IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

MODELING UNDER MATLAB OF THE DISCRETE INSTANTANEOUS AVAILABILITY OF A TECHNICAL MEDICAL DEVICE

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ABSTRACT

The study of the environment and constraints of exploitation of the devices and medical equipment allows an analysis of their reliability-maintainability-availability. That can result in the profile from the corresponding curve of the opérationo-functional calculus availability. This work proposed two digital models, under MatLab, of discrete instantaneous availability starting from the basic model of the continuous instantaneous availability. It is about the discrete instantaneous availability without restoring of the timer and the discrete instantaneous availability with restoring of the timer. The two models constitute innovating tools whose service of biomedical maintenance can be useful in a hospital to make decisions. Lastly, they are answers to criticisms in the literature on the constant rates of alternation of reliability and maintainability in the basic model.

KEYWORDS: Equipment, given to zero, reliability, maintainability, model, timer.

INTRODUCTION

The reparable industrial systems or not reparable undergo alternative moments of reliability and maintainability. These systems are characterized by effective times of operation and effective times of failure. They are thus the operating time and the unavailability times. According to [1] the measurements of the instantaneous availabilities on a given interval and stationary are deduced from the basic instantaneous availability model of the [2]. According to [3], the studies aiming the reliability of the devices and equipment medical (DEM) are done especially by manufacturers. If necessary, these studies indicate to the owners of the DEM, the techniques for improvement reliability. In the literature, a solid approach of calculation and follow-up of the availability opérationo-functional (AOF) of a DEM is rare in our opinion. Some studies such as [4] [5] [6] and [3] treated aspects of the availability of a DEM. Indeed, [6] revealed that the studies relating to the maintenance and inspection of the DEM between 1989 and 2013 are: the studies of optimization of the maintenance of the DEM; the studies of empirical research on the maintenance of the DEM; and the studies for priorisation of the DEM having to undergo activities of maintenance. Moreover, it is also necessary to note more the share of these studies are directed towards the management indicators of a park of DEM.

Therefore, since the years the 1990 scientific management studies of the DEM do not dig the practical concepts of the AOF of the DEM. Generally, the studies are clinical evaluations of the DEM for a reliable result on the patient [7]. However, studies [4] [5] [8] [9] and [3] try to develop preconditions for AOF study of the DEM following the example industrial equipments. From the exploitation point of view, a DEM is more constraining than industrial equipments [8]. However, all the strategies are in the instantaneous availability. According to Handbook [2], it is the instantaneous availability which generates the other forms of availability; some is the measurement of availability. In the basic model of the instantaneous availability in [2], there is the assumption that the rates of alternation of reliability and maintainability are constant. This assumption was criticized by [10] and [11], like a no precise assumption and that its use can lead to erroneous decisions. Moreover, one major analysis of the environment and constraints of exploitation of a DEM allow an analysis of its reliability [5]. We can thus distinguish the intrinsic availability and the extrinsic availability of a DEM. This is why the objective of this work is to propose two models of discrete instantaneous availability starting from the basic model of the instantaneous availability of [2].

MATERIALS AND METHODS

Material

The material used concerned of the basic complete mathematical model of the instantaneous availability, to see page 160 of [2], and the software MatLab R2010a.

Methodology ¶

Formulation of the instantaneous availability

Generally, probability of correct operation without failure over one period $[0;t[$ is reliability $R(t)$, noted with the equation (1).¶

$$R(t) = \mathrm{Re}\,liability\,([0;t[) \tag{1}$$

If we decide to put the timer at zero each time in order to observe a series of reliabilities, we will have the expression of the equation (2).

$$R(t_i) = \mathrm{Re}\,liabity_i\,([0;t_i[) \tag{2}$$

From the equation (2), we can deduce the instantaneous rate of discrete failure which we note $\lambda(t_i)$. In the same way, we can also deduce the instantaneous rate of discrete repair which we note $\mu(t_i)$.

