Review, Classification and Comparative Analysis of Maintenance Management Models

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Abstract:

The present article does a chronological tour through some representative maintenance management models, describes them in a general way and classifies them according to their functioning under declarative models and under process oriented models. It distinguishes in addition the innovations proposed by each author and compares the elements appearing on each model with some of the points mentioned by the ISO 9001:2008 standard, as well as other criteria considered suitable to the case. From this analysis are derived the results between which are distinguished some desirable characteristics for a modern and efficient maintenance management model. In addition the application of these models for supporting industrial needs, as well as its future challenges are discussed too.

Keywords: *maintenance, management, maintenance process, maintenance model, and maintenance tools.*

1. Introduction

Maintenance is defined (EN 13306:2001) as the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to a state in which it can perform the required function (or a combination of functions which are considered necessary to provide a given service). In the same standard, maintenance management is defined as all the activities of management that determine the maintenance objectives or priorities, strategies and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects. Different authors have proposed models, frames or systems seeking to manage maintenance in the best way. Using the most advanced techniques and proposing innovative concepts, every model proposed has strengths and weaknesses, which are matter of study in this paper.

In this paper we initiate briefly mentioning the importance of a maintenance management system, and later we describe the methodology we followed for the development of this research. The process consisted in an intensive search and compilation of the maintenance management models found in literature since 1990 up to date, their classification and comparative analysis following certain structured criteria.

This global search of maintenance management models and systems is also chronologically presented, at least for the twenty models that were selected, and then compared.

Models comparison is produced in different steps. In a first step, we divide the models into two types: declaratives and process oriented. Then innovations proposed/introduced by each model are chronologically distinguished. Finally, each scheme is compared with a specified criteria (based on ISO 9001:2008 standard), and then some results and conclusions are identified.

From this analysis finally we do a brief description of the application of these models in industry and the future challenges in this domain.

2. The importance of a maintenance management system

Maintenance has been experiencing a slow but constant evolution across the years, from the former concept of "necessary evil" up to being considered an integral function of the company and a way of competitive advantage.

Since approximately 3 decades, companies realized that if they wanted to adequately manage maintenance it would be necessary to include it in the general scheme of the organization and to manage it in interaction with other functions [15]. The challenge is to integrate maintenance within the management system of the company.

Several objectives are fulfilled after developing a maintenance management system in an organization: a more comprehensible system to all the people involved is created [24] and a structure that propitiates the providing of leadership direction and support is formed [7]. According with Prasad *et al*. [19] some others benefits of having a maintenance management model are: achievement of high productivity, overall equipment emergencies reduction, improvement in production efficiency, accidents reduction, verification of the investments profit, development of a flexible, multi skilled organization, among others. Then the ultimate reasons for maintenance management are fulfilled: to maximize the business profit and to offer competitive advantage. ([7], p. 6).

Therefore the challenge of "designing" the ideal model to drive maintenance activities has become as we will see later, a research topic and a fundamental question to accomplish the effectiveness and efficiency of maintenance management and to fulfil the enterprise objectives [19].

3. The literature review

The bibliographical search was done using the following electronic databases:

Abi/Inform Global - ProQuest, Blackwell Synergy, Business Source Premier - EBSCOhost, Compendex (Engineering Village) - Elsevier Engineering Information, Current

Contents Connect ISI, ISI Web of Knowledge ISI, NTIS - Ovid (SilverPlatter), Scopus - Elsevier, Springer Link, Wiley InterScience.

From this exploration, finished on February 18th 2008, a whole of 14 articles were selected, these articles are: Pintelon and Van Wassenhove (1990)[16], Pintelon and Gelders (1992)[15], Vanneste and Wassenhove (1995)[24], Riis *et al*. (1997)[2], Hassanain *et al*. (2001)[10], Tsang (2002)[23], Waeyenbergh and Pintelon (2002)[25], Murthy *et al*. (2002)[14], Cholasuke *et al*. (2004)[7], Abudayyeh *et al*. (2005)[1], Pramod *et al*. (2006)[18], Prasad *et al*. (2006)[19], Tam *et al*. (2007)[22], and Söderholm *et al*. (2007)[21].

