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Optimization of Preventive Repair in a Dynamic System of Machines

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Abstract

The determination of the number of preventive repair to make in a park of machines in a given period, in the majority of practical cases, is based on the knowledge of essential parameters obtained from the statistics such as:

1) Mean life duration of the equipment
2) Mean functioning duration until the first failure
3) Mean functioning duration between the failures
4) renewing intensity of the pa k of machines.

However theses values cannot be taken as credible base data to be able to optimise the number of repair of machines in a dynamic exploitation system of a park of machines and obtain the wanted number of machines at the end of the planned period. The cited 4 parameters depend on 2 principal factors:

- Evolution and importance of the park of machines (variable in time)
- Exploitation methods in the park (repair quality and used means).

The renewing intensity of the park of machines is a function of the demand and degradation intensity of machines. From another side, the repair duration depend on the functioning periodicity cited here, on their nature and their costs. These last influence, in a significant manner, the calculus results. It is then primordial to look for the solution of the problem by introducing the notion of parameters optimum values.

In this paper is given a new approach of the problem, which studies the dependence of the cited parameters, of the exploitation time and of the importance of the park of machines always renewed. This has for effect to act directly on the costs due to this dependence that is:

- The renewing costs (purchase of new machines and new repair means);
- The exploitation and repair costs.

This method permits to obtain optimal values:

- Of the number of repairs;
- Of the number of machines to purchase in the planned period;
- Of the exploitation duration of every machine.

Keywords: Renewing, Repair, Reliability, Cost, Modelling, Optimisation.

1. Introduction

The optimisation of a system destined to guarantee the repair and technical servicing of a park of machines begins with the determination of the number, the volume and the repair works composition on the entire park of machines. A reliable prevision of the repair demand, the determination of the number of repairs and the different servicing types for every type of machine is conditioned by a good choice of the servicing base capacity: An overestimation of the base entrains useless spending and an under use of the base equipment. On the contrary an under estimation of the base servicing volume entrains a degradation of the machines state and an increase in the forced stoppages.

In order to predict the repair works volume during the exploitation process of equipment of a number of machines, it is necessary to elaborate a practical method which determines the number of repairs at any time during the planned period $t_2 - t_1$.

The planning of repair works and technical servicing must be first based, on the census and the evaluation of the obtained data during the equipment control in exploitation. The control permits to:

a) Detect and eliminate the technical incidents
b) Get the system to a minimum of repairs with equipment stoppages
c) Exchange at the right time the defective elements.

Some approximated formulas have been proposed for the determination of the number of repairs, but these formulas can be used in the following cases

- The number of machines in the park doesn't change
- The machines are not replaced (relegated)
- No purchase of new machines
- The reliability of machines is maintained by the repairs.

In practise these cases have never been realised for the following reasons:

- The park of machines is always supplied by new machines; which entrains an increase of the functioning time (TTFF) until the first failure which exceeds by 40, 50 or 60% the functioning time between failures (TBF).
- Every year, one part of the used old machines, don't under any repair but are simply replaced.
- The duration between the preventive repairs and those to reject is not a fixed regulated duration, but only mean values around which is dispersed the duration until the first repair; the duration between the repairs and the total functioning duration (life duration).

The real cited factor here diminishes the repair demand in comparison with the demand determined in the approximated calculus.

What is important to underline is to take into account the park evolution (increase, with time, of the number of machines in the park), and we must make the difference between the number of machines recently installed and the number of machines repaired several times (old).

The old method doesn't take into account the periodicity variation between the repairs in time. Let's see now another more right approach of the problem. We must take into account:

a) The renewing and the reject of machines in the park;
b) The dependence between the functioning duration until the failure, between the failures, the total life duration and the exploitation time of the park of machines as a system. We take mean values of the cited parameters here.

The park of machines is divided into 2 parts:

- One part is composed of machines which have been repaired;
- The second part is composed of machines which have not been repaired.

We take into account the dynamic evolution of the park of machines by introducing criteria based on mathematical renewing methods. The renewing theory [1] is narrowly linked to the reliability theory and to the random processes and establish the elements failure process law and the methods of their predictions.

