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MAINTENANCE MODELS APLICABLE TO THE REMOTE CONTROLLED SYSTEMS

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ABSTRACT: *The paper presents the total replacement maintenance models in the case of the remote control systems. The author describes the mathematical models of the total replacement maintenance models and finally two study cases are presented. Total replacement maintenance models could be used to achieve the full readiness status of the remote control systems from the inventory. Thus in order to ensure the operational efficiency of the technical systems these models could contribute at the problem of solving of an increased number of requirements with reduced resources.*
KEYWORDS: *Total replacement maintenance, reliability, remote control system*

INTRODUCTION

In classic total replacement models [4] we assume that the equipment is always replaced completely, the replacement is done instantaneously, consumes no time, and the equipment failure is detected as soon as the failure takes place.

There are two types of replacement options:
- *Preventive replacement (RP). Is conducted on a preventive maintenance policy;*
- *Corrective replacement (RC). Is conducted after the equipment failure.*

Basic total replacement models normally consider the following preventive replacement policies:
- *Constant interval replacement. Replacement is done after a certain constant time interval;*
- *Age based replacement. Replacement is done when the equipment reach a certain operating time/age.*

TOTAL REPLACEMENT MAINTENANCE MODELS – CONSTANT TIME INTERVAL REPLACEMENT

Replacement is done after the occurrence of the failure or after a certain constant time interval t_p (Figure 1).

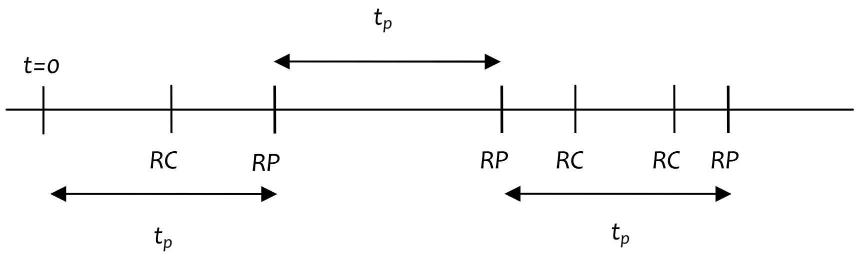

Figure 1. Constant Time Interval Replacement Maintenance

The model is built to determine the optimal time interval between two preventive replacements. The optimization criterion is to minimize the total expected cost per unit time. The notation that will be used is presented in Table no.1.

Table 1. Notation

Measure	Significance
Cp	Preventive replacement unit cost
Cc	Corrective replacement unit cost
t_p	Preventive replacement time
F(t)	Time to failure probability distribution function
R(t)	Reliability
f(t)	Time to failure probability density function
$\lambda(t)$	Failure rate
$N(t_p)$	Expected number of failures within the time interval (0,tp)
$CTU(t_p)$	Total expected cost per unit time.

If a failure is produced, within the time interval $[0, t_p]$, the total expected cost per unit time $CTU(t_p)$, for the interval t_p, will be as follows [2]

$$CTU(t_p) = \frac{CTU(0,t_p)}{Lungimea(0,t_p)} = \frac{C_p + C_c N(t_p)}{t_p} \tag{1}$$

It is known that the expected number of failures within the time interval $[0,t_p]$ is given by [4]

$$N(t_p)=\int_0^{t_p}\lambda(t)dt \tag{2}$$

where $\lambda(t)$ is the failure rate.

The failure rate is given by

$$\lambda(t)=\frac{f(t)}{R(t)} \tag{3}$$

The relation calculus between F(t) and R(t) is given by

$$F(t)=1-R(t) \tag{4}$$

The time to failure probability distribution function F(t) is given by

$$F(t)=\int_0^{t} f(t)dt \tag{5}$$

PREVENTIVE AGE BASED REPLACEMENT

In this case, the preventive replacement is done after the system/equipment functioned a certain operating time/age, t_p (Figure 2). In case of the system/equipment failure a corrective replacement is done and the next preventive replacement is scheduled after t_p units of time. The objective is to calculate the optimum t_p which minimizes CTU(tp).

