Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Industrial maintenance policy development: A quantitative framework

M. Faccio, A. Persona, F. Sgarbossa*, G. Zanin

Department of Management and Engineering, University of Padova, Stradella San Nicola 3, Vicenza, Italy

ARTICLE INFO

Article history:
Received 24 November 2011
Accepted 27 August 2012

Keywords:
Maintenance plan
Maintenance costs
Quantitative framework
Decision-making abacus

ABSTRACT

All manufacturing companies define their business strategies and competitive priorities based on several factors related to their production systems, like flexibility, productivity and quality. As a consequence, maintenance plays a crucial role in guaranteeing availability and reliability of production facilities; hence, designing proper maintenance policies allows companies reach their goals.

In the last decade, while some scientific contributions have developed qualitative frameworks to help choosing optimal maintenance policy, others have introduced different quantitative cost models related to each maintenance policy.

The purpose of this paper is to introduce a new quantitative framework to develop optimal maintenance policies, using several cost models, based on simple but relevant costs, like spare parts, labor, missing production costs and other indirect costs. A very simple, user-friendly abacus has been developed to guide the researchers and professionals to choose the optimal maintenance policies for their needs. The application on a real case study demonstrates the validity of the presented framework, and opens the field to several considerations about the possibility of new models and future research.

1. Introduction

Nowadays, maintenance is a strategic factor to guarantee high productivity of industrial systems, but the global economic crisis has brought companies to reduce maintenance expenses with critical consequences for long-term reliability.

The development of appropriate maintenance policies guarantees production plants efficiency, in terms of quality and availability. For this reason, the concept of maintenance itself has evolved significantly over time, thanks to large contributions in research and industrial settings. As a consequence several maintenance policies have been introduced such as failure-based maintenance (FBM), use-based maintenance (UBM), condition-based maintenance (CBM), design-out maintenance (DOM) and detection-based maintenance (DBM) (Waeyenbergh and Pintelon, 2002).

Although many maintenance models have been developed by researchers, the high complexity of industrial environment and the difficulty to collect correct data from the field make the definition and estimation of maintenance costs extremely complicated, and the selection of the optimal maintenance policy just as hard. A recent survey on maintenance management filled out by Italian manufacturing firms (Chinese and Ghirardo, 2010) has highlighted the relation between the abovementioned factors and the application of maintenance policies. The authors found that firms apply FBM policy in about 55% of the cases, UBM policy in 35% of the cases and CBM policy in 10% of the cases. These results are similar to those reported in studies performed in other countries (Chinese and Ghirardo, 2010; Pinjala et al., 2006), in spite of the fact that the percentages are well above the recommended values of 30% for FBM and 70% for UBM and CBM together.

International scientific researchers have widely studied this issue, introducing several approaches, taking into account the correct mix of maintenance actions, yet without offering a general and quantitative point of view. For this reason, it is necessary at this point to introduce a general methodology to justify the cost of maintenance policies, using a quick and user-friendly tool that guides the management to design and manage maintenance plans.

Starting from these considerations, the present research introduces a general quantitative framework to solve planning problems in maintenance policies; its focus is limited to FBM and UBM policies since these are the most common methods applied in industrial systems, as mentioned before. The authors will extend their approach also to the statement of predictive maintenance policies for many policies, included CBM.

The rest of this paper is organized as follows: Section 2 summarizes the review of the most significant scientific contributions on maintenance development, as an introduction to Section 3, where the general quantitative framework is introduced. Here the mathematical formulations of maintenance costs and the final decision making abacus are explained in details, while

* Corresponding author.
E-mail address: fabio.sgarbossa@unipd.it (F. Sgarbossa).

0925-5273/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2012.08.018

Please cite this article as: Faccio, M., et al., Industrial maintenance policy development: A quantitative framework. International Journal of Production Economics (2012), http://dx.doi.org/10.1016/j.ijpe.2012.08.018

Section 4 illustrates several numerical examples and presents a sensitivity analysis to highlight the most relevant factors on the design of maintenance policies. Then, in Section 5 a real case study demonstrates the applicability of this quantitative framework, to conclude with Section 6, which closes our study, but also opens some topics for further research.

2. Literature review

Today, the attitude towards maintenance is changing, and what was once considered a "necessary evil" is now seen as a "profit contributor" and considered almost an allied to achieve world-class competitiveness (Waeyenbergh and Pintelon, 2002).

In fact, appropriate maintenance planning reveals itself as a multi-objective goal for manufacturing companies that seek to improve availability and reliability of production systems, and maximize productivity, product quality and operation safety, minimizing the total maintenance costs.

Scientific Literature has defined maintenance into two main types: corrective maintenance that occurs after a system failure, and preventive maintenance, that is performed before systems failure in order to maintain the equipment in working condition by providing inspections, detection and prevention of incipient failures (Wang et al., 2007). The selection of the most suitable maintenance strategy for each specific industrial reality is very important for manufacturing companies and it is mainly based on an economical evaluation.