In the majority of the literatures on the availability of equipment, one generally makes the assumption that the instantaneous rates of failure $\lambda(t)$ and of repair $\mu(t)$ are constant. Consequently, they are noted as with the equation(3).

$$\begin{cases} \lambda(t) & = & \lambda \\ \mu(t) & = & \mu \end{cases} \tag{3}$$

Under this assumption, we have the expressions of the equation system (4).

$$\begin{cases} \lambda & = & 1/MTBF \\ \mu & = & 1/MTTR \end{cases} \tag{4}$$

With $MTBF$ (respectively $MTTR$) the average of times of correct operation (respectively the average of technical times of repairs).

Under the assumption of the equation (3), the complete mathematical model of the availability instantaneous proposed by [2], and known in the literature is written as with the equation (5).

$$D(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu}\exp[-(\lambda+\mu)t] \tag{5}$$

The equation (5) is the expression of the model of the basic instantaneous availability from which we reason in the following sections.

Formulation of the discrete instantaneous failure rate

Let us consider the figure 1.

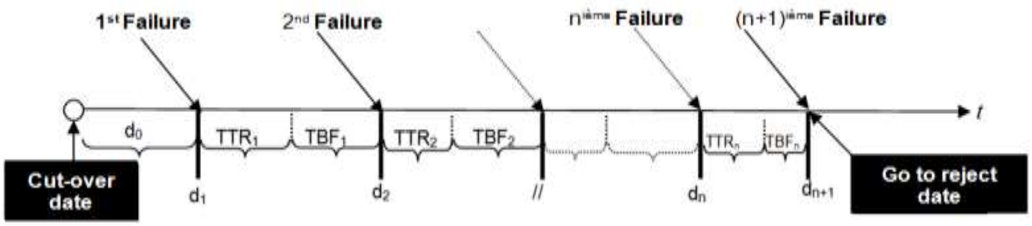

Figure 1: ***Illustration of the periods of repair and correct operation of a medical device enters the cut-over date and the date of reject.***

TTR = *technical time of repair;* TBF = *time of correct operation (it is about the useful addition of time of the clinical requests between two consecutive failures);* d_0 = *useful addition of time of the clinical requests before the first failure.* d_i = *the date of appearance of* $i-th$ *the failure.*

As $\lambda = 1/MTBF$ in the equation-4, we deduce the expression of λ for n failures by the equation-6.

$$\lambda = \frac{n}{TBF_1 + TBF_2 + ... + TBF_n} \qquad (6)$$

The equation (6) is an expression of the instantaneous failure which should not be constant. Thus, we can generate two various series of discrete instantaneous failure rate $\lambda(t_i)$. A first series of rate without restoring (srz) of the timer, that we note $\lambda(t_{srzi})$ and a second series of rate with restoring (rz) of the timer, which we note $\lambda(t_{rzi})$. The table-I presents these two series of discrete instantaneous failure rate.

Table 1. Discrete instantaneous failure rates

TBF_i	$\lambda(t_{srzi})$	$\lambda(t_{rzi})$
TBF_1	$\lambda(t_{srz1}) = \frac{1}{TBF_1}$	$\lambda(t_{rz1}) = \frac{1}{TBF_1}$
TBF_2	$\lambda(t_{srz2}) = \frac{2}{TBF_1 + TBF_2}$	$\lambda(t_{rz2}) = \frac{1}{TBF_2}$
//	// = //	//
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TBF_{n-1}	$\lambda(t_{srzn-1}) = \frac{n-1}{TBF_1 + TBF_2 + ... + TBF_{n-1}}$	$\lambda(t_{rzn-1}) = \frac{1}{TBF_{n-1}}$
TBF_n	$\lambda(t_{srzn}) = \frac{n}{TBF_1 + TBF_2 + ... + TBF_{n-1} + TBF_n}$	$\lambda(t_{rzn}) = \frac{1}{TBF_n}$

Formulation of the rate of discrete instantaneous repair

By comparison, we note $\mu(t_{srzi})$ the discrete instantaneous repair rate without restoring of the timer and $\mu(t_{rzi})$ the discrete instantaneous repair rate with restoring of the timer. The table-II shows the rates of discrete instantaneous repair with and without restoring of the timer.