The criteria for the selection of the mentioned 14 articles were:

1. The article had to propose a global maintenance management model and it had not to be focused only on a particular management phase or maintenance tool,
2. The model proposed in the article had not to be a computer model or CMMS (Computerized Maintenance Management Systems),
3. The article had to be published only by indexed scientific journals,
4. The article had to present not only a review or an application, but also a new model proposal,
5. The model in the article had to be preferably represented using a graphical diagram.

Besides the mentioned articles, a bibliographical search was carried out in which the following books were found and selected, due the models proposed by them fulfil the above mentioned criteria: Campbell (1995/2001)[4], Kelly and Harris (1997)[13], Wireman (1998)[26], Duffuaa (2000)[8], Kelly (2006)[12], Crespo (2007)[6].

In this way 20 contributions were selected, presenting the same number of maintenance management models that will be object of this study.

4. Declarative vs. process-oriented models

Once selected these 20 contributions, and as the reader may guess, to synthesize the content of each and every one of them is very difficult. In order to do so, we used a table to concentrate the information gathered from each model.

Based on this synthesis an initial classification is proposed, dividing the models into two types: *declarative models* (referenced from the concept "declarative language" found in the Encyclopedia Britannica (2008)[9]), and *process-oriented models* (from "business process orientation", a concept based upon the work of Porter (1985)[17], among others).

What is the difference between these two types of models?

Declarative models mention the components of a maintenance system, although they do not refer to the intercommunication/link between those components in an explicit form. In this type of models a clear information flow among the components is not distinguished, and therefore, some functional, interrelational and synchronization aspects cannot be clearly appreciated. However some of these kinds of models are very complete, including a great variety of aspects and tools related to maintenance.

Process oriented models normally offer a clear information flow between their components. In some of these models, inputs and outputs of the maintenance management system are identified. In some others, a closed loop sequence of steps is clearly represented. Though in many cases we may suppose that these models seem to be of easier application in organizations than declarative models, they require proper definition about the coordination among their elements in order to be effective, and this is sometimes missing.

We can observe that a process oriented model seems to impose a more tidy system; certainly the complexity degree for its implementation process is greater than in a declarative model, where is possible to take only the elements that are suitable to add to the already operating organization, and thus to obtain fast innovations and benefits in maintenance management ([19], p.163). It is undeniable that every type of model has its own pros and cons; therefore it is convenient to study and to analyze all of them to be able of distinguish which one may be better applied to certain kinds of scenarios and conditions.

Table 1. Models classification.

Declarative models	**Declarative models**
Pintelon & Van Wassenhove (1990) Pintelon & Gelders (1992) Cholasuke *et al.* (2004) Prasad *et al.* (2006) Tam *et al.* (2007)	Vanneste & Wassenhove (1995) Campbell (1995) Kelly & Harris (1997) Riis *et al.* (1997) Wireman (1998) Duffuaa *et al.* (2000) Hassanain *et al.* (2001) Tsang (2002) Waeyenbergh & Pintelon (2002) Murthy *et al.* (2002) Abydayyeh *et al.* (2005) Pramod *et al.* (2006) Kelly (2006)

As can be appreciated in Table 1, the majority of the models are process oriented; however, some of the declarative models - like Prasad *et al.* (2006)[19] - are especially wide, and can surely serve as an implementation and operation guide for any maintenance management system.

5. Model contributions analysis by chronological order

Some important aspects of this study have to do with the chronological analysis of the different author's contributions; Figure 1 represents the twenty models studied in this work arranged through a time line. In this figure we can observe that the interest in generating new proposals has remained constant during almost the last two decades.

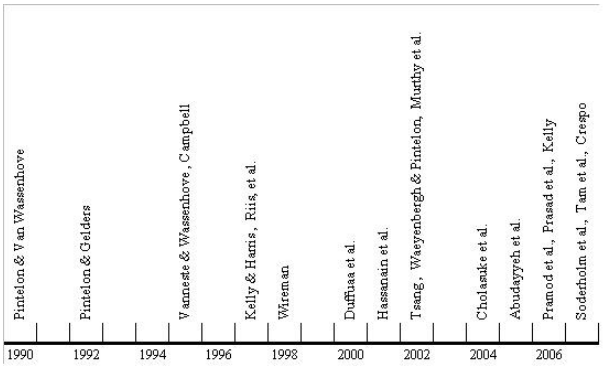

Fig. 1. Time line for the maintenance management models.

In many books and articles about maintenance it is commented the existence of different generations or stages of maintenance management models, but that evolution is not described in an explicit form about the integration of new elements and techniques into the models.