Barlow and Hunter (1960) and then Barlow and Proshan (1965) first developed two models for cost estimation of base maintenance policies widely used in industrial applications: use-based maintenance (UBM), as a corrective measure, and failure-based maintenance (FBM), as a preventive one. In the recent decades, progress in information and electronic technologies allowed the introduction of several more maintenance policies, such as: condition-based maintenance (CBM), design-out maintenance (DOM) and detection-based maintenance (DBM) (Waeyenbergh and Pintelon, 2002), which also considers operational effects using taking a systematic approach (Persona et al., 2009, 2010).

Moreover, the development of maintenance concepts started after a thorough study of existing maintenance concepts existing in literature (like e.g., reliability centered maintenance, total productive maintenance, business centered maintenance, integrated logistic support and logistic support analysis) (Waeyenbergh and Pintelon, 2004), all concepts whose implementation is often very time-consuming or only valid for a special class of equipment or a specific industry (Pintelon and Waeyenbergh, 1999).

As well described in "A framework for maintenance concept development" (Waeyenbergh and Pintelon, 2002), only an integrated approach allows the development of an effective maintenance concept. Consequently, it is very important to consider technical, organizational and economic factors in order to reach an optimal maintenance plan.

International standards, industrial practices and scientific literature contributions can help maintenance engineers to design maintenance plans. Generally, international and local standards suggest principles, criteria and methodologies to define, plan, manage and improve maintenance actions, providing guidelines and qualitative general suggestions, rather than structure-limited and quantitative methodologies. In most cases, the experiences of companies in designing correct maintenance plans that satisfy their very needs could not be applied directly to other case-studies, due to its proprietary characteristics, but could be the starting point for the development of other, more suitable, maintenance concepts.

While international literature contains several researches on the development of structural methodologies for the design of optimal maintenance plans, based on both real case studies and theoretical approaches, many researchers have concentrated their efforts to define a standard and general procedure, trying to introduce qualitative framework including general guide-lines to reach the goals, while others have adapted their concepts to several real cases, losing the general purpose of methodologies.

Pintelon and Gelders (1992) have proposed a framework consisting of three main parts: first modeling of maintenance, to understand how it interacts with other departments (production, finance and marketing); second, planning of maintenance decisions, without considerations about technical aspects; and third, defining statistical and informatics tools to estimate survival behavior.

Wireman (1998) proposed a series of steps to assure the regular functioning of maintenance plans, with the help of a computer maintenance management system (CMMS), grounding his research on the concept of TPM (Total Productive Maintenance), in order to configure the maintenance department.

Campbell (1995) suggested a formal structure for an efficient maintenance plan, starting from the definition of a strategy for each facility and developing a relative business plan, in order to check the state of facilities, using a CMMS system and planning maintenance actions accordingly, basing his research on RCM and TPM maintenance concepts.

Wang et al., 2007applied a fuzzy AHP (Analytical Hierarchical Process) method to evaluate maintenance policies, considering different factors such as safety, cost, added-value, feasibility.

Many contributions on this research carried out by Pintelon and Waeyenbergh (1999,), Waeyenbergh and Pintelon (2002, 2004, 2009), with the development of a proprietary method, studied at the Centre of Industrial Management, in Belgium. The method consists of a framework to define the guide-lines to make the proper decisions on maintenance plan, consisting of several modules: start-up module, technical analysis, choice of the appropriate maintenance policy, implementation and evaluation and continuous improvement of the selected policy. The start-up module, leads to the identification of objectives and resources, before an accurate technical analysis takes place to determine the most important systems (MISs) and the most critical components (MCCs). In the third module, the appropriate maintenance policy will be chosen and finely tuned to meet the specific needs of the system. The fourth module sees the implementation, and a consequent evaluation, of the measures applied, to determine the outcomes, and proceed to a constant tweaking of the policy applied, to meet the ever changing demands of the system.

As well reported in "CIBOCOF: A framework for industrial maintenance concept development. International Journal of Production Economics", (Waeyenbergh and Pintelon 2009), it is clear that in a large-scale project, with different types of failure, and consequently different types of maintenance policy (FBM, DOM, DBM, CBM, UBM) has to be chosen. This policy must be technically feasible and cost-effective, following a clear evaluation of advantages and disadvantages in order to decide on the most suitable decision. In this context, a relevant role is played by the maintenance cost estimation, since the optimal maintenance policy is a function of the cost factors used in the costs-benefits analysis.

In order to fully understand the ideas presented by Pintelon and Waeyenbergh (1999), Waeyenbergh and Pintelon (2002, 2004, 2009) and their concept of cost-benefits analysis, we need to clarify two important concepts:

- Direct maintenance costs: includes all the costs related to maintenance activities, such as cost of labor and spare parts used to perform repairs.
- No-direct maintenance costs: come from the unavailability of the production system and include lost production, idle