Table 2. Discrete instantaneous repair rates

TTR_i	$\mu(t_{srzi})$	$\mu(t_{rzi})$
TTR_1	$\mu(t_{srz1}) = \dfrac{1}{TTR_1}$	$\mu(t_{rz1}) = \dfrac{1}{TTR_1}$
TTR_2	$\mu(t_{srz2}) = \dfrac{2}{TTR_1 + TTR_2}$	$\mu(t_{rz2}) = \dfrac{1}{TTR_2}$
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TTR_{n-1}	$\mu(t_{srzn-1}) = \dfrac{n-1}{TTR_1 + TTR_2 + ...+ TTR_{n-1}}$	$\mu(t_{rzn-1}) = \dfrac{1}{TTR_{n-1}}$
TTR_n	$\mu(t_{srzn}) = \dfrac{n}{TTR_1 + TTR_2 + ...+ TTR_{n-1} + TTR_n}$	$\mu(t_{rzn}) = \dfrac{1}{TTR_n}$

Formulation of the availability at the added moments

In the basic complete expression of the instantaneous availability of the equation (5), let us admit that the steps of time t_i are different between the dates from two consecutive failures. We can thus write:

$$t_i = d_{(i+1)} - d_i \tag{7}$$

With $d_{(i+1)} > d_i$

By considering the equation (7), the basic instantaneous availability (expressed with the equation (5)), can be written as with the equation (8).

$$D(t = t_i) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} \exp[-(\lambda + \mu)t_i] \tag{8}$$

With μ constant and λ constant.

In the same way, according to the figure-1, t_i can be expressed under the expression of the equation (9).

$$t_i = TTR_i + TBF_i \tag{9}$$

From where, each moment t_i of the equation-8 is a sum corresponding duration of repair and duration of correct operation.

RESULTS AND DIGITAL SIMULATION

By the assumption that μ and λ are not constant (equation(10)) and vary according to the time step t_i. By deduction of the equation (5), we can express the discrete instantaneous availability in the form of the equation (11).

$$\begin{cases} \lambda = \lambda_i(TBF_i) & not \quad constant \\ \mu = \mu_i(TTR_i) & not \quad constant \end{cases} \tag{10}$$

$$D(t = t_i) = \frac{\mu_i(TTR_i)}{\lambda_i(TBF_i) + \mu_i(TTR_i)} + \frac{\lambda_i(TBF_i)}{\lambda_i(TBF_i) + \mu_i(TTR_i)} \exp[-[\lambda_i(TBF_i) + \mu_i(TTR_i)]t_i] \tag{11}$$

The equation-11 is the principal model of discrete instantaneous availability which we propose in this work. It is this model which is used to generate respectively:

- the discrete instantaneous availability without restoring of the meter; and

- the discrete instantaneous availability with restoring of the meter.

We simulated the two models under the software MatLab R2010a. To do that, we wrote a code which takes into account two vectors of the same size. A vector of technical times of repair and a vector of times of correct operation. The figure 2 illustrates the comparative result between the model of basic continuous instantaneous availability and the two models of discrete instantaneous availability suggested.