The aim of the prevision method is the determination of:

- Optimal repair number to realise every year in the time interval t_1 to t_2.
- Available machine number in the park at the end of this period. The number of machines being in a continuous renewal because of the arriving of new machines (bought) with an intensity *V(t)*.

By optimal renewal period, we must understand the machine control with a given reliability in order to guarantee a required technical level for a minimum exploiting cost, without any change of their availability in the technical resources limits of the machine.

2. Hypotheses

The number of servicing and preventive repair for each machine is determined on the basis of data on the real exploiting period corresponding to the type of servicing and preventive repair as well as the beginning of the exploitation.

The distribution of equipment exploitation characteristics such as: t_{tr}; t_{br}, $t_{l.t}$ respectively: functioning period until the first repair; period between the repair and total functioning life, are expressed by the corresponding expressions of distribution density *f(t), g(t)* and $f_{l.t}(t)$, varying in function of the machine age. In studied renewing process, the distribution densities are different.

Planning the servicing works in function of the technical state of machines requires the knowledge of the technical state, during the preceding exploitation periods (history of machines) stating with t_0, taken as beginning of exploitation.

On fig.1 is shown the variation model of the machine technical state in function of exploitation period (in years).

The period lasting δ preceding the observation period must satisfy the following inequality:

$$\delta \geq t_1 - t_0$$

For more accurate calculus results, mainly on the first year of the planned period, it is important to have information on:

a) New machines acquisition;

b) The distribution of functioning times in the interval preceding lasting δ, as well as for each moment of period $\Delta = t_2 - t_1$. Any machine put in exploitation before will be, at time t_1, out of use and will not influence the number of repairs.

In the practice, it is recommended to determine the repair volume only at the moment t_2, that is at the end of the last year of the planed period t_k.(fig.1). For this, we must have the following basic data:

1) The number of machines supplied in a year; given in the form of the function V(t) or in a table form;
2) The variation of the distribution densities parameters *f(t), g(t)*; the total or annual working lapses during all the period t_k depending on the machines beginning time of exploitation. Because of the quality improvement of newly installed machines, these parameters vary only in certain intervals. For this purpose, we must decompose t_k in *m* intervals in which the parameters of all the distribution are taken as constants.

2. Basic formulas

We recall some formula of the renewing theory that will be used in this article.

1) The renewing density, or repair means (breakdowns) of machines per time unit at the moment t, in the case where $f(t) \neq g(t)$ is written:

$$h(t) = f(t) + \int_0^t g(t-\tau)h(\tau)d\tau \text{ Where } 0 \le \tau \le t \quad (1)$$

2) The number of machines in the system at the moment t is expressed by the availability function and is determined by:

$$N(t) = n_0 Q_{l.t}(t) + \int_0^t V(t-\tau)Q_{l.t}(\tau)d\tau \quad (2)$$

Where n_0 - number of machines at the beginning f the exploitation (initial);

$Q_{l.t}(t) = 1 - F_{l.t}(t)$ Life time function of the machine (3)

3) The function $N_{l.t}(t)$ (reject function) which designate the number of machines having used all their resources at the moment t in the system.

$$N_{l.t}(t) = n_0 F_{l.t}(t) + \int_0^t V(t-\tau)F_{l.t}(\tau)d\tau \quad (4)$$

Where $F_{l.t}(t)$ - distribution function of the machine life time $(t_{l.t})$

4) Repair means number of machines during *t* (renewing function).

$$H(t) = n_0 Q_{l.t}(t).h(t) + \int_0^t V(t-\tau).Q_{l.t}(\tau).h(\tau)d\tau \quad (5)$$

3. Research Method

The determination of the necessary repair number to maintain the availability of machines is a function of optimal numbers of $t_{l.t}; t_{t.p}; t_{b.p}$ (respectively: life duration; functioning period until the first preventive repair; period between the preventive repairs) and the variation coefficients of these characteristics which influence considerably on the calculus results.

