high-impact problems. Employees have low competence	Skills development plan for maintenance employees nonaligned with the area's needs	Skills development plan aligned with the area's needs	Skills development plan aligned with the area's needs. Polyvalent maintenance employees, with involvement of production employees in certain activities	Skills development plan aligned with the objectives of the area. Polyvalent maintenance employees, involved in improvement activities. Involvement of production employees in certain activities. Plans for recognition and reward
Results management (maintenance costs and quality)	High and uncontrolled cost; high waste of materials and high recurrence of failures	High and uncontrolled cost, with some actions performed sporadically to reduce waste and recurrence of failures	Implementation of actions to control costs, with level of waste and recurrence of failures measured but not investigated	Controlled costs, with level of waste and recurrence of failures measured and investigated	Controlled costs, low waste and low recurrence of failures

main aspects are considered for its characterization in the model: attitude toward change, continuous improvement and teamwork.

3.2 Maintenance policy (2)

The maintenance policy is usually not defined explicitly in companies such as it is in the quality area due to the certification of the quality management system. A policy defines the intention, direction and aims. When no policy is defined explicitly or implicitly, there is no clear aim to be pursued by the organization.

Cholasuke *et al.* (2004), in his research in the British industries, proposed a category of classification in which the maintenance policy should be derived from the business strategy of the company or the organization's manufacturing strategy, a concept that is also held by some other researchers (Kelly, 1997; Tsang *et al.*, 1999). Jonsson (1997), in its assessment work of the state of maintenance in Swedish companies, noted that the lack of connection between the maintenance policy and the company's overall strategy may result in poor performance of the maintenance area. Robson *et al.* (2013) proposed a model that from reading the external environment, directs the manufacturing strategy, which, in turn, is connected to, and directs the maintenance strategy, in order to derive the maintenance policy.

The maintenance policy class of the model considers the role of maintenance perceived by the organization and the way of acting, leading to the achievement of predefined objectives in the area.

3.3 Performance management (3)

According to Muchiri *et al.* (2011), maintenance managers need a good track of performance on maintenance operations and results, and also need to know the relationship between the input of the maintenance process and the outcome in terms of total contribution to manufacturing performance and business strategic objectives. An overview of the available literature shows that several authors emphasize that performance indicators used by the maintenance area should be aligned with organizational goals. Performance indicators, besides supporting the identification of improvement actions, guide the behavior of people that seek to influence them. Therefore, good practices can be adopted if the indicators are aligned with the objectives to be achieved and therefore to the maintenance policy.

The European standard EN 15341:2007 (2007), designated by Maintenance – Maintenance Key Performance, proposes a large number of maintenance indicators that are classified as economical, technical and organizational indicators. According to this standard, indicators can be used at different levels to evaluate the performance of all production, a production line or a given equipment or asset. When indicators are used at the equipment level, they allow determining critical equipment and prioritizing improvements.

The results of the survey performed by Oliveira *et al.* (2016) to Brazilian companies showed that the frequency of use of performance indicators in maintenance area is low and is dependent on the number of equipment, maintenance staff size, TPM adoption and CMMS utilization. The most frequently used indicators are technical, namely, downtime and availability, and economical indicators. These indicators measure mostly the maintenance results and are referred to as lagging indicators. The organizational indicators, which monitor maintenance efficiency, that can be referred to as leading indicators are less used. However, leading indicators are important because they have the potential to avoid unfavorable situations from occurring (Muchiri *et al.*, 2011).

Performance indicators should measure accurately what we want to evaluate. According to Lopes, Sousa and Nunes (2016), in the performance measurement process, several factors may contribute to increase the difference between the measured value of the performance measure and the true value. No physical quantity can be measured with certainty affecting the quality of the performance measures used in an organization which may lead to higher risk in decisions.

Therefore, for the definition of each level of the performance management class, the focus is given to the type of indicators in use, to their frequency of use and their accuracy.

3.4 Failure analysis (4)

Maintenance is aimed at properly managing the equipment in order to avoid failures or mitigate their effects. For maintenance performance to be effective, data collection, and especially the ability to analyze these data, is a key aspect.

