The maintenance management framework

A practical view to maintenance management

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Abstract

Purpose – The purpose of this paper is to define a process for maintenance management and to classify maintenance engineering techniques within that process.

Design/methodology/approach – The paper presents a generic model proposed for maintenance management which integrates other models found in the literature for built and in-use assets, and consists of eight sequential management building blocks. The different maintenance engineering techniques are playing a crucial role within each one of those eight management building blocks. Following this path it characterizes the "maintenance management framework", i.e. the supporting structure of the management process.

Findings – The paper offers a practical vision of the set of activities composing each management block, and the result of the paper is a classification of the different maintenance engineering tools. The discussion of the different tools can also classify them as qualitative or quantitative. At the same time, some tools will be very analytical tools while others will be highly empirical. The paper also discusses the proper use of each tool or technique according to the volume of data/information available.

Practical implications – 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 buffers of inventory in the plants clearly put more pressure on the maintenance system. The present maintenance management framework has been proposed in order to diminish this pressure. 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 techniques proposed in this paper besides the integration of platforms known as "next generation manufacturing practices" This implies the use of e-maintenance as a sub-concept of e-manufacturing and e-business.

Originality/value – This paper presents not only a process but also the framework and techniques to manage and improve maintenance effectiveness and efficiency. This paper will be useful to researchers, maintenance professionals and others concerned with maintenance management.

Keywords Maintenance, Modelling

Paper type Research paper

Introduction

Since approximately three decades, companies realized that if they wanted to manage maintenance adequately it would be necessary to include it in the general scheme of the

Journal of Quality in Maintenance
Engineering
Vol. 15 No. 2, 2009
pp. 167-178
© Emerald Group Publishing Limited
1355-2511
DOI 10.1108/13552510910961110

This research is funded by the Spanish Department of Science and Innovation Project DPI2008-01012 (Modelling e-maintenance policies for the improvement of production systems dependability and eco-efficiency).

organization and to manage it in interaction with other functions (Pintelon and Gelders, 1992). Once achieved this, maintenance could receive the importance that deserves and be developed as one more function of the organization, which generates "products" to satisfy internal clients, fulfilling or contributing to the fulfillment of specific goals of the organization.

Therefore, the challenge of "designing" the ideal model to drive maintenance activities has become a research topic and a fundamental question to reach the effectiveness and efficiency of maintenance management and to fulfill enterprise objectives (Prasad Mishra *et al.*, 2006). In the historical development of maintenance, diverse authors have proposed what they consider the best practices, steps, sequences of activities or models to manage this function.

The generic model proposed for maintenance management that will now be proposed and defined integrates other models found in the literature for built and in-use assets, and consists of eight sequential management building blocks. Each block is, in fact, a key decision area for asset maintenance and life cycle management. Within each of these decision areas we can find methods and models that may be used to order and facilitate the decision-making processes.

The maintenance management process

The maintenance management process can be divided into two parts: the definition of the strategy, and the strategy implementation. The first part, definition of the maintenance strategy, requires the definition of the maintenance objectives as an input, which will be derived directly from the business plan. This initial part of the maintenance management process conditions the success of maintenance in an organization, and determines the effectiveness of the subsequent implementation of the maintenance plans, schedules, controls and improvements. Effectiveness shows how well a department or function meets its goals or company needs, and is often discussed in terms of the quality of the service provided, viewed from the customer's perspective. This will allow us to arrive at a position where we will be able to minimize the maintenance indirect costs (Vagliasindi, 1989), those costs associated with production losses, and ultimately, with customer dissatisfaction. In the case of maintenance, effectiveness can represent the overall company satisfaction with the capacity and condition of its assets (Wireman, 1998), or the reduction of the overall company cost obtained because production capacity is available when needed (Palmer, 1999). Effectiveness concentrates then on the correctness of the process and whether the process produces the required result.