The mean number of machines which compose the park at the moment t is determined by the availability function *N(t)*. At the beginning t_0 the number of machines is equal to A_0. Each having exhausted all its resources is taken off the exploitation. The intensity to put in reject depends on the value *N(t)* and on the distribution function of the life duration $F_{l.t}(t)$. The relationship between the life duration $(t_{l.t})$, the function *N(t)*, the reject intensity $V_{l.t}(t)$ and the renewing intensity *V(t)* is written:

$$N(t) = A_0 + \int_0^t [V(\tau) - V_{l.t}(\tau)]d\tau \quad (6)$$

et

$$V_{l.t}(t) = f[N(t), t_{l.t}] \quad (7)$$

In order to maintain the required park exploitation level, the number of machines must attain at the moment, t_1 the value A_1 $(A_1 \succ A_0)$. Then $N(t_1) = A_1$ (8)

The exploitation of the machine park equipment shows 2 ways of servicing. The number of machines predicted in the park can be attaining by:

1 The intensive acquisition of new machines, decreasing their life time;

2 The increase of the life time and decrease of the acquisition of the machine number.

The first case permits to diminish the repair number and the exploitation expenses. However the diminishing of the life duration entrains an increase in the acquisition expenses of new machines.

The second case, even if it permits to diminish the expenses for the acquisition of new machines, increases the exploitation expenses and the capital servicing expenses because of the variation of the machines technical characteristics.

On fig.2 the variation of the machines servicing costs in function of the exploitation period. The minimum of the expenses function Φ corresponds to the optimal exploitation duration $t^*_{l.t}$

The costs *Ca* for the acquisition of new machines increase progressively. An important change in the servicing expenses is observed during the exploitation. This one decreases because of new machines acquisition in relation with the increase in the life duration.

We can explain the curves shape by the fact the sum spent for the technical servicing is distributed on a set of several machines newly got from the beginning of the exploitation t_0. Fig.3 represents the variation characteristic of exploitation expenses to maintain the availability of a machine in function of its age. The cascade shape of the curve is linked to different type of repairs. The existence of a form more or less regular of the curve is conditioned by the improving of the quality of servicing and repair.

3.1. Basis and the aim of the optimization.

In the general case the optimisation of the repair periodicity requires the diminishing to a minimum:

- The acquisition expenses of new machines;
- The repair expenses;
- The exploitation expenses
- The probability, so that the number of machines in the park at the moment *t* is equal *N(t)*, must be equal to one.

Let's examine the influence degree of the machines reliability characteristics on the repair frequency. We designate by:

- $f_f(t)$ - Distribution density of the machine functioning time until the first failure;
- $g_f(t)$ - Distribution density of the machine functioning time having got at least one repair;
- $t_{t.f}$, $t_{b.f}$ - Mathematical hope of these two parameters (MTTF and MTBF respectively).

The 2 functions $f_f(t)$ and $g_f(t)$ characterise the functioning without failure until the first repair and between the repairs, respectively. They determine the technical reliability degree of the machine. In this case where there is no preventive servicing, that is for a normal wear process of the machine, the repair intensity depends, at any time, on the functions $f_f(t)$ and $g_f(t)$.

In the case of the existence of a servicing policy, we designate by:

- Distribution density of functioning time before the first preventive repair;
- Distribution density of functioning time between the preventive repairs;
- Mathematical hopes for these 2 parameters.

The distribution shape of the values $f_p(t)$ et $g_p(t)$ doesn't vary with the variation of normalised values $t_{t.p}$ of et $t_{b.p}$.

The machines functioning periods $t_{t.f}$ and $t_{t.f}$ for non planed repairs; as well as $t_{b.f}$ and $t_{b.p}$ for planed repairs are linked to 2 distribution pairs $\lfloor f_f(t);\ f_p(t) \rfloor$ and $\lfloor g_f(t);\ g_p(t) \rfloor$ (see fig.4). we can then, for each pair of distribution and at any moment t, determine the repair probability density of machines which have 3 variants:

- The machine has a failure but the preventive repair periodicity is not yet attained;
- The preventive repair time has arrived before the failure;
- The repair time coincides with the failure.