Andersen and Fagerhaug (2006) define the root cause analysis as a collective term that designates a wide range of approaches, tools and techniques used to find out the causes of problems. They note that the key issue is not to learn and apply all the tools, but to become familiar with the root cause analysis tools available and apply the most appropriate tool to solve a specific problem.

Critical equipment and critical failures should be identified in order to give rise to the implementation of measures based on risks. Identifying the critical equipment consists of determining which equipment has the greatest potential impact on the attainment of business goals. Therefore, the analysis allows minimizing or mitigating the causes of malfunctions, canceling out or diminishing the effects of their consequences, or finding means of early detection that allow acting in a timely manner.

The levels of the failure analysis class were defined based on the frequency of failure analysis and on how the issue is addressed.

3.5 Planning and programming of preventive maintenance activities (5)

Kelly (2007) sustains that a maintenance strategy involves the identification, resourcing and execution activities and, to accomplish goals, a maintenance schedule needs to be formulated, defining the maintenance resources (men, spares, tools, information) and the organization to enable the schedule.

To achieve excellence in maintenance, the balance of maintenance performance, risks and costs must be taken into account in the identification of tasks to be performed (Campbell *et al.*, 2011). A preventive maintenance strategy is frequently applied considering technicians' experience or equipment manufacturer recommendations. However, to correctly balance the involved factors and to take into account the operating conditions, the preventive activities should be reviewed based on failures occurrence and equipment monitoring.

Thus, the distinction between the levels of the class designated by planning and programming of preventive maintenance activities was made taking into account the approach used to define planned activities and the fulfillment of the maintenance plan.

3.6 CMMS (6)

According to Fernandez *et al.* (2003), to be effective, a strategy must be firmly supported by a valuable asset: information. For Wienker *et al.* (2016), without a CMMS world-class maintenance is difficult to achieve.

A computer system simplifies and reduces the data acquisition time compared to a manual system. Fernandez *et al.* (2003) denote that, despite the availability of many computer systems in the market, several companies choose to develop customized applications tailored to their needs, in order to provide maintenance planners a platform for decision support often ignored in commercially available solutions on the market. Selecting an appropriate CMMS that meet the maintenance needs should not be dictated by the system characteristics, but dictated by the objectives of the maintenance department. Fernandez *et al.* (2003) also note that it would be a mistake to buy a system with a focus on software, rather than considering the real needs of end-users. As a result, the modules which would never be used harm the system potential.

Therefore, for the class designated by CMMS, the aspects that were emphasized to define the levels were the type of support, which allows the perception of the ease of access to data and information, and its degree of use.

3.7 Spare parts inventory management (7)

According to Wireman (2010), inventory has a greater impact on maintenance productivity than any other support group.

Asikainen (2013) proposed a model for evaluating the maturity level for the purchase area involving all processes of the supply chain. The proposed model explores the stage where there is no classification of stock items, evolving to the stage where items are classified based on relevant characteristics (criticality, value and logistics). A classification that uses several criteria reflects better the different particularities and allows a better assignment of an adequate inventory management policy. Several authors proposed multi-attribute techniques to classify spare parts (Roda *et al.*, 2014).

With regard to demand forecasting methods, Asikainen (2013) considers that the elementary stage is one where there is no criterion to predict future demand for spare parts and the reference stage is one where the demand for spare parts is analyzed from the combinations of methods aligned with the specific needs of the different parts groups and are regularly reviewed. For stock control policy, the model distinguishes between situations where there is no inventory policy and no systematic analysis to stock control and situations where inventory policy is regularly updated based on the product life cycle and based on demand patterns.

González-Prida *et al.* (2014) suggest to basing the parts acquisition strategy on reliability analysis, using statistical models to evaluate distribution parameters and failure rate behavior.

The proposed spare parts inventory management class considers the two aspects, classification of spare parts and forecasting of demand, to assign the maturity level, taking into account for each the recommendations of the cited works.