The second part of the process, the implementation of the selected strategy has a different significance level. Our ability to deal with the maintenance management implementation problem (for instance, our ability to ensure proper skill levels, proper work preparation, suitable tools and schedule fulfilment), will allow us to minimize the maintenance direct cost (labour and other maintenance required resources). In this part of the process, we deal with the efficiency of our management, which should be less important. Efficiency is acting or producing with minimum waste, expense, or unnecessary effort. Efficiency is then understood as providing the same or better maintenance for the same cost.

In this paper, we present a generic model proposed for maintenance management integrates other models found in the literature (Pintelon and Gelders, 1992; Vanneste and van Wassenhove, 1995) for built and in-use assets, and consists of eight sequential management building blocks, as shown in Figure 1. The first three building blocks condition maintenance effectiveness, the fourth and fifth ensure maintenance efficiency, blocks six and seven are devoted to maintenance and assets life cycle cost assessment, finally block number eight ensures continuous maintenance management improvement.

Maintenance management framework

In this section, we will briefly introduce each block and discuss methods that may be used to improve each building block decision-making process (Figure 2).

Regarding the definition of maintenance objectives and key performance indicators – KPI's (Phase 1), it is common the operational objectives and strategy, as well as the performance measures, are inconsistent with the declared overall business strategy (Gelders *et al.*, 1994). This unsatisfactory situation can indeed be avoided by introducing the balanced scorecard – BSC (Kaplan and Norton, 1992). The BSC is specific for the organization for which it is developed and allows the creation of KPIs for measuring maintenance management performance which are aligned to the organization's strategic objectives (Figure 3).