The dependence between the repair intensity *H(t)* and the unknown values of the machine exploitation characteristics ($t_{t.p}$ et $t_{b.p}$), for known distributions of functioning time without failure (fig.5) is written:

$$H(t) = \left(t, t_{1.t}; t_{b.p}; t_{t.p}; V(t)\right) \tag{9}$$

For the determination of the repairs intensity function *H(t)* we must first write, using the formulas (2) and (5) the distribution density of the machine functioning time until the repair *f(t)* and between the repairs *g(t)* based on:

a) The distribution functions of the functioning time for non planed repairs $F_f(t)$ and $G_f(t)$ and planed $F_p(t), G_p(t)$
b) The given values of these periods variation coefficients $V_{t.p}$ (until the repair) and $V_{b.p}$ (between the repairs);
c) The unknowns values of mathematical hopes of ($t_{t.p}$ and $t_{b.p}$)

Where $V_{t.p} = V_{b.p} = \frac{\sigma_{t.p}}{t_{t.p}} = \frac{\sigma_{b.p}}{t_{b.p}}$ - σ - mean quadratic discard. (10)

To write the expressions of *f (t)* and *g (t)* we must:

1 Give ourselves the discreet values of mathematical hopes of the machine functioning time until the first preventive repairs $t_{t.p_1}$, $t_{t.p_2}$.$t_{t.p_i}$.$t_{t.pk}$. Each value of $t_{t.pk}$ corresponds to a value of $t_{b.pi}$. We suppose that the exploitation reliability in the period before the repairs is tributary of the reliability between the repairs.

2 If the distributions $f_f(t)$ and $g_f(t)$ vary following the normal law with the same values of the variation coefficients between $t_{t.p}$ and $t_{b.p}$, is written under a simpler form and characterise the repair degree. From (10) we obtain:

$$\frac{t_{b.p_i}}{t_{t.p_i}} = \frac{t_{b.f}}{t_{t.f}} = q \text{ Repair coefficient } (q = 0 \div 0{,}95) \tag{11}$$

(For example for $t_{b.p}$ = 7200 h and $t_{t.p}$ = 1200 h → q = 0,6);

3 Knowing the distribution law of $f_f(t)$ and $g_f(t)$ as well as the variation coefficient *V* we can form a pair of distribution functions of the preventive repair time $F_{p_i}(t)$, $G_{p_i}(t)$ for every value of i (i = 1,2,3, k).

4 Knowing the functions, $G_f(t)$ and $F_{p_i}(t)$, $G_{p_i}(t)$ we can determine the distribution functions of the functioning duration until the first repair *f(t)* and between the repairs *g(t)*. In the following way:

$$F(t) = \underbrace{[1 - F_f(t)].F_p(t)}_{F_1(t)} + \underbrace{[1 - F_p(t)].F_f(t)}_{F_2(t)} + \underbrace{F_f(t).F_p(t)}_{F_3(t)} \tag{12}$$

Where:

F1 *(t)* - Probability That During *t* There Won't Be Any Failure And The Machine Won't Need Preventive;;

F2 (t) - Probability that during *t* the failure will take place and won't need a preventive repair;

F3 (t) - Probability that during *t* there will be in the same time failure and preventive repair .

The density distribution *F (t)* is then written:

$$f(t) = [1 - F_f(t)]\, f_p(t) + [1 - F_p(t)] f_f(t) \tag{13}$$

We can determine in the same way G*(t)* and g*(t)*.

$$g(t) = [1 - G_f(t)].g_p(t) + [1 - G_p(t)].g_f(t) \qquad (14)$$

For the calculus of the repair intensity *H(t)* we should include the formulas (13) and (14) in (5) for every value i of $t_{t.p_i}$ and $t_{b.p_i}$ or $t_{t.p_i}$ and q_i .

The intensity *H(t)* depends as well as on life duration values $t_{l.t}$ and the acquisition function *V(t)* see formula (09). These values are considered as important factors influencing on the exploitation cost of machines; that's why the values are tightly linked with the expenses of every type of repair

4. Costs function

The costs function varies in time in function of the servicing types and repair. In the general case the costs function can be presented in the form:

$$D = \Phi(C_r, C_e, C_a) \qquad (15)$$

Where:

C_r - Machines repair expenses;

C_e - Current exploitation expenses;

C_a - Acquisition cost of new machines.

Let's examine each of these expenses.