3.8 Standardization and document control (8)

Standardization ensures that all do the same work in the same and efficient way, whether by persons related to maintenance or operations. It also ensures the memory of the company, because it preserves the information, practices and procedures, when changes occur in teams.

Kelly (1997) defines maintenance documentation as any record, catalog, manual, drawing or computer file containing information that might be required to facilitate maintenance work.

In the requirements specification for a CMMS for an automobile company, Lopes, Senra, Vilarinho, Sá, Teixeira, Lopes, Alves, Oliveira and Figueiredo (2016) define augmented reality as a requirement to be implemented in the new system. Augmented reality aims to provide a 3D view of equipment and respective information. This kind of technology, which is under development, will be helpful in the maintenance area facilitating the transmission of information and instructions to technicians. The accessibility to equipment information is valuable, mainly in the diagnosis of a malfunction.

The absence of normalization and documentation means a high dependence on actual maintenance technicians and also more time spent performing maintenance interventions. Therefore, the highest maturity level in this class considers a quick and easy access to documentation of equipment and processes, and the actualized standardization of processes and activities.

3.9 Human resource management (9)

Any maintenance planning strategy involves assessing human resources to identify availability and skills, which may be a limitation to planning, either because of scarcity or because of the level of training (Bouzidi-Hassini *et al.*, 2015; Touat *et al.*, 2017). Mather (2005), in his proposal for the maintenance scorecard adoption, argues that human performance can be oriented by the identification of the skills map that will be required to achieve the corporate goals. According to Wireman (2005), without good quality training programs, the maintenance area will never be cost-effective and, therefore, companies must constantly assess the frequency of training programs for all maintenance personnel.

Several developed maturity models sustain that the management of human resources is a fundamental and important class in order to achieve planned results. In an early stage of maturity, human resources management is not focused on achieving the organization's objectives, while in a full maturity stage, the management of human resources is focused on achieving the organization's objectives and the training plan reaches all members of the team at all levels and is continuously reviewed to keep up with the technological evolution of equipment and processes (Bessant *et al.*, 2001; Cholasuke *et al.*, 2004; Hackos, 2004; ISO 9004:2009, 2009; Wireman, 1992).

The TPM methodology recommends the participation of operators in simple maintenance tasks that do not require specific skills, such as cleaning and lubrication, which is called autonomous maintenance. Autonomous maintenance allows technicians' availability for tasks that require their specific skills and still allows the production does not have to wait for a technician to perform a task that operators themselves can perform.

Such as previous works, the human resources management class focuses on training and its alignment with organizational objectives in the area. In addition, it considers the collaboration of production in maintenance activities.

3.10 Results management (10)

In this class, maintenance cost and quality of the performed works are considered. According to Khalil *et al.* (2009), knowing the costs associated with the maintenance process is fundamental in order to evaluate its performance and contribution to the company. Maintenance investments have a significant return, since the maintenance process compensates for their costs through profit achieved by improving the quality of the final product, the increase of the operational availability of equipment, the increase of the life cycle of equipment and facilities, the quality assurance of equipment, among others.

For Gulati and Smith (2009), all maintenance works involve some risks, that is, they have the potential to induce additional failures in the asset in which maintenance was performed. Cholasuke *et al.* (2004), in their maturity model, define as a stage of innocence (Level 1) in the financial management of maintenance, companies that do not have information and knowledge about maintenance costs, as well as problems related to losses of production due to poor quality of maintenance services. Using the same aspects for characterizing maturity, the excellence stage of the proposed results management class considers that the collection, treatment of information and use of appropriate techniques allow the identification of maintenance costs as well as improvement actions to minimize the effects of productivity losses.

Concerning costs and the quality of maintenance activities, the model of Campbell and Reyes-Picknell (2006) characterizes maintenance processes as efficient and effective in the highest maturity level. In the proposed model, concerning quality of maintenance activities, the highest level is assigned when the improvements are due to the systematic implementation of continuous improvement programs, which result in the reduction of the level of losses, rejects, rework, waste of material, recurrence of failures, as well as recovery time, resulting in a low impact on productivity.