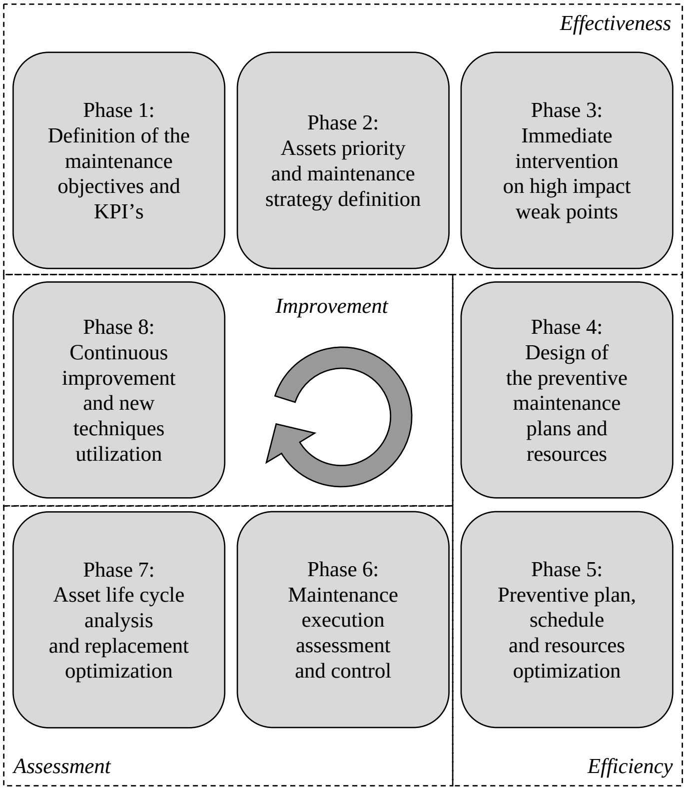


Figure 1.
Maintenance management model

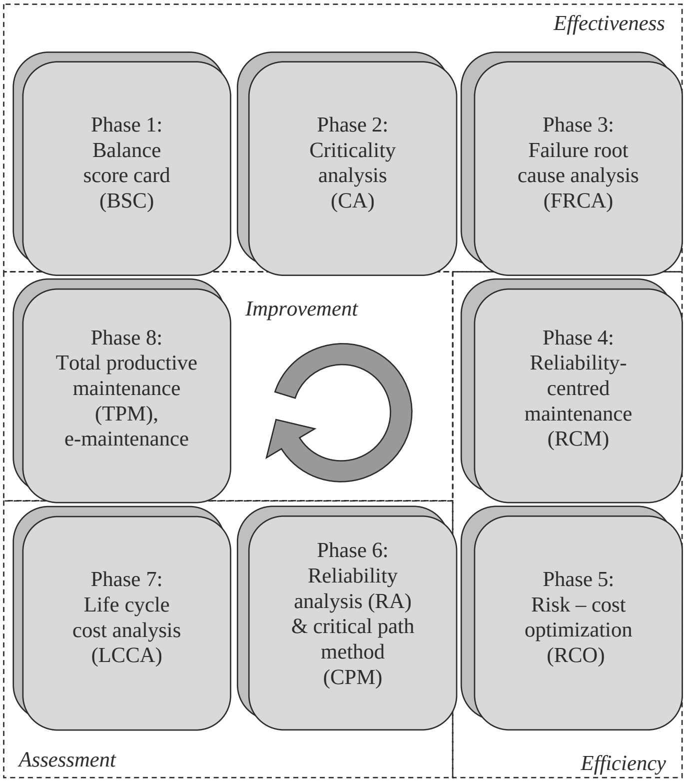
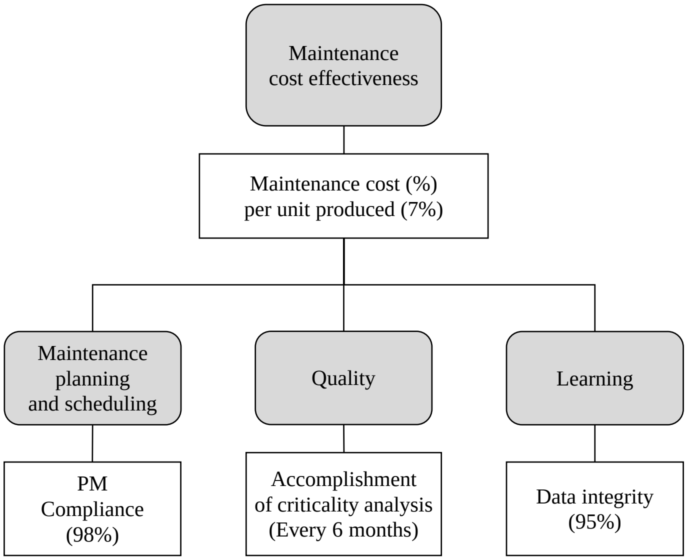


Figure 2.
Sample of techniques within the maintenance management framework

Unlike conventional measures which are control oriented, the BSC puts overall strategy and vision at the centre and emphasizes on achieving performance targets. The measures are designed to pull people toward the overall vision. They are identified and their stretch targets established through a participative process which involves the consultation of internal and external stakeholders, senior management, key personnel in the operating units of the maintenance function, and the users of the maintenance service. In this manner, the performance measures for the maintenance operation are linked to the business success of the whole organization (Tsang *et al.*, 1999).

Once the maintenance objectives and strategy are defined, there are a large number of quantitative and qualitative techniques which attempt to provide a systematic basis for deciding what assets should have priority within a maintenance management process (Phase 2), a decision that should be taken in accordance with the existing maintenance strategy. Most of the quantitative techniques use a variation of a concept known as the "probability/risk number" – PRN (Moubray, 1997).

Assets with the higher PRN will be analysed first. Often, the number of assets potentially at risk outweighs the resources available to manage them. It is therefore extremely important to know where to apply available resources to mitigate risk in a cost-effective and efficient manner. Risk assessment is the part of the ongoing risk management process that assigns relative priorities for mitigation plans and implementation. In professional risk assessments, risk combines the probability of an



Source: Crespo Marquez (2007)

Figure 3.
From KPIs to functional indicators

event occurring with the impact that event would cause. The usual measure of risk for a class of events is then $R = P \times C$, where P is probability and C is consequence. The total risk is therefore the sum of the individual class-risks (see risk/criticality matrix in Figure 4).

