DETERMINATION OF OPTIMUM MAINTENANCE METHOD BASED ON MAINTENANCE COST

Vasile DEAC
Assoc. Prof., PhD
Bucharest University of Economics, ROMANIA

Gheorghe CARSTEA
Univ. Prof., PhD
Bucharest University of Economics, ROMANIA

Constantin BAGU
Univ. Prof., PhD
Bucharest University of Economics, ROMANIA

Florea PARVU
Univ. Prof., PhD
Bucharest University of Economics, ROMANIA

Abstract: *The present economical and financial crisis that affects all industrial organizations, have also large impact on the maintenance activity .Unfortunately, due to the pressure of costs reduction, this activity still continues at a very low level, with important effects in the future. The decision to adapt a maintenance method should be the result of a scientific analysis, taking into account a series of technical and security factors, as well as, economic ones, and certainly, all the other costs this activity includes.*

Key words: total productive maintenance, corrective maintenance, systematical preventive maintenance, conditional preventive maintenance, probability of failure, direct costs, cost of downtime.

Taking into account all the maintenance methods from the specialized magazines all over the world, there are different opinions regarding the maintenance methods that are likely to be used, fact that comes from the reality belonging to different organizations from one country or another or even from the same country. Thus, there is a wide variety of maintenance methods starting with the traditional systems of maintenance and repairs (which are still in use in our country) and ending with „Total productive maintenance" (in Japan).

In our opinion, in order to define an efficient maintenance policy we should take into account the fact that there is not a „good maintenance method" itself, but we will have to adopt a particular maintenance method for each industrial equipment, achieving an economic and technical balance. As a consequence, we suggest the following classification of the possible methods of maintenance to be applied in our country: **corrective maintenance; systematical preventive maintenance; conditional preventive maintenance**[3]

1. The corrective maintenance is the maintenance which is used when the equipment breaks down. There is a slight ambiguity when defining the corrective maintenance as „correction" the breaking down includes the notion of betterment. After the failure that occurred within the maintenance and work repairs, we perform work repairing trying to work out the failing function. The corrective maintenance involves the following:

- an analysis of the causes of the breaking down;
- work repair;
- a potential correction trying to avoid the rework repair of the failure or to reduce its effects on the system;
- observing all the elements regarding the intervention (the cause, the works, spare parts, parts which have been replaced, the cost of the work, time of not functioning), thus allowing a future operation.

Corrective maintenance represents that type method of maintenance which is used before developing the systematical preventive maintenance, but the latter does not eliminate in all the equipment breaking, downs and, what is more, they cannot be applied in all the situations in acceptable economic conditions. As a consequence, this method is usually applied to equipments whose breaking down does not involve people's security and does not require high costs when it comes to the unavailability, of equipments. Also, this maintenance method can be applied to all equipments during the warranty period and especially during the operation time.

When we decide to adopt the maintenance method, we must estimate correctly the costs of breakdowns. The cost of an equipment breakdown comes from the cost of the necessary corrective maintenance to restart it (direct cost) and the cost of all the unavailable situations for the equipment (indirect cost).

The systematical preventive maintenance is that type of anticipated, organized maintenance and programmed before an anticipated breakdown. In order to apply the systematical preventive maintenance, the plant must have the terminology and the record of all the equipments in accordance with the terms of their usage, their preventive systematical maintenance /tear-and-wear as well as a short history of the equipments.

The systematical preventive maintenance can be of „surveillance" or „absolute" maintenance.

- „absolute"- means that no inspection is done between two scheduled maintenance checks;
- „surveillance"- there can be set "regular scheduled maintenance" checks to check the constant state and the estimated state when the average time of operation is identified.

In accordance with their complexity and the length of time, volume or preventive systematical maintenance, the systematical preventive maintenance can be divided on different levels, for each level we must set the operations that should be applied to an equipment (working or not working) such as, checks, replacements, renovations, etc of some critical elements.

The conditional preventive maintenance is that maintenance of the evolution of a typical symptom of an event which can be identified with the help of different means: diagnosis, the wear measurement, information from a receiver. This method of maintenance anticipates the appearance of some more sources of damage as a result of the unnecessary disassembling taking action at the right time. This is the plus which is added to the „time's" and which improves the conditioned maintenance.

The control and diagnostic operations in case of a conditional preventive maintenance follow the lifespan of the equipment. The first condition to put this method into practice is that the equipment should be suitable for this method that is there should be a progressive and detectable degradation and there should be a correlation between the measurable parameter and the condition of the equipment. Taking into account this aspect, it is necessary to have a period of systematical and preventive maintenance in order to set a line of accessibility' where it should be a stop. It is compulsory to have "alarm" signal when intervention must take place.