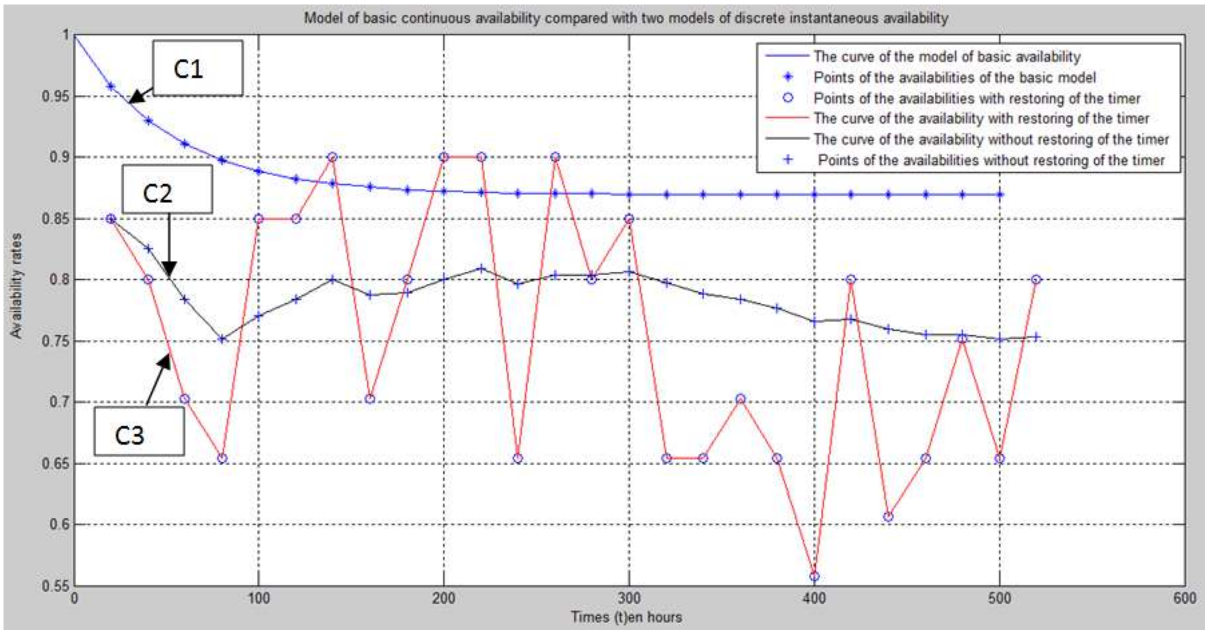

Figure 2 : ***The curve of comparison of the instantaneous availabilities*** ¶

DISCUSSION

The blue curve (C1) is the basic model of the continuous instantaneous availability. The red curves (C3) and black curves (C2) are those of the discrete instantaneous availability respectively with restoring of the timer and without restoring of the timer. These two curves C2 and C3 are generated by the model of the equation-11. Contrary to the model of the curve C1 which is continuous, the models of the discrete curves C2 and C3 will be applicable to realities of exploitation of the devices and medical equipment in a hospital medium.

For industrial equipment, a normal time of necessary correct operation is known and defined in advance. On the other hand, on medical equipment, times of necessary correct operation depend on times of the episodes of care of health of the patient. These times are not known in advance. Indeed, for the same equipment, these times vary from a patient with another, a user with another and a context with another. The two discrete models will serve as a true approach of calculation and follow-up of the opérationo-functional calculus availability of the devices and equipment medical.

Lastly, let us recall that in the model of the basic instantaneous availability of the curve C1, the authors [2] made the assumption that the rates of alternation of reliability and maintainability are constant. This assumption was criticized by [10] and [11] like a no precise assumption and that its use gives erroneous decisions. Then, with the two models of the curves C2 and C3, proposed in this work, it is a response to criticisms in the literature on the constant rates of alternation of reliability and maintainability.

CONCLUSION

Using the software MatLab R2010a and the mathematical model of the basic continuous instantaneous availability, two models of the discrete instantaneous availability are obtained. This starting from new assumptions made on the rates of alternation of reliability and maintainability of a device, in general, and a medical device, in particular. The results constitute a fundamental improvement in the study of the triplet reliability-maintainability-availability of equipment of industrial production. The adopted approach tallies as well the context of exploitation of the devices and equipment in hospital areas environment medium. It is about a strategy for improvement and adaptation to the medical devices, techniques of engineering which were always applied successfully in industry to improve the performance in the management of maintenance equipment of production. Indeed, the hospital nowdays is comparable with an industry which has a great number of various equipment. It must profit significantly from the techniques of optimization, like that of estimate of the discrete instantaneous availability suggested by this work, in the processes of management of its equipment.

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