4. Model application

In order to test the proposed maturity model, it was first applied to a textile company located in Portugal, and after to companies of two different sectors of the industrial center of Manaus (Brazil).

Concerning the Portuguese company, a work intended to analyze the maintenance area and set some improvement initiatives was recently held in the company by a graduate student within the scope of his master's thesis (Pereira, 2016). The analysis made by Pereira (2016) in the maintenance area allowed gathering relevant information to identify the company' maturity for some of the model classes. However, additional information was necessary to apply the whole model, and was gathered by interviewing the maintenance staff.

This first application was made by the authors and functioned as a pre-test of the model. However, the following two applications were made by the companies themselves, since the model is intended to be a self-assessment tool. For these applications, the model was sent to the companies to be used by the person in charge of maintenance management. Latter, the person in charge was interviewed in order to obtain information that contributes to the evaluation and clarification of the selected levels. Then, improvement actions aimed at reaching the highest maturity levels were identified together with the person in charge. Finally, information about the model and suggestions for improvement were collected.

4.1 Company of the textile sector

The company under study currently produces the most varied pieces in the area of home textiles, including covers, duvets, pillows, tablecloths, napkins, kitchen cloths and so on.

The maintenance area supports the company's production sectors, including weaving and confection, keeping a permanent staff to perform corrective activities and another one to preventive maintenance activities. The team has 30 employees, including managers and technicians being geared for the quick action and according to the production area needs, organized under the electrical, mechanics, fluid, weaving, confection and energy areas.

Pereira (2016) made a global diagnosis of the maintenance area of the company based on the principles of Lean Manufacturing applied to maintenance. His analysis focuses on: corrective and preventive maintenance tasks, the state of housekeeping and organization, the CMMS running in the company, performance measurement, practices associated to TPM, failure analysis tools and supply and management of spare parts.

The additional needed information that was gathered interviewing the staff of the company maintenance area included information on: organizational culture, maintenance policies, standardization and control of documents, spare parts management, as well as human resources management. The interview with the maintenance responsible focused on the conditions to be created to drive improvements and involvement of employees. These factors that are covered by the maturity model were considered important by the maintenance responsible besides the other factors directly related to the maintenance activities such as CMMS, maintenance planning and spare parts management.

The information collected through the previous study and interviews that is summarized in Table III allowed characterizing the maintenance area taking into account the classes of the model as presented in the radar chart of Figure 1.

This first application leads to some improvements in the maturity model to make it more concise and easier to understand. It was also possible to verify that the classes are appropriate and cover all aspects of maintenance management.

4.2 Company of the optical sector

The second company in which the model has applied acts in the optical sector and manufactures ophthalmic lenses. The maintenance team comprises 35 employees, organized