Risk assessment techniques can be used to prioritize assets and to align maintenance actions to business targets at any time. By doing so we ensure that maintenance actions are effective, that we reduce the indirect maintenance cost, the most important maintenance costs, those associated to safety, environmental risk, production losses, and ultimately, to customer dissatisfaction.

The procedure to follow in order to carry out an assets criticality analysis following risk assessment techniques could be then depicted as follows:

(1) define the purpose and scope of the analysis;

(2) establish the risk factors to take into account and their relative importance;

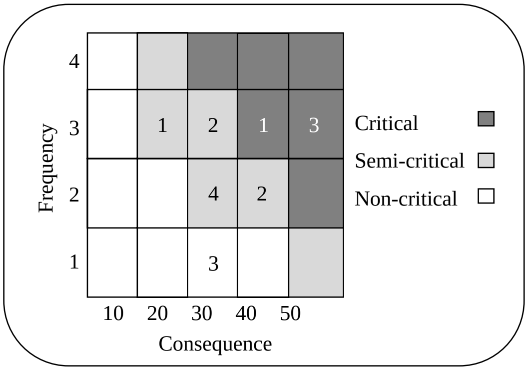


Figure 4.
Criticality matrix and assets location

(3) decide on the number of asset risk criticality levels to establish; and
(4) establish the overall procedure for the identification and priorization of the critical assets.

Notice that assessing criticality will be specific to each individual system, plant or business unit. For instance, criticality of two similar plants in the same industry may be different since risk factors for both plants may vary or have different relative importance.

On some occasions, there is no hard data about historical failure rates, but the maintenance organization may require a certain gross assessment of assets priority to be carried out. In these cases, qualitative methods (Figure 5) may be used and an initial assets assessment, as a way to start building maintenance operations effectiveness, may be obtained.

In Figure 5, the flowchart orders the sequence of the questions that the team needs to answer for each secific asset considered for the analysis. This flowchart only allows the classification of the assets within one of the three groups A, B or C that are defined per each criterion question. For instance, the environmental impact of a certain production equipment or asset is the first aspect to be considered. With respect to environment, an asset falling within category “A” may cause an important and “business external” environmental impact in case its maintenance is not planned and carried out properly. By external impact we mean, for instance, that the business unit may have to inform local authorities about the incident and adopt specific contingency plans. An example can be a failure in a cooling system producing a gas leak to the atmosphere with high-ammonia content. Category “B” is reserved for those assets whose failures may produce environmental problems that can be solved internally. For instance, this would be the case of a failure producing the leak of a certain liquid that can be treated within the water network of the company, producing no external consequences to the community water network. Finally, assets falling within category “C” are assets whose failures might create no environmental consequences.

In Figure 5, safety issues are considered next. Category “A” assets are now assets whose failures may produce accidents causing temporal or permanent worker absence

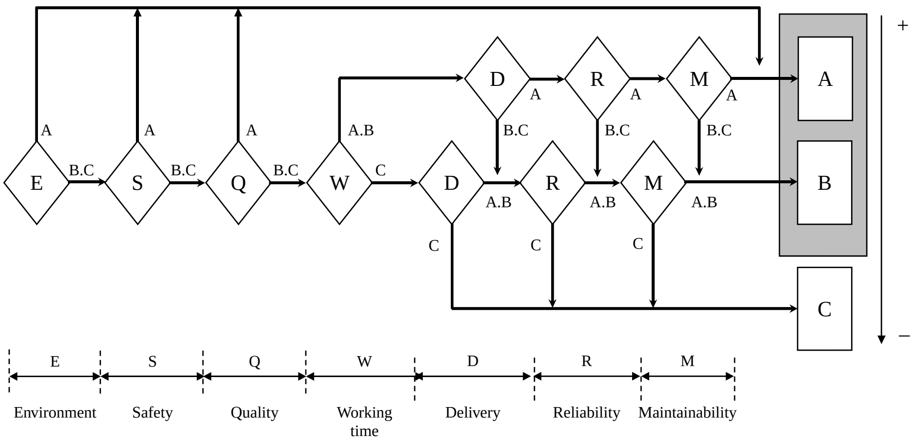


Figure 5. Qualitative criticallity assessment

Source: Crespo Marquez (2007)

to the work place. Category "B" assets failures would cause only minor damage to people at work, producing no work absence. Again, assets falling within category "C" are assets whose failures might create no consequences related to safety. Same type of questionnaire could be followed for the next topics in the flowchart.