Since history lessons can be of great interest for us we summarize in Table 2 the innovations identified in the main-tenance management models studied, according to a chronological order.

It is necessary to mention that the indicated innovations correspond to those subjects detected appearing for the first time inside a model of maintenance management, it does not mean that they are new concepts also out of the maintenance subject.

Discussing briefly the results presented in Table 2 we can summarize that maintenance management models have been acquiring new elements and trends through the years, such as: approach to processes; innovating propo-

Table 2. Innovations of maintenance management models in chronological order.

Year	Innovations	Author(s)
1990	Propose a complete system of maintenance indicators.	Pintelon & Van Wassenhove
1992	Expose the necessity of linking between maintenance and the other organizational functions. Highlight the importance of using quantitative techniques for maintenance management. Glimpse the utilization of expert systems. Mention TPM (Total Productive Maintenance) and RCM (Reliability Centered Maintenance).	Pintelon & Gelders
1995	Propose an analysis focused in effectiveness and efficiency of maintenance. Emphasizes the importance of the managerial leadership in maintenance management. Introduces the concept of "maintenance reengineering".	Vanneste & Wassenhove Campbell
1997	Propose an integrated modelling approach based on the concepts of situational management theory.	Riis *et al.*
2000	Propose the use of a great variety of Japanese concepts and tools for the statistical control of maintenance processes in a module called "feedback control".	Duffua *et al.*
2001	Orientate the model to the computer use, expressed in IDEF 0 language (a standard for information exchange).	Hassanain *et al.*
2002	Glimpses the use of e-maintenance. Proposes a guide to analyze the outsourcing convenience as an entry element to the maintenance framework. Incorporate both the tacit knowledge and the explicit one and integrates them in a computer database. Give special value to the knowledge management.	Tsang Waeyenbergh & Pintelon
2006	Suggest the union of tools: QFD (Quality Function Deployment) and TPM into a model.	Pramod *et al.*
2007	Propose a process view in which maintenance contributes to the fulfilment of "external stakeholders" requirements. Proposes a model with a methodology of application clearly expressed, oriented to the improvement of the operational reliability besides the life cycle cost of the industrial assets.	Soderholm *et al.* Crespo

sals in technical aspects; use of standard languages for information exchange (in order to be used subsequently in CMMS and other computer applications); successive incorporation of quantitative techniques and computer tools (due the increasing amount of maintenance, operational and financial data generated); evaluation and constant improving of maintenance operations (for instance, using automated tools); analysis of the assets life cycle besides the evaluation of the maintenance function; integration of the assets strategy with the maintenance strategy, etc.

6. Comparative analysis of the maintenance managing models

In order to compare and to analyze the previously mentioned models, we constructed a checklist that captures different important elements to appear in a maintenance system oriented to the continuous improvement of its activities.

A first group of our checklist elements is inspired in ISO standard 9001:2008. This standard is chosen since it is the international reference for any quality management system, which turns into a generic guide for a process operation in which fulfilment with requirements should be demonstrated, such as in the case of the maintenance function. The elements of this check list are: related to Quality Management System (process approach, sequence and interaction of the processes, description of the elements of each process, generation of documents or records), related to Management Responsibility (entailment with strategic targets of the organization, objectives definition, top management commitment, clear definition of responsibilities and authorities, suitable communication), related to Resource Management (humans beings, materials, infrastructure), and related to Measurement, Analysis and Improvement (audits, studies of the internal client satisfaction, information analysis, corrective and preventive actions, continuous improvement approach).

A second group of the checklist elements is elaborated considering the "support tools and techniques for maintenance management" mentioned in the studied models. Some of theme are: techniques about economic or financial maintenance aspects, CMMS, techniques about human resources management, application of operations research or management sciences, life cycle analysis, TPM, RCM, simulation, inventories models, reliability theory, expert systems, etc.

Finally, the last observation done to every model for its analysis is: Does the model have a methodology for its implementation? This is a key question. As we mentioned above some models limit themselves to enumerate the elements that must conform a maintenance management system, without explaining the dynamics of the system in operation. Nevertheless, an organization that wishes to initiate with the implementation of a maintenance system, may not find information enough concerning the steps to follow for this purpose in that kind of models.

There are relatively few models that define a clear methodology to implement it and to operate a maintenance management system, reason why this criterion becomes a key appreciation in this work.