Table III. Summarized information gathered for the model application

Classes	Textile company	Optical company	Material plastic company
Organizational culture	Continuous improvement is encouraged, but there is a certain reluctance and resistance to change. The transmission of the strategy from the organization to the maintenance teams is done in stages, taking place first between higher hierarchical levels that, in turn, unfold the strategies for the respective teams	The company follows an internal methodology based on Lean Manufacturing that is called LIFE (Lean Initiative For Excellence). However, the model is still in the implementation stage in the plants of Manaus. The 5S and the EER (Equipment Efficiency Ratio) are already in place. The company watches over the diversity as well as the teamwork and team spirit, being main values shared among all the members	The improvement actions are isolated within the organization and between the areas, with emphasis on the manufacturing area of lids. However, it can be seen that the relationship between the areas, and between the managers, does not contribute to a peaceful coexistence, with many points of friction and non-existent collaboration and team spirit. Collaboration occurs when there are extreme demands
Maintenance policy	There is no defined policy. Maintenance is stated to be strategic for the organization. However, the few improvement actions, as well as those that will be implemented, are the result of the individual initiative of the maintenance manager looking for higher levels of the maintenance area performance	For a long time the company only performed corrective maintenance. After the new management taking possession, the goal was to have a preventive maintenance plan, since an increase of production that would use the total capacity of the machines was anticipated for the following years	Although the team of managers who participated in the interview affirmed the commitment of the organization with maintenance, the activities are carried out according to the need of each company area and guidance to act in the shortest possible time prevails
Performance management	The maintenance area does not adopt performance indicators and, therefore, it is not possible to establish quantitative goals. The current computerized system does not allow the correct parameterization for its calculation	There are KPIs defined by the directors for each sector that are evaluated on a monthly basis. They are a bonus given by the company to the employees if the sector goals are reached. The performance indicators adopted are EER (equivalent to OEE), MTBF, MTTR	The maintenance area adopts a single performance indicator: availability. There is no clear understanding of indicators such as OEE, MTBF, MTTR, for instance, but they intend to adopt at least the MTBF
Failure analysis	There is no systematic evaluation of failures that occur in the company and, therefore, some failures have a high recurrence. To define priorities for maintenance interventions, no specific method is adopted and common sense is used by the maintenance area	8D methodology was defined for analyzing significant failures. But in practice its use is still very confusing. Usually cause and effect diagram and 5whys are used. Each analyst uses the tool he deems most assertive. However, this behavior tends to change with the implementation of LIFE	Punctual actions and tools/failure analysis methodologies are unknown
Planning and scheduling of preventive	A global preventive maintenance plan is defined in which the planning of activities was based on what is stipulated by the equipment manufacturers.	To create the maintenance plan the team followed the manufacturers' recommendations, recommended in the	Planning is only formal, since execution does not always happen according to schedule. There is a high backlog, mainly because the

(continued)

Classes	Textile company	Optical company	Material plastic company
maintenance activities	Time-based maintenance is the dominant type of preventive maintenance; only a few condition-based interventions are performed. Planning and execution are done based on the equipment availability, depending on the respective production plans, and are usually executed during the week, with some actions taken during the weekends. Delays in the finalization of preventive maintenance services due to the non-allocation of technicians generate backlog	technical manuals. However, for the older injectors, the referential was the empirical knowledge of the technicians	maintenance activities are carried out when the production releases equipment. Some interventions frequencies are based on the equipment utilization
CMMS	The company owns a CMMS with functions that are common in CMMS, such as registration of equipment, materials, interventions, planning, human resources and organization of documentation. However, it is considered limited, time-consuming and, difficult to parameterize and use. The maintenance plan is only reported in paper documents. Requests for corrective interventions are time-consuming and the classification of malfunctions is not allowed. The company has a SCADA system for monitoring parameters in some auxiliary equipment and there is no integration between this system, the CMMS and the production control system	The maintenance area uses a VBA management system, which still requires a lot of manual inputs and does not communicate with production floor management and factory management systems. Work orders are generated manually	SAP preventive maintenance module is used. However, only the area of plastic covers uses it more effectively, due to the experience acquired by the maintenance responsible of this sector. The other areas do not use the SAP module as they do not dominate the system and consider it difficult to use. With that, all the control is made in spreadsheets. The absence of History is also a weakness in management. In addition, SAP is not integrated with the other company systems and not all equipment is included in the plan registered in the system
Spare parts inventory management	There is no effective control of parts used for preventive and corrective maintenance. Parts for corrective activities are acquired in accordance with the critical assessment of the maintenance area and technical management. Parallel stocks, inadequate storage of parts, lack of control of existing inventory and lack of identification of the condition of parts (good, repaired or irreparable) were identified	Although there is an attempt to control inventory, there is still a great deal of material shortage for maintenance, as most of the time they are imported parts and the procurement sector does not have a lead time control/ forecast	The maintenance area uses SAP module for stock control. However, not all the parts are registered and there is a control made in parallel to the system, generating inaccuracy and problems in inventory control

(*continued*)

Table III.