Let us try to exemplify this process of strategy definition by assuming that we have the assets classified according to three categories of criticality: A, B and C. This was the case for our example in Figure 5.

An example of detailed maintenance actions for category A assets – where we try to reach optimal reliability, maintainability and availability levels – could be (CEN, 2001):

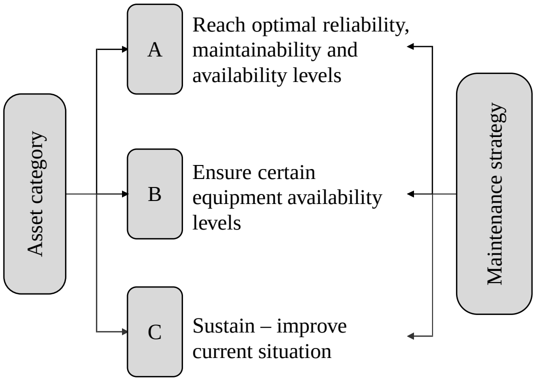
- apply failure mode, effect, and criticality analysis (FMECA) for critical failure mode analysis;
- apply reliability centred maintenance (RCM) for optimal maintenance task selection;
- standardise maintenance tasks;
- analyse design weaknesses; and
- continue review FMECA and RCM.

An instance of detailed maintenance actions for category C assets – where we try to basically to sustain or improve current conditions – could be:

- apply root-cause failure analysis (RCFA) to avoid repetitive failures; and
- standardise maintenance tasks.

As mentioned above, once there is a certain ranking of assets priority, we have to set up the strategy to follow with each category of assets. Of course, this strategy will be adjusted over time, and will consist of a course of action to address specific issues for the emerging critical items under the new business conditions (Figure 6).

Once the assets have been prioritized and the maintenance strategy to follow defined, the next step would be to develop the corresponding maintenance actions associated with each category of assets. Before doing so, we may focus on certain repetitive – or chronic – failures that take place in high-priority items (Phase 3).



Source: Crespo Marquez (2007)

Figure 6.
Example of maintenance strategy definition for different category assets

Finding and eliminating, if possible, the causes of those failures could be an immediate intervention providing a fast and important initial payback of our maintenance management strategy. The entire and detailed equipment maintenance analysis and design could be accomplished, reaping the benefits of this intervention if successful.

There are different methods developed to carry out this weak point analysis, one of the most well known being RCFA. This method consists of a series of actions taken to find out why a particular failure or problem exists and to correct those causes. Causes can be classified as physical, human or latent. The physical cause is the reason why the asset failed, the technical explanation on why things broke or failed. The human cause includes the human errors (omission or commission) resulting in physical roots. Finally, the latent cause includes the deficiencies in the management systems that allow the human errors to continue unchecked (flaws in the systems and procedures). Latent failure causes will be our main concern at this point of the process.

Designing the preventive maintenance (PM) plan for a certain system (Phase 4) requires identifying its functions, the way these functions may fail and then establish a set of applicable and effective PM tasks, based on considerations of system safety and economy. A formal method to do this is the RCM, as in Figure 7.

Optimization of maintenance planning and scheduling (Phase 5) can be carried out to enhance the effectiveness and efficiency of the maintenance policies resulting from an initial PM plan and program design.