4.1. Repair expenses of machines

The repair quality coefficient can have several values: $q_1, q_2, \ldots q_j$. In this case the repair intensity $H_{i.j}(t, t_{l.t}, V)$ can be determined as well as for each functioning duration before the preventive repair and for the repair coefficient value q_j. The repair quality influences not only the number of repairs but also the its cost. The relationship between the general revision cost (R.G) of a machine and its repair quality is written

$$Sr_j = Sr(q_j) \qquad \text{Where } j = 1, 2, \ldots..m \qquad (16)$$

The total cost of the machines repairs put in exploitation during the planed period can be presented under the form:

$$Cr_{i.j}(V, t_{1.t}) = \int_{t_0}^{t_1} H_{i.j}(t).Sr_j.e^{-\delta.t}dt \qquad (17)$$

From this fact, the total expenses for the repairs during all the planed period Δ, are determined for *j* – unknown values variants of $t_{t.p}$ and q . Every variant can be considered as a mathematical hope function and of the acquisition function (of renewing) *V(t)*.

The proposed method for the determination of the number and cost of repairs can be applied in this case where the distribution of the functioning duration until the first failure for new machines doesn't vary during all the planed period. This is to optimise the renewing for each assembly of elements, having the same time functioning distributions of the functioning duration without failure until the first breakdown (of MTTF)

4.2. Expenses of exploitation

The current exploitation expenses and their intensity depend on the exploitation duration and of the servicing character.

- The diminishing of these costs is conditioned by the diminishing of the preventive repair duration and by the increase of the expenses for the general revision. Then this increase entrains the increase of the repairs number and the increase of the repairs quality.

- The intensity of these current exploitation expenses $S_e(t)$ depends on the function *N(t)*, of *V(t)* and of the distribution character of the life duration $t_{l.t}$. $S_e(t)$ can be written:

$$S_e(t) = f\left[N(t), V(t), t_{l.t}, t_{t.p}, t_{b.p}, q\right] \quad (18)$$

Every group of machines require, at a given time t, the following exploitation expenses:

$$C'_{e_j}(t, t_{l.t}, V) = \int_0^t S_{e_{i.j}}(\tau).V(\tau).e^{-\delta.\tau}.d\tau \quad (19)$$

Here

$$S_{t_{i.j}}(t) = c(\alpha_1 + 2\alpha_2 t + 3\alpha_3 t^2) \quad (20)$$

Where c, α_1, α_2 - coefficients obtained from the statistics.

The sum of reduced exploitation expenses of machines during all the planed period is written: (the park of machines has been renewed after the moment t_0)

$$C_{e_{i.j}} = \int_{t_0}^{t_1} C'_{e_j}(t, t_{l.t}, V)dt \quad (21)$$

4.3. The expenses of acquisition

The renewing expenses (of acquisition) of machines are expressed by the following difference:

$$C_a = C_n - C_0 \quad (22)$$

With:

$$C_n = \int_{t_0}^{t_1} V(t).S_n(t).dt \quad (23)$$

and

$$C_0 = \int_{t_0}^{t_1} V_c\left[N(t), t_{l.t}\right]S_0\left[t_{l.t}, S_n(t)\right]dt \quad (24)$$

Where: C_n - Acquisition machines cost destined to renew the park during $\Delta = t_1 - t_0$;

C_0 - Residual cost of all the machines. Every machine rejected has a residual cost S_0 which depends, as well as on the acquisition cost of a new machine $S_n(t)$ and on the mean life duration $t_{l.t}$

For precise expenses calculus of renewing expenses it is necessary to determine all the functions involved in the general formula of the renewing costs that is to determine:

V(t) - Machines renewing intensity;
$S_n(t)$ - New machine cost;
$S_0(t)$ - Residual cost;
$V_{l.t}(t)$ - Machines reject intensity.

At the beginning of the planed period t_0 the number of machines acquiesced annually is known. The renewing function is in general an increasing linear function of the type:

$$V(t) = a + bt \quad (25)$$

The variation of a new machine cost is expressed by the formula:

$$S_n(t) = S_{n_0}.e^{-\gamma.t} \quad (26)$$

Where:

S_{n0} - Cost at the moment t_0, γ - normal wear coefficient.