Classes	Textile company	Optical company	Material plastic company
Standardization and document control	Few tasks or maintenance activities are standardized, organized and documented	The documentation exists and can be easily found, according to the premises of the ISO 9001 standard. However, the updating of the documents does not occur as soon as the process changes, which ends up generating non-conformities	The documentation is accessible, but there is no systematic review and standardization of the procedures adopted by the area
Human resource management	Training is made occasionally and the effectiveness of the actions performed is not verified. There is a matrix to register competencies for the highest hierarchical levels. The company does not have an incentive system, but plans to define and implement one in the future	There is a plan defined and prepared by the area manager, where the limitations and needs of the team are identified and, thus, the training required for the maintenance team members is defined	There is no ongoing training policy, although the administration wishes to implement one. There is a great deficiency of process knowledge and this causes conflict between maintenance and production areas on agreement about the origin of a given problem, and who should take the appropriate actions. In general, there is a little concern about conflict management, since they are more concerns with technical performance. A minority of the members has a higher level of education
Results management (costs and quality maintenance)	It is considered that the total maintenance cost is low, but there is no effective control and data to prove this information, since the record and control is only done for the energy consumption and there is no stratification of maintenance costs. Regarding the quality of maintenance activities, there is failure recurrence, but the losses resulting from failures are not considered high. Production considers that maintenance spends too much time in repairs	Focus on cost management, where actions are undertaken sporadically due to budget constraint	The main concern of managers is related to costs. Actions for containment and elimination of waste are not carried out. Faulting is one of the main factors affecting results. The loss of material has not a high impact because material is reused, reintroducing it again in the process. However, a lot of time is lost with equipment stops because the process does not stabilize immediately

Table III.

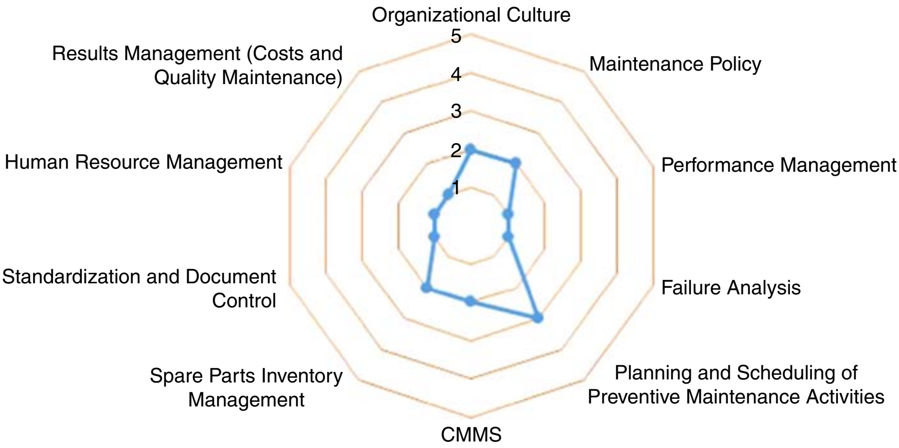

Figure 1. Maturity levels of the textile company

in three shifts under the electrical, facilities and mechanics areas, responsible for the maintenance of 1,355 equipment, including facilities and production equipment.

As a brief overview, the manufacturing plant is characterized by having some old machines that have gone through adaptations, improvements and retrofits and the diversity of machine suppliers makes it difficult to control and purchase parts, which makes maintenance time-consuming and inventory expensive. In 2017, the company decided to eliminate predictive maintenance and reduced preventive maintenance, since the associated costs were considered high. During the year 2018, this policy was reviewed and preventive activity was retaken, since the numerous stops due to lack of maintenance in the previous year had a significant impact on the results. Currently, actions to train the team in methodologies of failures analysis and prevention are also ongoing, in addition to bonuses as a way to encourage preventive activities.

The information gathered considering each class of the model is summarized in Table III and the classification of maturity is presented in Figure 2.