The decision to adapt one of these methods must be the result of a scientific analysis on a basis of scientific models and methods and taking into account economic, technical and security factors. Unfortunately, the present financial and economic crisis that all the plants have to deal with has severe effects on the maintenance activity. This activity functions is at the minimum level due to the cost reduction. Taking into account this aspect and the fact that the maintenance service is not a real purpose but a quite expensive necessity for the production, we consider that it is difficult to consider it a useful method of maintenance without taking into consideration the economic aspect as well as the costs resulted from this activity.

The present approach has as a starting point the estimation and the comparison of the average costs of the three maintenance methods, mentioning at the same time that in case of an accidental breaking down, people's security will not be affected.

As for the **systematical preventive maintenance method**, we talk about interventions in a systematical manner as well as replacements or renovations of some elements of some critical situations after a while.

As a result, the optimum period of systematical intervention depends on reliability of some elements considered critical and this law can be defined in accordance with some indicators:

- $\lambda(t)$ = the rate of the breaking down;
- $R(t)$ = the probability of survival;
- $F(t)$ = the probability of breaking down;
- $f(t)$= the density of the probability of the breaking down.

In the case of „T" intervention within the systematical maintenance there is a probability of the breaking down $F(t)$. As a consequence, the total cost of the maintenance and the unavailability (Ct_s) will be given by:

$$Ct_s = C_d + C_i \times F(t), \text{ where}$$

C_d = the direct costs or costs of maintenance;

C_i = the indirect costs of unavailability in case of a breaking down;

$F(t)$ = the probability of breaking down.

If there is such an accidental breaking down before the moment T (that is $F(t)>0$), the average time to operate between two successive interventions m(t) will be smaller than T and it will be determined according to :

$$m(t) = \int_0^T R(t)\,dt$$

$$m(t) = \int_0^T (1-Fm)dt$$

$$m(t) = T - \int_0^T Fmdt$$

Consequently, the average cost per time unit for the systematical maintenance (Ct_{sm}) will be:

$$Ct_{sm} = [\, C_d + C_i \times F(t)] \,/\, m(t)$$

The optimum duration of operation between two successive interventions (Top) will be given by the value Ctsm which is the minimum. On the one hand, this depends on the shape of the curve of breaking down probability F(t) and, on the other hand, by the function: C_i/ C_d (the indirect costs in case of a breaking down / direct costs of systematical maintenance). See in figure 1.

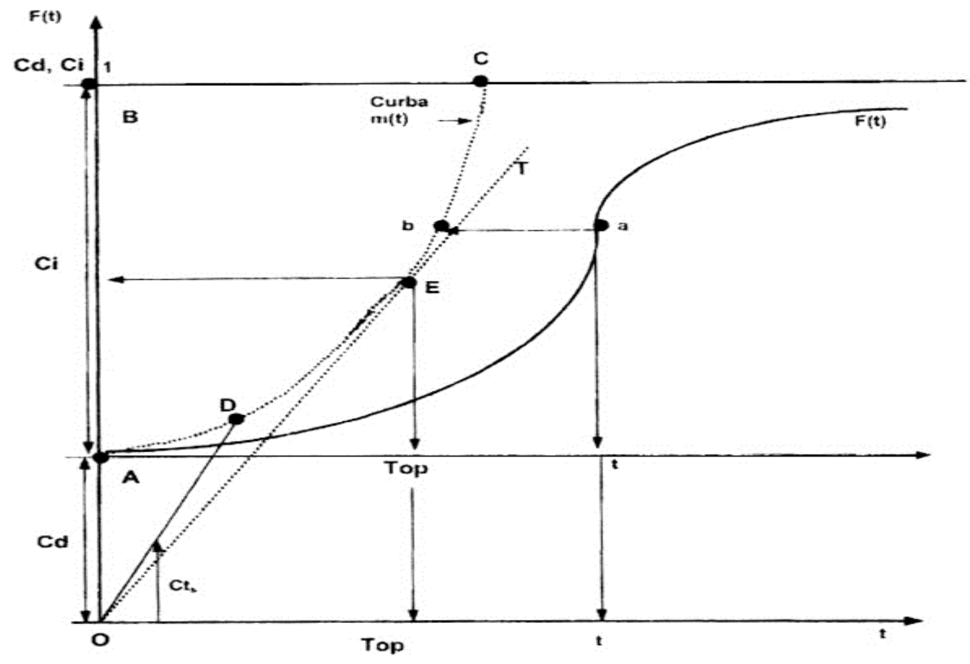

Figure 1. The graphic determination of the suitable time of operation in the systematical preventive maintenance.

The slant of the OD line represents the average cost per time unit which must be optimized by establishing the time of intervention. But this slant can be minimized when point D coincide with the contact point of the tangent which goes from the curve m(t) to point E.