Knowing the function *V(t)* and *S(t)* we can, with the formula (23) determine the acquisition expenses of new machines in function of the coefficients *a* and *b* of the function *V(t)* knowing that S_0 depends on the life duration which can be given under the general form:

$$S_0(t) = \left(d_1 e^{-\lambda . t_{l.t}} + d_2\right) S_n(t) \qquad [27]$$

Where:

λ, d_1, d_2 - Calculus parameters; depending on each particular case.

The reject intensity $V_{l.t}$ is determined by the formula:

$$V_{l.t}(t) = n_0 . f_{l.t}(t) + \int_0^t V(t-\tau) f_{l.t}(\tau) . d\tau \qquad [28]$$

Knowing the functions $V_{l.t}(t)$ and $S_0(t)$, with the formula (24) we can determine the total residual cost of all the machines taken off the exploitation during the planed period. We will determine after the renewing cost *Ca* by the formula (22).

Let's write the reduced expenses function expressing the dependence of each term of unknowns characteristics of the periodicity function and of renewing.

$$\Phi = C_a(V, t_{l.t}) + C_{r_{i.j}}(V, t_{l.t}) + C_e(V, t_{l.t}) \quad \rightarrow \quad \min \qquad [29]$$

For every combination of characters $(t_{l.t}, q)$ the minimum of this function can be found for a corresponding choice of the renewing intensity $V = a + bt$ and of the mean life duration $t_{l.t}$ respecting the condition $N(t_1) = A_1$.

Using this condition, as well as the formulas linking the reliability function *N(t)* with the acquisition of new machines and the reject intensity, we can express the renewing intensity through the initial conditions A_0 and A_1 and the life duration $t_{l.t}$.

$$V = V(A_0, A_1, T_{l.t}, t) \qquad [30]$$

Then the optimisation of the repair periodicity and renewing leads to the determination of optimal values

1. Of the mean life duration $t_{l.t}$;
2. Of the value of mean functioning duration until the first preventive repair $t_{t.p}$
3. Of the repair quality coefficient *q*.

Every value of the quality coefficient is function of the corresponding repair technology, that's why the number of possible values of *q* is not important. The calculus order of the optimal repair, of renewing is the following:

- We give ourselves a value for the quality coefficient q_j (exp. q_1);
- We search for possible values of $t_{t.p}$;
- For every combination $(q_1, t_{t.p})$ let's find the value of $t_{l.t}$ (life duration) for which the cost function takes a minimum value. We redo it again for every value of q_j.
- We retain, then the optimal values of $t^*_{l.t}$, $t^*_{t.p}$, and q^* for which the cost function takes a minimum value

In table 1, are shown the data for the optimisation calculus of the repairs number corresponding to the optimal exploitation period of the machines and between preventive repairs and too the yearly number of machine acquisition during the period from1985 to 2005

Table 1:

Designation	**Values**	**Basic data**
Δ	20	- Planned period duration (year)
A_0	192	- Number of machines at the beginning of the planed period
A_1	250	- Number of machines at the end of the planed period
$t_{l.t}$	20	- Existing mean life duration (year)
V_0	0.2	Variation coefficient of the life duration (existing)
V	0.2	- Variation coefficient of the life duration (planned)
$S_{n.o}$	560000	- Cost of a new machine
C	28800	- Initial value of the current exploitation costs
λ	0.05	- Parameter of the residual cost of the machine
γ	0.32	- Parameter of the moral wear
δ	0.11	- Parameter of costs
d_1 d_2	*0.73* *0.077*	- Parameter of the machine residual cost
α_1 α_2 α_3 α_4 α_5	*1.0* *0* *0.015* *0* *0*	- Coefficient of the exploitation expenses function
S_r	82000	Machine repair cost
t_{tp}	2,5	Mathematical hope of functioning time before preventive repairs
σ_{tp}	0,5	Mean quadratic discrepancy for $t_{t\,p}$ (year)
$t_{t.f}$	2,0	Mathematical hope of functioning time before first failure (year)
$\sigma_{t \cdot f}$	0,4	Mean quadratic discrepancy for $t_{t.f}$ (year)
q	0,6	- repair quality coefficient
$t_{b.f}$	1,5	Mathematical hope for functioning time between failures (year)
$\sigma_{\phi.\beta}$	0,3	Mean quadratic discrepancy for $t_{b.f}$
t_{bp}	1.5	Mathematical hope for functioning time between preventive repair (year)
$\sigma_{\pi\beta}$	0,3	Mean quadratic discrepancy for $t_{b.p}$ (year)