The CMMS and spare parts inventory management classes of the model were those in which the company obtained a lower level of maturity. In this sense, improvement actions

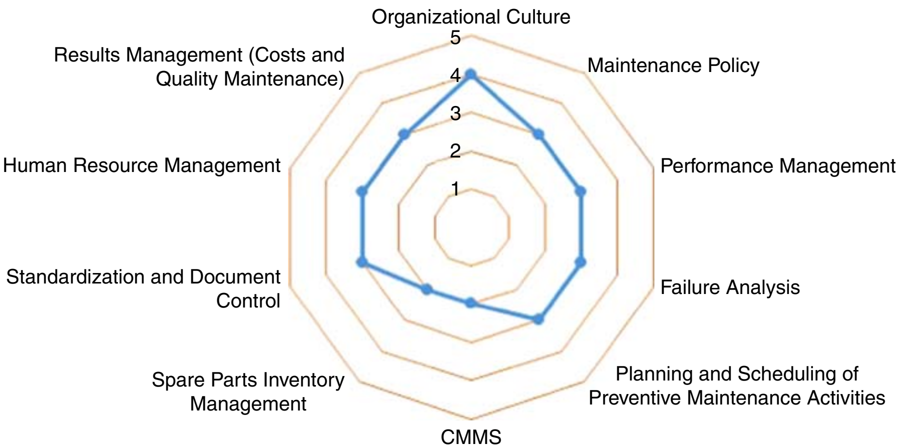

Figure 2. Maturity levels of the ophthalmic lenses company

to reach higher levels can involve the acquisition of an effective computerized maintenance system for management and control of maintenance activities. This option could also drive improvements related to the control of spare parts and consumables used in maintenance activities.

Regarding the perception of the maturity model, the manager in charge informed that he did not know about any maturity model in the maintenance area or other. The model was considered attractive and easy to use, due to its simplicity. He pointed out that they have had difficulties, in the past, in making assessments and diagnosis. In the understanding of the manager, the model does not include autonomous maintenance. The company did not adopt this maintenance practice, but it was introduced recently with the qualification of some employees, which greatly helped in improving the machine's efficiency.

4.3 Company of the plastic material sector

The third company acts in the plastic material sector and manufactures plastic beverage caps, polypropylene bi-oriented films for food packaging and overpacks, and plastic material in general. The maintenance area keeps a permanent staff of 26 employees to perform corrective and preventive maintenance activities to 130 equipment covering all manufacturing processes and facilities organized in different areas (plates and utilities, extrusion and caps, plastic packages).

A brief characterization of the situation of the maintenance area of the company shows that maintenance teams are oriented to corrective activities, since the company does not have a strategy focused on prevention. In addition, the use of computerized resources for maintenance management as well as spare parts control is limited. In terms of performance management, the area does not have a set of indicators that can aid management on decision making. The use of methodologies for analysis and prevention of failures is also limited, largely due to a lack of training in available tools and methodologies. Apart from the low investment in training, teamwork is little or almost never stimulated, and there is a strong barrier to collaboration between areas.

The information collected through the interview and the classification based on the model are, respectively, presented in Table III and Figure 3.

The performance management, failure analysis and human resource management classes were those in which the company obtained a lower maturity level. Therefore, improvement actions to reach higher levels can involve the implementation of a set of key

