Reliability Engineering and System Safety 94 (2009) 370–381

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

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

Maintenance and replacement policies under technological obsolescence

Julien Clavareau [*,1], Pierre-Etienne Labeau

Service de Métrologie Nucléaire, Université Libre de Bruxelles, Av. Franklin Roosevelt 50, CP165/84 Bruxelles B-1050, Belgium

ARTICLE INFO

Article history:
Received 16 October 2007
Received in revised form
25 February 2008
Accepted 29 March 2008
Available online 11 April 2008

Keywords:
Preventive and corrective maintenance
Replacement strategies
Technological obsolescence
Monte Carlo simulation

ABSTRACT

The technological obsolescence of a unit is characterized by the existence of challenger units displaying identical functionalities, but with higher performances. This paper aims to define and model in a realistic way, possible maintenance policies of a system including replacement strategies when one type of challenger unit is available. The comparison of these possible strategies is performed based on a Monte Carlo estimation of the costs they incur.

1. Introduction

Most often, papers studying optimization of preventive or corrective maintenance policies rely on the assumption that failed or used pieces of equipment are replaced by identical items. Actually, the technological reality is often quite different. In practice, new equipments are regularly available on the market achieving the same missions, but with higher performances. These higher performances can be understood as smaller failure rates, lower energy consumption, a lower purchase cost, etc. At the same time, it can be more and more difficult or costly to find old-generation spares to replace degraded units. This situation is characteristic of technological obsolescence.

Managers then face important issues, such as, for instance: how to optimally schedule the replacement of old-type units by new-type ones? Is it economically more interesting to preventively replace all the old equipments, without benefiting from their residual lifetime, by their more performing challengers, or on the contrary is it preferable to replace gradually the old components in a corrective way, progressively with their normal outage, but at the risk of a larger number of failures? Such questions become even more crucial when spare parts are to be dealt with.

The aim of our work is therefore to define replacement policies of these obsolete equipments and to help the decision maker find an optimal strategy among them.

Previous works envisaged this problem in a simplified way.

In Ref. [1], the case of one single component subject to ageing, which can be either periodically maintained or replaced by a technologically more advanced unit was studied.

In Ref. [2], authors studied analytically the following case: A set of n identical and independent units can be either preventively or correctively replaced by new-type units. The replacements take a negligible time. The new-type units have a lower constant failure rate and a lower consumption rate. The so-called "K strategy" was introduced as follows [3]: first, new-type components are used only to replace failed old-type units; then, after K corrective actions of this kind, the $n-K$ old-type remaining components are preventively replaced by new-type ones at the time of the Kth corrective intervention. The 0 strategy represents the preventive replacement of all old-type components at the initial moment. In Ref. [2], the authors reached the following conclusion: no matter which values are chosen for the data and the time horizon, only three strategies can be optimal: either all the components are replaced preventively ($K=0$), or one component is replaced correctively and the others preventively immediately after this first failure ($K=1$), or all the components are replaced correctively ($K=n$).

In Ref. [4], units subject to ageing and non-negligible stochastic replacement durations were envisaged and the same conclusions reached.

In the continuation of the works presented in Refs. [2,4], we introduce in this work more realistic maintenance actions, as extensions of the K strategy, and develop a complete model for the

* Corresponding author. Tel.: +32 2 650 40 42; fax: +32 2 650 45 34.
E-mail addresses: jclavare@ulb.ac.be (J. Clavareau), pelabeau@ulb.ac.be (P-E Labeau).

[1] Grant FRIA, Belgium.

0951-8320/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2008.03.033

management of a set of identical units subject to obsolescence, in the presence of a maintenance policy and of challenger units with a limited number of maintenance teams.

This paper summarizes and extends the works presented in Refs. [5,6]. It is organized as follows: Section 2 describes the model proposed and the assumptions on which it is based. Section 3 illustrates, by numerical results based on Monte Carlo (MC) simulation, some aspects of the whole model and some of the strategies proposed. In particular, we compare in Section 3.1 our MC results with the analytical solution of the simplified problem from [2]. Section 3.2 treats how to deal with the spare part inventory and the time horizon on which the transition between technological generations takes place. In Section 3.3, we discuss on the basis of another set of data the ability to forecast a budget for the replacements, which is regularly distributed in time. Finally we conclude by some possible perspectives and extensions of the model.

2. Model description

In this work, we will consider a set of n identical units, likely to be replaced by their more performing challengers. These units are subject to ageing and can be either replaced, imperfectly preventively maintained or repaired.

In this work, the new-type units will be more performing according to two criteria: their consumption rate and failure rate will be lower than that of the old ones.

