Available online at www.sciencedirect.com
ScienceDirect
Reliability Engineering and System Safety 94 (2009) 44–52
RELIABILITY ENGINEERING & SYSTEM SAFETY
www.elsevier.com/locate/ress

Optimization of maintenance policy using the proportional hazard model

M. Samrout[a], E. Châtelet[a,*], R. Kouta[b], N. Chebbo[c]

[a]Information Sciences and Technologies Institute, University of Technology of Troyes, 10000 Troyes, France
[b]M3M Laboratory, University of Technology of Belfort Montbéliard, France
[c]Industrial Systems Laboratory, IUT, Lebanese University, Lebanon

Received 24 March 2006; received in revised form 23 February 2007; accepted 2 December 2007
Available online 23 December 2007

Abstract

The evolution of system reliability depends on its structure as well as on the evolution of its components reliability. The latter is a function of component age during a system's operating life. Component aging is strongly affected by maintenance activities performed on the system. In this work, we consider two categories of maintenance activities: corrective maintenance (CM) and preventive maintenance (PM). Maintenance actions are characterized by their ability to reduce this age. PM consists of actions applied on components while they are operating, whereas CM actions occur when the component breaks down. In this paper, we expound a new method to integrate the effect of CM while planning for the PM policy. The proportional hazard function was used as a modeling tool for that purpose. Interesting results were obtained when comparison between policies that take into consideration the CM effect and those that do not is established.

Keywords: Preventive maintenance policies; Corrective maintenance; Proportional hazard model

1. Introduction

Reliability is an important parameter to assess industrial system performance. Its value depends on the system structure as well as on the component availability and reliability. These values decrease as the components' ages increase, i.e. their working times are influenced by their interactions with each other, applied maintenance policy and their environments. Among the different types of maintenance policy, we suggest to study the preventive maintenance (PM), widely applied in large systems such as transport systems, production systems, etc.

PM consists of a set of technical, administrative and management actions to decrease the components' ages in order to improve the availability (and the reliability) of a system (reduction of probability failure or the degradation level of a system's component). These actions can be characterized by their effects on the component age: the component becomes "as good as new", the component age is reduced, or the state of the component is lightly affected only to ensure its necessary operating conditions, the component appears to be "as bad as old". The PM corresponds to the maintenance actions that come about when the system is operating. However, the actions that occur after the system breaks down are regrouped under the title of corrective maintenance (CM).

Some of major expenses incurred by industry are related to the replacements and repairs of manufacturing machinery in production processes. The PM is a main approach adopted to reduce these costs.

A lot of studies have been made to reach the "optimal" PM policy. Some papers [1–4] present surveys over the PM models and its evolution since the PM concept has appeared. Recently, studies begin to concentrate on the optimization of PM policies. This optimization process can take different ways, it can be made by adding features and conditions that make this PM policy more realistic, i.e. taking into consideration working conditions, the

*Corresponding author. Tel.: +33 325715804; fax: +33 325715699.
E-mail addresses: mohamad.el_samrout@utt.fr, mohamad_samrout@yahoo.co.uk (M. Samrout), chatelt@utt.fr (E. Châtelet).

0951-8320/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2007.12.006

Nomenclature

PM	preventive maintenance
CM	corrective maintenance
MSS	multi-state system
UMGF	universal moment generating function
$h_0(t)$	baseline hazard rate
$\varphi(z{:}\ \beta)$	positive functional term
z	$n\times 1$vector containing n covariates
β	$n\times 1$vector of regression coefficients corresponding to n covariates
$r(t,z)=r(t)$	component's reliability
$r_0(t)$	baseline reliability function dependent only on time
z_{CM}	the covariate representing the corrective maintenance
β_{CM}	the coefficient defining the CM effect
$p(t)$	the probability of making a replacement when the component fails
$q(t)$	the probability of making a minimal repair when the component fails
$p_e(t)$	the component's failure probability at time t
p_e^I	probability of total failure knowing that the component has failed
m_{imp}	the improvement factor associated with a simple repair act
m_{par}	the improvement factor associated with a replacement
$m_{\mathrm{CM}}(t)$	the expected improvement factor of the corrective maintenance at time t
X_{j+1}	the $(j+1)$th time to failure
Y	a random performance of a given component
$t_0(j)$	the component age after the jth corrective maintenance action
t_j	the time when the jth CM action is made
Nc	total number of components
$T_{\mathrm{P}}=(T_1, T_2,\ldots,T_{Nc})$	solution vector of system component inspection periods
T_i	the chosen time to make the preventive maintenance for the ith component
N_i	the total number of corrective maintenance for the ith component
m_{CM_j}	the improvement factor associated with the jth CM action
$\mathrm{IF}_i(t)$	the Birnbaum importance factor of the ith component at time t
G_i	the nominal performance of the ith component
$G_{\mathrm{sys}}(t)$	the output performance of the system at time t
G_0	the required system's performance

production schedule of the industry, perfect and imperfect actions [5–9].

In spite of CM having a direct influence on the component, it was not sufficiently studied.

Under the title of PM optimization, Tsai et al. [10] presented periodic PM of a system with deteriorated components. Two activities, simple PM and preventive replacement, are simultaneously considered to arrange the PM schedule of a system. The CM effect was only taken into account from the cost point of view. Dedopoulos et al. [11] have developed a method to determine the optimal number of PM activities to be scheduled within a time horizon for a single unit working in a continuous mode of operation characterized by an increasing failure rate. Only the CM cost is considered. The same issue is repeated with Park et al. [12] when they tried to minimize the cost of a periodic maintenance policy of a system subject to slow degradation. Levitin et al. [13], Zhao [14] and Hsu [3] have considered the CM as a minimum failure while they were proposing their optimized PM policies.

In this paper, the proportional hazard model (PHM) is used as a modeling tool to integrate the effect of the CM on the component's reliability through its influence on the component's age.

The PHM was first introduced by Cox (1972). Since then various applications of the PHM in reliability analysis have been presented. The basic approach in the proportional hazards modeling is to assume that the hazard rate of a system consists of two multiplicative factors, the baseline hazard rate, $h_0(t)$, and generally an exponential function including the effects of the monitored variables. For example, these monitored variables can be lubricant pressure, temperature, etc. Hence, the hazard rate of a system can be written as [23] $h(t;\, z)=h_0(t)\exp(z\beta)$, where z is a row vector consisting of covariates, explanatory variables, any monitored variable or any state indicating variable, and β is a column vector consisting of the corresponding regression parameters. The unknown parameter β defines the influence of the monitored variables on the failure process. In this study, we propose to consider the CM as a monitored variable and we offer a way to calculate its β. The influence of the CM action would be considered as an important factor while choosing the PM action.

In fact, Kumar et al. [15] review the existing literature on the PHM. At first, the characteristics of the method are explained and its importance in reliability analysis is presented. In order to determine economical maintenance intervals, Percy et al. [16] investigate two principal types of general model, which have wider applicability. The first considers fixed PM intervals and is based on the delayed alternating renewal process. The second is adaptable, allowing variable PM intervals, and is based on proportional hazards. Martorell et al. [17] have presented a new age-dependent reliability model that includes parameters related to surveillance and maintenance effectiveness and working conditions of the components. The accelerated life