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Improvement indicators for Total Productive Maintenance policy

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ABSTRACT

Many papers have been written on financial indicators to assess the use of a maintenance policy based on Total Productive Maintenance, while others have compared results showing the impact of criteria such as the Mean Time Between Failures. This paper provides the maintenance managers indicators which can assess the relevance of the actions carried out as well as readjustment of the planned maintenance program. In long term, this indicators knowledge may lead them to review their maintenance policy. To reach this aim, we propose several indicators for reliability, diagnosis and prognosis to assess and improve the maintenance policy based on Total Productive Maintenance. Methods used to obtain these indicators are only based on operating maintenance activities. These latter were extracted from a database produced by a Computerized Maintenance Management Information System. This work focuses on a maintained process based on total productive maintenance in which available sensor data are not indicative of degradation level achieved by the system. Indicators presented were obtained using Survival Laws, Hidden Markov Model and Support Vector Machine. As a concrete case study, an alloy foundry process is used.

1. Introduction

The World War II was the beginning of a new era for the world economy. The massive destruction of production tools worldwide and population movements in the years 1936–1946 generated hitherto unprecedented needs in capital assets, consumer products and services. It was the start of the post-war boom era (1946–1975). During these thirty years, the economy developed rapidly but the increase in industrial production took place without any real strategy or policy. Consequently, these developments led to a great increase in the consumption of raw materials. Since the 1970s, the energy crisis, stock exchange crisis and industrial catastrophes have contributed to the evolution of company management policies. Since 1971, the choice of Japanese management techniques by Western industry has transformed the organization not only of production systems but also of services that concern the entire company (Fig. 1).

In 1971, in Japan, the concept of Total Productive Maintenance (TPM) was introduced to solve maintenance problems of systems by giving operators and employees more responsibility (Nakajima, 1984). Many approaches to this concept can be found in the literature, as the following quotations illustrate. "The goal of TPM is to implement perfect manufacturing to do more with less." (Lawrence, 1999); TPM is "an integrated life-cycle approach to factory maintenance and support" (Blanchard, 1997); TPM is a program that "addresses equipment maintenance through a comprehensive productive-maintenance delivery system employees from production and maintenance personnel to the top of management" (Mckone & SCHROEDER, 1999); "TPM is a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. It encompasses the concept of continuous improvement and total participation by all employees and by all departments." (Society Of Manufacturing Engineers, 1995); "TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets."; TPM is intended to "bring both functions (production and maintenance) together by a combination of good working practices, team working, and continuous improvement." (Cooke, 2000); TPM is "all of the strategies needed to sustain a healthy maintenance log." (Steinbacher & Steinbacher, 1993).

The Japan Institute of Plant Maintenance (JIPM) describes the implementation of TPM with eight pillars, as shown in Fig. 2 (Ahuja & Khamba, 2008).

TPM starts with 5S (Fig. 2), which methodically organize the workplace and working practices. The 5S approach requires a new philosophy and way of working. It can be broken down into 5 phases, named after 5 Japanese words each beginning with the letter "S" (Sort, Straighten, Shine, Standardize, Sustain), hence the name 5S. Methods and techniques based on the concept of TPM have been successfully implemented in Japan and in many countries in the world. Today, TPM is among the essential strategies for maintenance policies (Simões, Gomes, & Yasin, 2011).

When implementing a TPM maintenance policy, managers need to use indicators capable of informing about failure situations. Many tools can be used, for examples: Check sheet, Flow Chart, Histogram, Control Chart, Pareto Chart, Ishikawa diagram, Scatter diagram... These different monitoring tools may enable experts to identify for example, interactions between different factors leading to failure situations (Borris,

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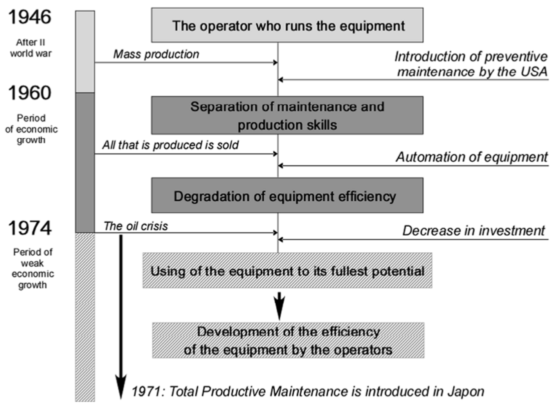

Fig. 1. Evolution of industrial practices since World War II.

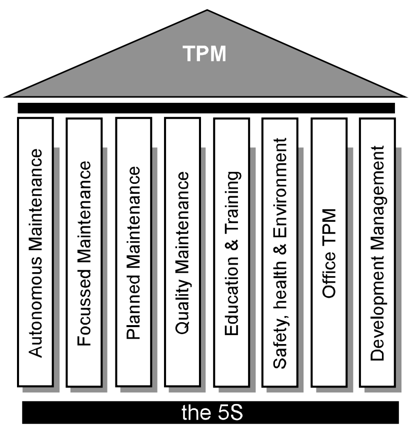

Fig. 2. Eight pillars approach for TPM implementation (suggested by JIPM).