This depends, on the one hand, on the shape of the curve of the breaking down probability F(t), and on the other hand, on the function C_i/ C_d, where the indirect costs in case of a breakdown and the direct cost of systematical maintenance as it is in figure 1. As a consequence, the optimum time of intervention Top depends on the shape of the curve F(t) (or R(t) which is symmetrical). This way, in case of a constant breaking down $\lambda(t)$ which is constant in time and which corresponds to a law of reliability (Rt), it is represented through a decreasing exponential function, the average duration between the two successive interventions m(t) is a line just like in figure 2.

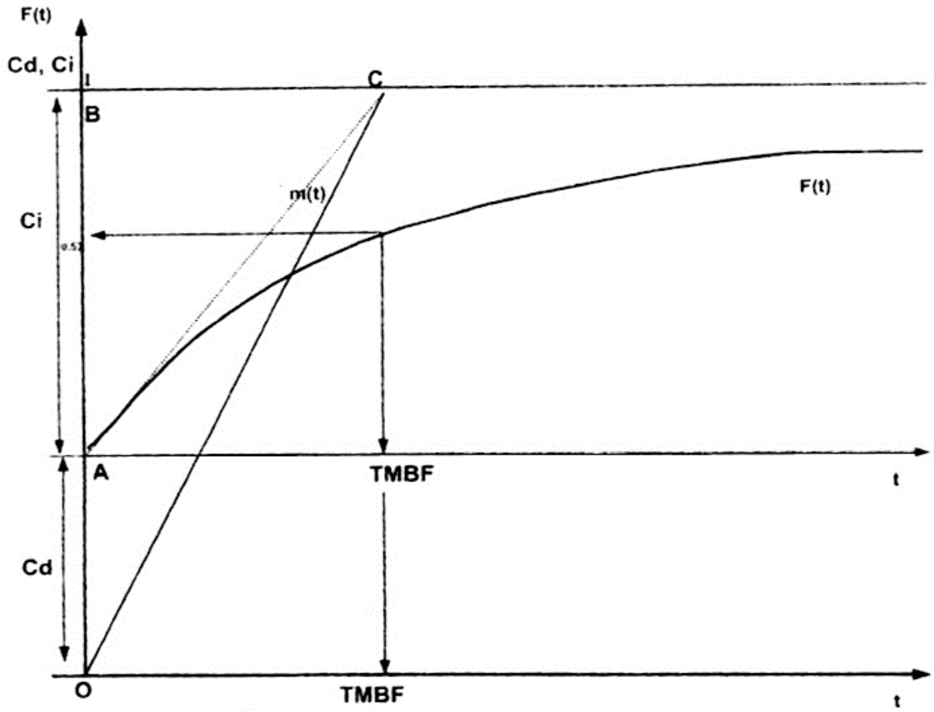

Figure 2 .The situation whom the rate of the breaking downs is steady

In this case, the tangent for the curve m(t) from the starting point towards the OC line. Consequently, the optimum time of operation between two successive interventions corresponds with the time of the breaking down, and the systematical preventive maintenance goes towards the corrective maintenance and the average duration of operation merges with the average time of good functioning (TMBF).

When the indirect costs of unavailability in case of a breaking down are unimportant as size, the tangent for the m(t) curve goes towards a straight line which is a parallel with the ox axis , and the tangent tends to go to $C_{i,}$ the superior point of the m(t) curve and it corresponds to a rate of the breaking down which is equal to 1 – that is the corrective maintenance. (figure 3).

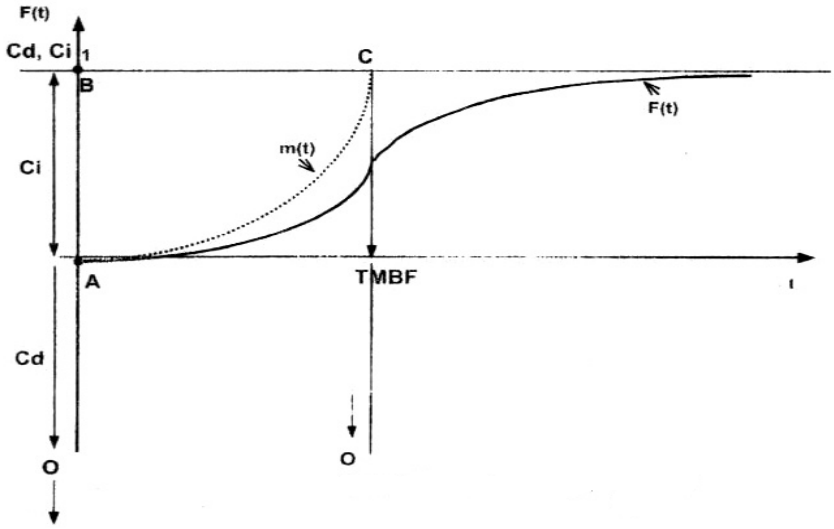

Figure 3. The case when the fraction $C_i/C_d \longrightarrow 0$

In the opposite situation where the indirect costs of unavailability in case of a breaking down (C_i) are very high, the point O will be very close to A (the origin of the m(t) curve, and the tangent OT to this curve is close to the abscissa).