2.1. Component failure modes

For both generations of components, we consider the following failure causes:

- *Ageing*: we model the ageing of the components by failure times exponentially distributed with time-dependent failure rates. These failure rates are the sum of a constant term λ_0 embodying purely random failures and a time-shifted Weibull-like contribution corresponding to ageing. At time t, the cumulative probability function of the failure time of one unit of a given generation is thus given by an expression of the form:

$$F(t)=\begin{cases}1-\mathrm{e}^{-\lambda_0(t-t_s)} & \text{if} \quad \tau(t)\leqslant v\\ 1-\mathrm{e}^{-\lambda_0(t-t_s)((\tau(t)-v)/\alpha)^{\beta}} & \text{if} \quad \tau(t)>v \text{ and } \tau(t_s)\leqslant v\\ 1-\dfrac{\mathrm{e}^{-\lambda_0(t-t_s)((\tau(t)-v)/\alpha)^{\beta}}}{\mathrm{e}^{-((\tau(t_s)-v)/\alpha)^{\beta}}} & \text{if} \quad \tau(t_s)>v\end{cases} \tag{1}$$

  where t_s is the instant at which the unit underwent the last intervention and $\hat{o}(t_s)$ the unit age after the intervention. The location parameter í is an effective working time before which the ageing of the unit does not affect its failure rate. The age $\hat{o}(t)$ to be considered to evaluate the failure probability is the effective (or virtual) age of the unit. This effective age is different from the calendar working time of the unit and depends on its past and on the maintenance interventions it has undergone. In particular, we consider that the different interventions affect this effective age by a rejuvenation factor. See Section 2.2, Eq. (3), for more details.
- *Common cause failures*: we also consider possible common cause failures modelled according to Atwood's shock model [7]. This model considers one (or several) external cause(s), whose occurrence entails an on-demand failure risk for the units, with a failure probability possibly specific to each component. In this work, the occurrence of the only initiating cause considered is distributed according to a negative exponential pdf (parameter χ); it is supposed that the old-type units have a conditional failure probability p_O different from that p_N of the new-type equipment.
- *On-demand start-up failure*: For the stocked units, we assume a cold stand-by situation. When a component is replaced by a new one, the latter has a probability to fail on demand depending on the storage time. In the model, this probability is given by a Weibull law of the form (1).
- *Incompatibility*: As already introduced in Ref. [4], a probability of incompatibility $p_{\mathrm{inc}}(t)$ is accounted for, in order to model the fact that the on-site implementation of new-type components could turn out to be problematic, and some replacements could not be immediately successful, as technicians are not familiar yet with this new technology. This probability of incompatibility is an on-demand probability of unsuccessful restart after a replacement of an old-type unit by a new-type unit. For these replacements, the incompatibility comes in addition to the on-demand start-up failure.
- Part of this probability will decrease when both the informa tion on the installation procedure and experience increase. This incompatibility should consequently not favour early replacements. This incompatibility hazard is difficult to model, especially its time-dependent part. A first approach consists in limiting this dependence on the number of replacements per formed on the system under study. Adopting this simplification, we can write:

$$p_{\mathrm{inc}}(t)=p_0+\frac{p_i}{f^{n_{\mathrm{int}}(t)-1}} \tag{2}$$

  where p_0 is the purely ra ndom on-demand failure probability of the new-type components, p_i is the contribution to incompatibility for the first replacement intervention, n_{int} (t) is the number of replacements of old-type units by new-type ones achieved on the whole system and f is a parameter larger than 1. Yet a more satisfying modelling depending on the calendar time should be developed in future works.

2.2. Interventions

As mentioned before, we consider a limited number of maintenance teams, which are supposed to perform four different types of actions. The first one is the preventive imperfect maintenance of the components at constant time intervals. The second one consists in repairing a failed component. The last two actions are the corrective and the preventive replacements.

To model the effects of these interventions, we use, among the available models in the literature, the effective age model [8,9]. This effective age is different from the physical component age (absolute or calendar age) that gives the time elapsed from the time the component was first started until the current time. The effective age rather represents an equivalent working time of the unit, given the different interventions it has undergone. The effective age $\tau(t)$ is the one taken into account (see Eq. (1)) in the Weibull law to evaluate the failure probability of a component.

The imperfect preventive maintenance actions are carried out at regular intervals. The effect of an imperfect preventive maintenance is to reduce the unit's effective age by a rejuvenation factor ε_m. The effective age τ_a after a preventive maintenance is given by

$$\tau_a=\varepsilon_m\tau_b, \quad 0\leqslant\varepsilon_m\leqslant 1 \tag{3}$$

where τ_b is the effective age of the components before the maintenance and ε_m ($\leqslant 1$ except if the intervention deteriorates the component) is the rejuvenation factor due to a preventive maintenance. If $\varepsilon_m=0$, the maintenance is perfect (*as good as new*) and if $\varepsilon_m=1$ the maintenance has no effect (*as bad as old*).