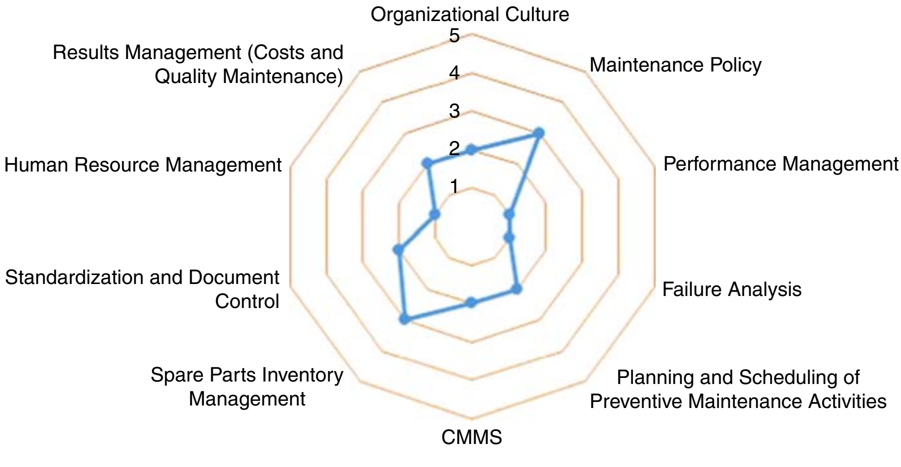

Figure 3.
Maturity levels of the plastic material company

performance indicators such as MTBF, MTTR and OEE, for instance, as well as training on failure analysis tools linked to a strong program of training and development of technical and behavioral skills. The company should promote harmony between teams and develop more collaborative work. The SAP preventive maintenance module, which is used already in the area of plastic covers, should be adopted for all company maintenance areas.

Such as for the optical company, the maturity model was considered easy to understand, and easy to apply. The maintenance manager indicated that the model allowed using concepts of quality management aimed at maintenance and reflecting on the path they are taking to improve maintenance effectiveness. In his point of view, it brought a clear view of the current situation of the company's maintenance and allowed emphasized that there is a lack of agreement between the production and maintenance areas. The production accuses the maintenance of a lack of technical knowledge, alleging that even preventive actions occur in a sloppy way, while maintenance states that the huge amount of line breaks occurs due to the simple lack of availability of production lines for preventive maintenance.

From the manager perspective, the model could also identify if the maintenance area performs a cost-benefit analysis in the acquisition of equipment and services.

4.4 Discussion

In the meetings with the maintenance managers during which information was collected on the different maintenance factors covered by the model, the interviewers verified that the levels assigned by the managers correspond effectively to the maintenance practices of the company, which demonstrates the ability of the model to be used as a self-assessment tool.

The managers that used the model pointed out its easy application. The application involves the comparison of the statements present in the model grid with the factual behavior of the organization. Therefore, if the statements are clearly expressed, the exercise is not complex.

The application of the model consists of the assignment of a maturity level to each class. However, overall value to characterize the overall maturity is not determined. This was not felt as a need in the application of the model in the different companies. By reading the statements on the grid, managers understand their positions and, more importantly, the directions they must follow to achieve world-class behavior and thus, world-class results.

It was noticed that, on the one hand, not all classes have the same impact on outcomes and, on the other hand, improvements in some classes are more difficult and time-consuming to achieve (e.g. organizational culture class). Another aspect to highlight is that some improvement initiatives can influence more than one class. In this way, in the identification of improvements and priorities setting, managers can focus on lower maturity classes or/and on classes which are expected to have the greatest impact on the results. Furthermore, an implementation plan covering short- and long-term measures can be established.

Regarding the model comprehensiveness, the autonomous maintenance that was pointed out as missing in the model is actually considered, within the human resources management class without, however, using this terminology to facilitate understanding. The acquisition of equipment and services were not considered by the model as noticed by an interviewed manager, which is justified by the fact that the model focuses only the internal maintenance management. Analyses in the equipment and services acquisition, although significant, fit into the broader issue of asset management.

5. Conclusion

Maturity models are tools that support decisions, since they assist in the recognition of the current state of the organization and promote the adoption of measures so that improvement actions are identified, implemented and measured. The use of maturity models can lead to a positive spiral in maintenance management, preparing the organization for future steps to be given, around powerful support systems based on best practices developed in the scope of organizational management.

This paper proposes a new maintenance maturity model which main focus is the improvement of the maintenance area, instead of being oriented to external benchmarking. To its development, the previous maintenance maturity models were reviewed and an extensive literature review was performed to identify the relevant factors in maintenance management and the best maintenance management practices. Then, the model was applied in three companies for testing its effectiveness and making improvements which lead mainly to clarify some statements. The model allowed defining the direction for future improvements in the three companies.

The model allows the recognition of the current state of the maintenance area and gives the necessary support to achieve the following stages of evolution. In addition, it allows knowledge transfer on maintenance management best practices to maintenance managers. The self-evaluation through the model and identification of improvements actions is an easy and prompt task since the levels are based on maintenance management behaviors or practices.

In the future, an assessment guideline with a sequence of questions to support the model application, as well as a computer application for information gathering, will be developed.

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