Table 2: Results Calculus

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
$t_{l.t}$ (year)	18	20	22	18	20	22	18	20	22
$t_{b.r}$ (year)	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
ϕ (10^6)	95,1	83,7	74,7	630	594	569	1164	1105	1064
Ca (10^6)	5,82	4,78	3,96	39,7	37,4	35,8	73,3	69,6	67,1
Cr (10^6)	38,7	37,5	36,4	256	241,6	231	473	449	432,5
Ce (10^6)	50,5	41,5	34,3	334,3	315	302,2	617,7	586,4	564,4
N (t)	376	337	307	569	449	365	763	560	423
$N_{l.t}$ (t)	124	86	55	335	216	133	547	347	211
H	1160	1090	1030	3090	2870	2710	5020	4650	4380

Conclusion

The proposed method to determine the necessary volume of repair works during the exploitation process of the equipment of a machine park permits to plan the buying of the exploitation machines and the necessary equipment to maintain the availability of theses machines (spare parts, repair tools…). It also permits:

- To follow the park state evolution;
- To intervene at the right time in order to preserve the reliability and availability of the production equipment;
- To minimise the servicing costs;

Figure 1: Variation model of the machines technical state.

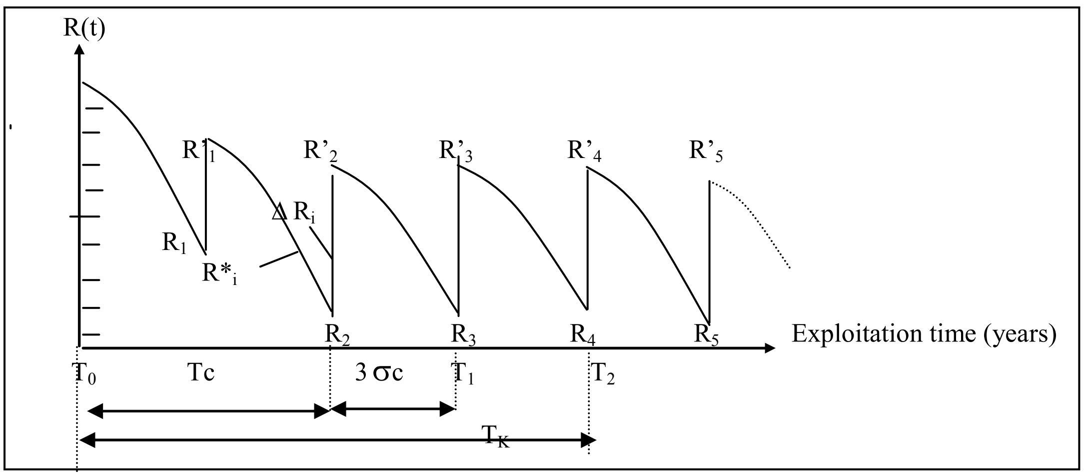


Figure 2: Exploitation costs in function of the servicing periodicity

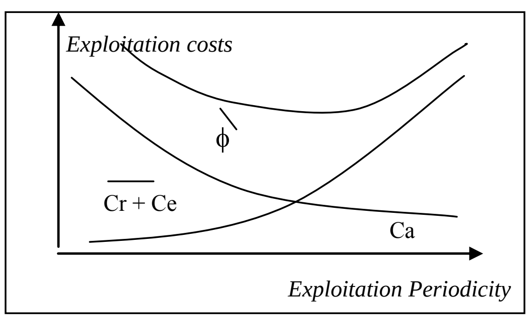


Figure 3: Machine longevity characteristic graph.