Table 1
List of abbreviations and notations.

Abbreviation	Description
TPM	Total Productive Maintenance
HMM	Hidden Markov Model
RUL	Remaining Useful Life
SVM	Support Vector Machine
ROE	Return On Experience
Notation	**Description**
$\lambda(t)$	Failure rate
$\mu(t)$	Repair rate
$X(t)$	Degradation process
S(t)	Survival function
$f(t)$	Density function
$F(t)$	Cumulative distribution function
$h(t)$	Hazard rate
$\Lambda\ (t)$	Cumulative hazard
$\hat{m}(t)$	Estimation of the function m(t)

2005; Kiran, Cijo, & Kuriakose, 2013; Kumar & Suresh, 2006; Norddin & Saman, 2012). The implementation of these different monitoring requires improving the 5S.

As the aim is to assess the maintenance actions based on the TPM policy, some methods which can be used to assess and improve it was identified. They come from the areas of reliability, diagnosis and prognosis. These latter provide indications respectively on failure probability, system health, and Remaining Useful Life (RUL). The specificity of the methods used lies in their ability to use discrete observations, in our case of application, maintenance activities available in the Computerized Maintenance Management Information System (CMMIS).

Abbreviations and notations used in the paper are explained in Table 1.

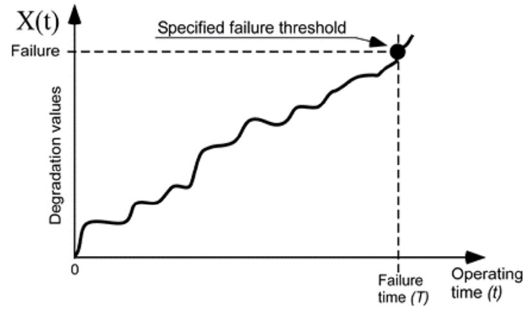

Fig. 3. Degradation level estimation.

The paper is organized as follows: Section 2 deals with different statistical methods able to provide answers to reliability issues. Non-parametric and semi-parametric laws are presented. In Section 3, a Hidden Markov Model (HMM) is proposed to provide help for the maintenance plan (diagnosis). This Section also contributes to another solution to help maintenance managers by estimation of the Remaining Useful Life with HMM and Support Vector Machine (SVM). In Section 4, we show the industrial application used to perform the tests. Results are presented in Section 5, followed by concluding remarks.

2. Survival laws in reliability analysis

The study of reliability is very often used by experts so as to benefit from the Return On Experience (ROE) on a system or component. Reliability is precisely described in the international norm IEC 62308 ED1.0 (IEC 62308 ED1.0, 0000). In this section, we present the set of laws that are the most frequently encountered in the analysis of survival data. These laws can be applied to many fields: the insurance business and banking, medicine, services, etc. (Collett, 2015; Khalaf, Hamam, Alayhi, & Djouani, 2013; Ye, Xia, Zhang, & Zhu, 2015). There are various cases which can produce failures. The origin of these cases can be internal or external (Montoro-Cazorla & Pérez-OcÓn, 2006; Rausand & Vatn, 2008). System structure and design is the cause of internal failures (e.g. material quality or wear). The environmental conditions in which systems operate are usually the cause of external failures (e.g. weather, vibrations). In our case study, we consider only the internal conditions. Indeed, the data available are only the maintenance activities about TPM maintenance policy. External data are not available.

Data extraction or data analysis can lead to a survival analysis. With these approaches, time until failure (or event) is of interest. Response is often mentioned as an event time, a survival time, or a failure time. In our study, we focus on the case of laws for continuous degradations modeled by X(t) stochastic process (Fig. 3). Fig. 3 will be used later, to specify our work in more detail considering the process degradation. The survival function is characterized by

$$S(t) = \mathbb{P}(T > t) = 1 - F(t), \quad t \geq 0. \tag{1}$$

with F(t) the cumulative distribution function.

The recent abundance of literature regarding failure prognostics may be a positive point, but it can also be a source of confusion, especially for those who are beginning to work in this domain. The standard ISO 13381-1 (ISO, 2004) defines failure prognostics, details the steps of the prognostics process, gives indications on the monitoring system and on how to estimate the confidence interval associated with the calculated RUL and proposes some mathematical tools which can be used to model the degradation. This prediction is first based on a detailed analysis of the ROE data (Birolini, 2012).

Specifically, the study of the RUL of a system or a component is an element of Reliability, Availability, Maintainability, and Safety studies (RAMS). Our study deals with the topics of reliability and availability (Cox, 1972; Hopp & Wu, 1988).

There are different laws to characterize the reliability of a system (Briš & Martorell, 2010; Hastings & Ang, 1995). These different laws can be classified into three categories.