The optimum duration (Top) matches the rate of Top, a reducing breaking down and Top is inferior to TMBF, the difference depends on the size of the function (the higher value the function will have, the higher the difference between TMBF and Top will be). This is shown in figure 4.

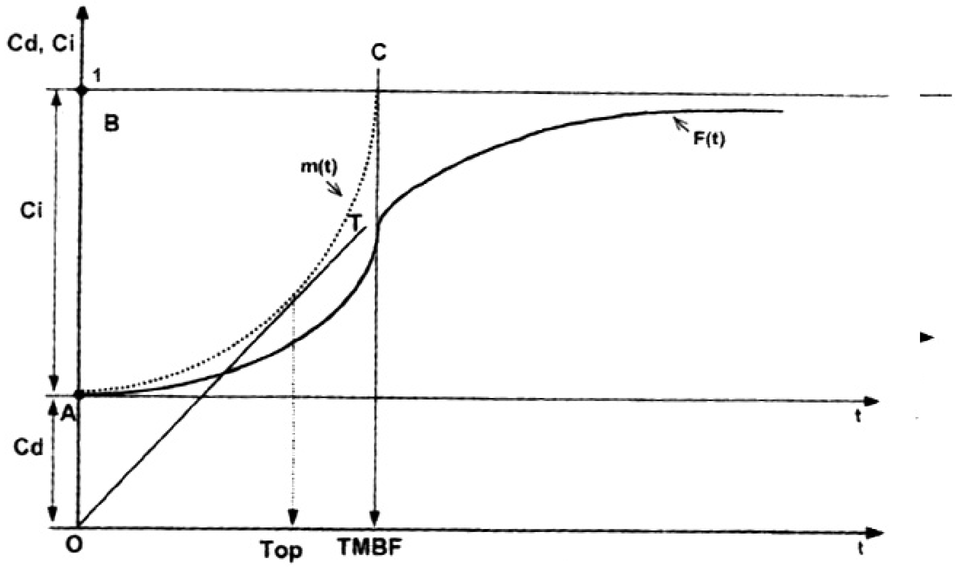

Figure 4. The case when the fraction C_i/C_d is higher

In case of the **conditional preventive maintenance**, the average duration between the successive interventions which is linked to the evolution of a symptom, is very close to TMBF. It can be calculated like this:

m(t) = K x TMBF, where

K = the coefficient which takes into account the necessary time between the alarm moment and the acceptable time when the conditioned and preventive maintenance has a value close to 1.

There exists a series of costs to implement this method of maintenance such as costs of acquisition of different measurement and control equipment and their use.

These costs to implement the conditional preventive maintenance between two successive interventions can be calculated as it follows:

C_c = (A/ D x TMBF) + C_a, where

C_c = the costs to implement the conditional preventive maintenance;

A = the costs of acquisition of the necessary measurement and control equipment;

D = the probable duration of the use of these equipments;

C_a = the costs of these measurements and controls for critical elements for a certain period of time – TMBF.

So, the average cost per time unit in case of conditioned and preventive maintenance (Ct_{cm}) will be:

$Ct_{cm} = (C_d + C_c) / (K \cdot TMBF)$

As for the **corrective maintenance**, the average cost per time unit (Ct_{crm}) will be:

$Ct_{crm} = (C_d + C_c) / TMBF$

If we are to compare the average cost per time unit which corresponds to each maintenance method, it can be identified the most efficient method of maintenance taking into account the costs.

When it comes to the indirect costs of the unavailability in case of a breaking down, they are not important, that is the function C_i/C_d is zero or it has a very small value (it has the tendency to go to zero), and the corrective maintenance method becomes the most advantageous; on the other hand, it can be justified the implementation of the conditional preventive maintenance methods or systematical preventive maintenance.

In case of a breaking down, people's security or the goods safety is severely damaged (C_i has a high value as it is well known that life is priceless) it is advisable to use the conditional preventive maintenance method; that involves a high rate of measurements and controls of the systems.

As it has already been shown, the method of conditional preventive maintenance involves the existence of a progressive degradation law which can be identified and the correlation between a measurable parameter and the equipment state. If this is not possible, the systematical preventive replacements are a means to reduce the risk of breaking down. When it is difficult to identify a rate of the breaking downs, one last solution is to update the equipment.

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