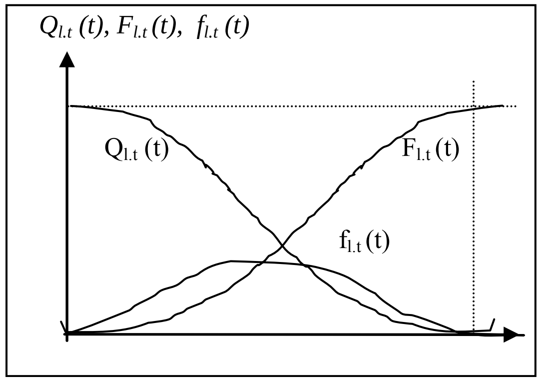
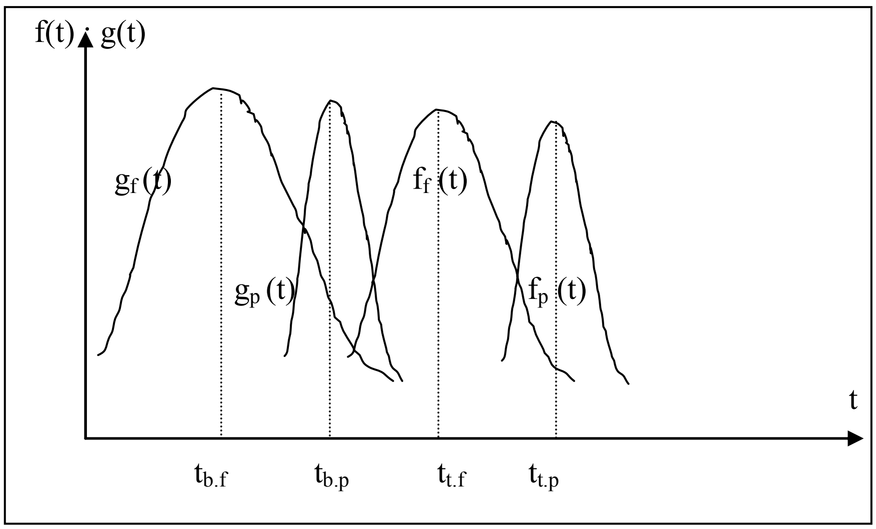


Figure 4: Distribution of functioning time and preventive repair time



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Designation

$V(t)$	–	intensity of a continuous renewal because of the arriving of new machines (Machines renewing intensity).
$t_{t.r}$	-	functioning period until the first repair .
$t_{b.r}$	-	period between repair.
$t_{l.t.}$	-	Life duration (the total functioning life).
f(t), g(t) and fl. t(t)	-	the corresponding expressions of distribution density
$N(t)$	-	The number of machines in the system at the moment *t* .
$F_{l.t}(t)$	-	Function of distribution of the machine life time $(t_{l.t})$
$N_{l.t}(t)$	-	(reject function); designate the number of machines having used all their resources at the moment t in the system.
$H(t)$	–	an average number of repair of machines during *t* (function of renewal).
A_0	-	The number of machines at the beginning. t_0
$V_{l.t}(t)$	-	Intensity of reject.
$t_{t.p}$	-	Functioning period until the first preventive repair.
$t_{b.p}$	-	Period between the preventive repairs.
$f_f(t)$	-	Distribution density of the machine functioning time until the first failure;
$g_f(t)$	-	Distribution density of the machine functioning time having got at least one repairs;
$t_{t.f},\ t_{b.f}$	-	Mathematical hope of these two parameters (MTTF et MTBF respectively).
$f_p(t)$	-	Distribution density of functioning time before the first preventive repair;
$g_p(t)$	-	Distribution density of functioning time between the preventive repairs;
$t_{t.p}, t_{b.p}$	-	Mathematical hopes for these 2 parameters.
Cr	-	Expenses of repair of the machines;
Ce	-	Expenses of exploitation;
Ca	-	The costs for the acquisition of new machines;
$S_n(t)$	-	New machine cost;
$S_0(t)$	-	Residual cost;
$V_{l.t}(t)$	-	Machines reject intensity.
$F_f(t);\ G_f(t)$	-	The distribution functions of the functioning time for non planed repairs;
$F_p(t) G_p(t)$		The distribution functions of the functioning time for planed repairs;
$V_{t.p}$	-	Coefficient of variation until the repair;
$V_{b.p}$	-	Coefficient of variation between repairs.