Models to optimize maintenance plan and schedules will vary depending on the time horizon of the analysis. Long-term models address maintenance capacity planning, spare parts provisioning and the maintenance/replacement interval determination problems, mid-term models may address, for instance, the scheduling of the maintenance activities in a long plant shut down, while short-term models focus on

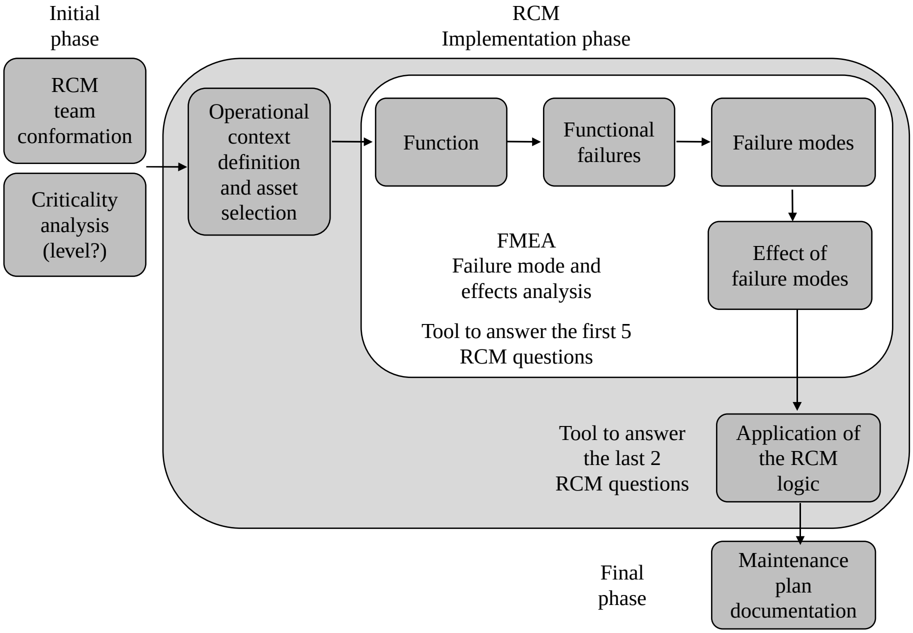


Figure 7.
RCM implementation process

resources allocation and control (Duffuaa, 2000). Modelling approaches, analytical and empirical, are very diverse. The complexity of the problem is often very high and forces the consideration of certain assumptions in order to simplify the analytical resolution of the models, or sometimes to reduce the computational needs.

For example, the use of Monte-Carlo simulation modelling can improve PM scheduling, allowing the assessment of alternative scheduling policies that could be implemented dynamically on the plant/shop floor (Figure 8).

Using a simulation model, we can compare and discuss the benefits of different scheduling policies on the status of current manufacturing equipment and several operating conditions of the production materials flow. To do so, we estimate measures of performance by treating simulation results as a series of realistic experiments and using statistical inference to identify reasonable confidence intervals.

The execution of the maintenance activities, once designed planned and scheduled using techniques described for previous building blocks have to be evaluated and deviations controlled to continuously pursue business targets and approach stretch values for key maintenance performance indicators as selected by the organization (Phase 6). Many of the high-level maintenance KPIs, are built or composed using other basic level technical and economical indicators. Therefore, it is very important to make sure that the organization captures suitable data and that data are properly aggregated/disaggregated according to the required level of maintenance performance analysis.

A life cycle cost analysis (Phase 7) calculates the cost of an asset for its entire life span (Figure 9). The analysis of a typical asset could include costs for planning, research and development (R&D), production, operation, maintenance and disposal. Costs such as up-front acquisition (research, design, test, production and construction) are usually obvious, but life cycle cost analysis crucially depends on values calculated from reliability analyses such us failure rate, cost of spares, repair times, and component costs. A life cycle cost analysis is important when making decisions about capital equipment (replacement or new acquisition) (Campbell and Jardine, 2001), it reinforces the importance of locked in costs, such as R&D, and it offers three important benefits:

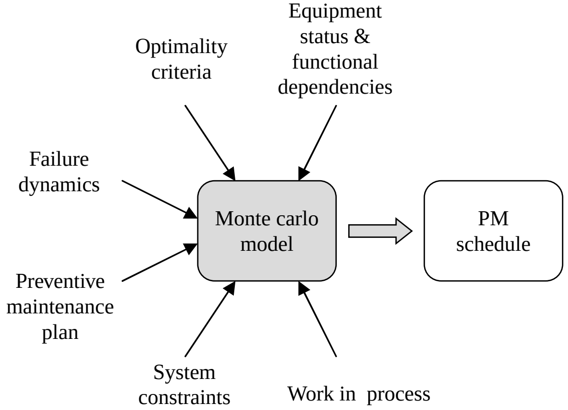


Figure 8.
Obtaining the PM schedule

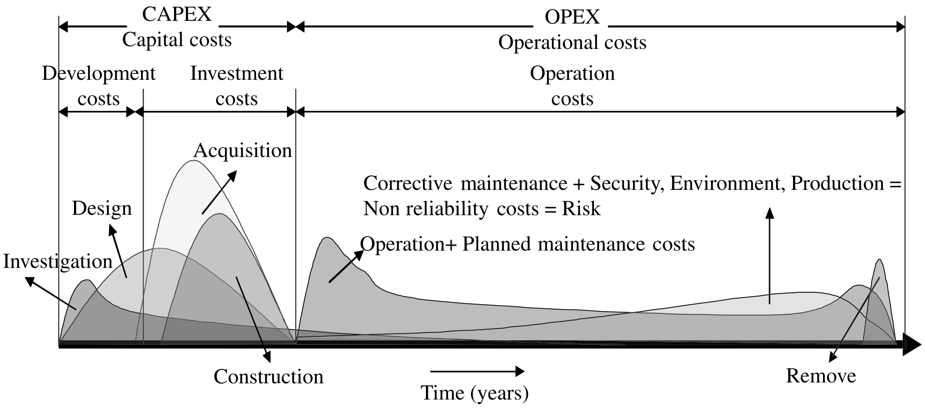


Figure 9.
Life cycle cost analysis

(1) All costs associated with an asset become visible. Especially: upstream; R&D, downstream; maintenance.

(2) Allows an analysis of business function interrelationships. Low R&D costs may lead to high-maintenance costs in the future.

(3) Differences in early stage expenditure are highlighted, enabling managers to develop accurate revenue predictions.

Continuous improvement of maintenance management (Phase 8) will be possible due to the utilization of emerging techniques and technologies in areas that are considered to be of higher impact as a result of the previous steps of our management process. Regarding the application of new technologies to maintenance, the "e-maintenance" concept (Figure 10) is put forward as a component of the e-manufacturing concept

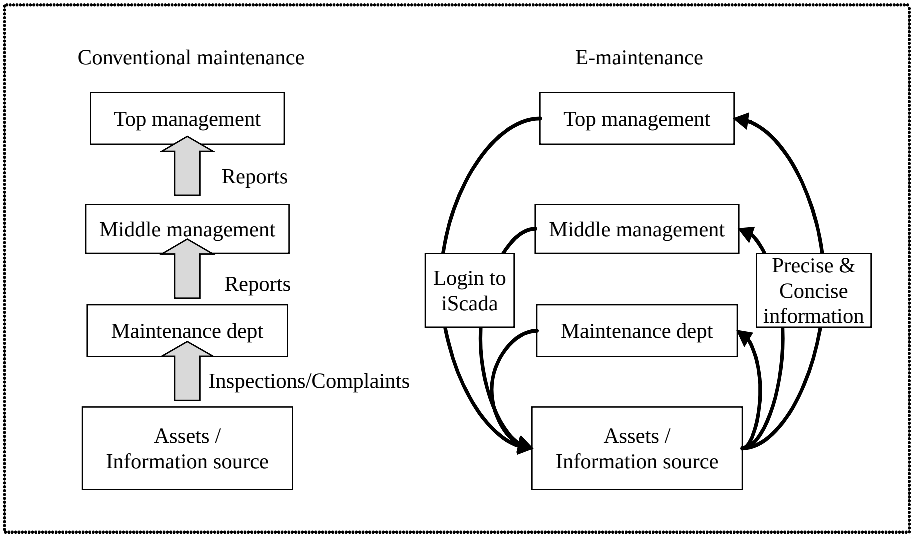


Figure 10.
Implementing e-maintenance

Source: www.devicesworld.net

(Lee, 2003), which profits from the emerging information and communication technologies (ICTs) to implement a cooperative and distributed multi-user environment. e-Maintenance can be defined (Tsang *et al.*, 1999) as a maintenance support which includes the resources, services and management necessary to enable proactive decision process execution.