Discussing briefly the results of the comparative analysis done:

About the management system: within the models, declarative ones do not count with an input - output process approach and do not consider either a clear methodology for its implementation. In general, these models do not mention either the advanced quantitative techniques in maintenance. But on the other hand, all kind of models generate documents and records as inputs for the decisions making process.

About the management responsibility: all models define objectives for the maintenance function; however, not all of them link these goals with strategic company targets. Also, most of the models do not make a clear reference to principles of responsibility, authority and a good communication. Maybe this could be because these elements are considered as an initial assumption.

About the maintenance support: approximately half of the models incorporate the use of support techniques such as operational research techniques or management sciences techniques. TPM and RCM are the most mentioned and they tend to appear together in management models. Also CMMS is mentioned as an indispensable tool in the majority of the models. Recent models include another techniques as the use of e-maintenance, expert systems, etc.

About the management of resources: the majority of models mention something on the matter, though in several schemes this topic is omitted. An explanation could be that this subject is considered to be an assumption. For example, almost the third part of models does not mention techniques for inventory management and purchase control. Curiously, in earlier models, a major emphasis in aspects related to the human resources management is appreciated.

About measurement, analysis and improvement: all the models consider different phases for maintenance evaluation, analysis and improvement. Although few more than half of them mention literally the concept "continuous improvement", this trend has grown especially in the last years.

About the methodology and the operation of the model: a very important attribute of some models is the inclusion of an application/implementation methodology, which stimulates the continuous improvement. Few ones clearly incorporate this feature.

7. Use of maintenance management models to support industrial needs and applications

As a consequence of the implementation of advanced manufacturing technologies and just-in-time production systems, the nature of the production environment has changed during the last two decades. This has allowed companies to massively produce products in a customized way. But the increase in automation and the reduction in inventory buffers in the plants clearly put more pressure on the maintenance system [5].

Many of the maintenance management models have been created in order to reduce this pressure, it means: from a real necessity to apply them in industry. Some of them look for an operational guide to reach the mainte-

nance and organizational goals, others have the final purpose of developing a computerized system, and some more persecute the only objective to obtain an evaluation of the maintenance function. In all cases the main sense of designing a maintenance management model is to continuously improve the maintenance performance.

The majority of the models analyzed also were already applied in a variety of industries. That is the case of Pramod (2006)[18]: the practical implementation feasibility of his model was checked in an automobile service station. Söderholm (2007)[21] has another model that has been applied even in different industrial sectors. Waeyenbergh (2001)[25] applied his model in a company that has several plants, each one with different types of installations, using different technologies and having different ages.

The models implementation reveals its practical validity, but in fact maintenance deals with highly diverse problems even in firms within the same productive sector, due to this is very difficult to design an operating methodology of general applicability. That is one reason to be attentive to future challenges and developments.

8. Conclusions and future challenges

After doing the state of art investigation, the classification and the comparative analysis of some of the most important maintenance management models of the last twenty years, we could observe the ultimate trends in this regard. ISO 9001:2008 standard and maintenance techniques proposed by the considered authors were used as references. From this study is possible to identify some elements that seem to be important factors to consider during the design and application of a maintenance management model that looks for efficiency. These elements or characteristics are: input-output processes approach, a clear methodology of application, generation of documents and records, objectives entailment, incorporation of support technologies (TPM, RCM, etc.), orientation to CMMS, flexibility against rapid structural changes, management of material, human and information resources, focus on constant improvement, evaluation and improvement and finally, a cyclical operation. Nevertheless, whatever the model an organization adopts, it has to be evolving to continue being useful against the fast changes that occur in business, communications and industry. A key to achieve this could be the incorporation of the modern tools and platforms known as “next generation manufacturing practices” (NGMS). This implies the use of e-maintenance as a sub-concept of e-manufacturing and e-business. E-maintenance is defined by the Intelligent Maintenance Centre (IMC) as "the ability to monitor plant floor assets, link the production and maintenance operations systems, collect feedbacks from remote customer sites, and integrate it upper level enterprise applications". A more general definition is that "maintenance management concept whereby assets are monitored and managed over the Internet" (Crespo & B. Iung, 2006). In this way, e-maintenance would have to be integrated to maintenance management models looking for new ways of working that involves collaboration and availability of knowledge and intelligence any time and any place, perhaps changing also the entire business process.

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