This support not only includes e-technologies (i.e. ICT, web-based, tether-free, wireless, infotronic technologies) but also, e-maintenance activities (operations or processes) such as e-monitoring, e-diagnosis, e-prognosis, etc. Besides, new technologies for maintenance, the involvement of maintenance people within the maintenance improvement process will be a critical factor for success. Of course, higher levels of knowledge, experience and training will be required, but at the same time, techniques covering the involvement of operators in performing simple maintenance tasks will be extremely important to reach higher levels of maintenance quality and overall equipment effectiveness.

Conclusions

This paper summarizes the process (the course of action and the series of stages or steps to follow) and the framework (the essential supporting structure and the basic system) needed to manage maintenance. A set of models and methods to improve maintenance management decision making is presented. Models are then classified according to their more suitable utilization within the maintenance management process. For further discussion of these topics, the reader is addressed to a recent work of one of the authors (Crespo Marquez, 2007).

References

Campbell, J.D. and Jardine, A.K.S. (2001), *Maintenance Excellence*, Marcel Dekker, New York, NY.

CEN (2001), *Maintenance Terminology. European Standard*, EN 13306:2001, European Committee for Standardization, Brussels.

Crespo Marquez, A. (2007), *The Maintenance Management Framework, Models and Methods for Complex Systems Maintenance*, Springer, London.

Duffuaa, S.O. (2000), "Mathematical models in maintenance planning and scheduling", in Ben-Daya, M., Duffuaa, S.O. and Raouf, A. (Eds), *Maintenance, Modelling and Optimization*, Kluwer Academic Publishers, Boston, MA.

Gelders, L., Mannaerts, P. and Maes, J. (1994), "Manufacturing strategy, performance indicators and improvement programmes", *International Journal of Production Research*, Vol. 32 No. 4, pp. 797-805.

Kaplan, R.S. and Norton, D.P. (1992), "The balanced scorecard – measures that drive performance", *Harvard Business Review*, Vol. 70 No. 1, pp. 71-9.

Lee, J. (2003), "E-manufacturing: fundamental, tools, and transformation", *Robotics and Computer-Integrated Manufacturing*, Vol. 19 No. 6, pp. 501-7.

Moubray, J. (1997), *Reliability-centred Maintenance*, 2nd ed., Butterworth-Heinemann, Oxford.

Palmer, R.D. (1999), *Maintenance Planning and Scheduling*, McGraw-Hill, New York, NY.

Pintelon, L.M. and Gelders, L.F. (1992), "Maintenance management decision making", *European Journal of Operational Research*, Vol. 58, pp. 301-17.

Prasad Mishra, R., Anand, D. and Kodali, R. (2006), "Development of a framework for world-class maintenance systems", *Journal of Advanced Manufacturing Systems*, Vol. 5 No. 2, pp. 141-65.

Tsang, A., Jardine, A. and Kolodny, H. (1999), "Measuring maintenance performance: a holistic approach", *International Journal of Operations & Production Management*, Vol. 19 No. 7, pp. 691-715.

Vagliasindi, F. (1989), *Gestire la manutenzione. Perche e come*, Franco Angeli, Milan.

Vanneste, S.G. and van Wassenhove, L.N. (1995), "An integrated and structured approach to improve maintenance", *European Journal of Operational Research*, Vol. 82, pp. 241-57.

Wireman, T. (1998), *Developing Performance Indicators For Managing Maintenance*, Industrial Press, New York, NY.

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