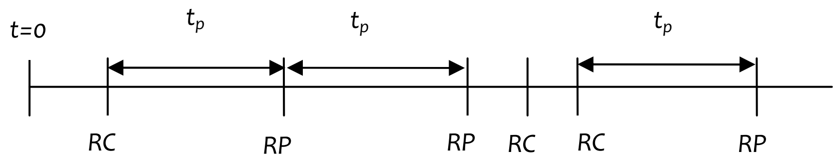

Figure 2. Preventive Age Based Replacement Maintenance

The time the equipment could reach the preventive replacement time is t_p. This will happen with a probability equal to $R(t_p)$, or fail before that time, with a probability equal to $F(t_p)$.

The expected cost for the interval $(0,t_p)$ is now equal to $C_pR(t_p)+C_cF(t_p)$, and the expected length of the cycle is equal to t_p times the probability of the preventive cycle $R(t_p)$, plus the expected length of the failure cycle times the probability of the failure $F(t_p)$.

The length of the failure cycle can be estimated as follows [2]

$$TD(t_p)=\frac{\int_0^{t_p} tf(t)dt}{F(t_p)} \tag{6}$$

The total expected cost per unit time $CTU(t_p)$, for the interval t_p, will be as follows [2]:

$$CTU(t_p)=\frac{C_pR(t_p)\ +C_cF(t_p)}{t_pR(t_p)+TD(t_p)F(t_p)} \tag{7}$$

Case Study 1 – Input Data

In order to present the application of the above mentioned model we consider the case of a remote control system (Figure no. 3) which is designed to equip the armored vehicles. The main components of the remote control system are presented in Table no. 2.

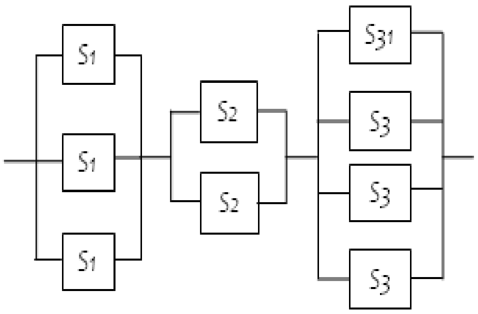

Figure 3. A schematic view of the remote control system

Table 2- Main components of the remote control system

No.	System	Subsystem
1	Operational control system (S1)	Target tracking system (S11)
		Computing system (S12)
		Driving gear system of the operational control system (S13)
2	Main system (S2)	Acting component (S21)
		Feeder (S22)
3	Command and control system (S3)	Acquisition data module from operational control system (S31)
		Acquisition data module from main system (S32)
		Acquisition data module from electrono-optic system (S33)
		Integration/processing/command module at system level (S34)

The failures occurred within the interval [0,27] as well as the calculus in order to obtain the time to failure probability density function f(t) are presented in the Table 3. Thus will be obtained

$$f(t) = \frac{1}{27}, \quad \text{pentru} \quad 0 \le t_p \le 27$$

Table 3. Failures of the remote control system

Periods	Failure/ Fire control system	Failure/ Main system	Failure/ Command and control system	Total	f(t)
1	1/S13	1/S22	1/S31; 1/S34	4	4/108=1/27
2	1/S11;1/S13	1/S21	1/S34	4	4/108=1/27
3		1/S21;1/S22	1/S32;1/S33	4	4/108=1/27
4	1/S12		1/S31;2/S32	4	4/108=1/27
5	1/S13;1/S12		1/S32;1/S34	4	4/108=1/27
6	1/S11	3/S22		4	4/108=1/27
7	1/S13	2/S21	1/S32	4	4/108=1/27
8		2/S22	1/S32;1/S34	4	4/108=1/27
9		2/S21;2S22		4	4/108=1/27
10		2/S22	2/S34	4	4/108=1/27
11	1/S13;1/S11	1/S22	1/S34	4	4/108=1/27
12	1/S13;1/S11	1/S22	1/S34	4	4/108=1/27
13	1/S13;1/S11	1/S22	1/S34	4	4/108=1/27
14	2/S13		2/S34	4	4/108=1/27
15	1/S13	2/S22	1/S34	4	4/108=1/27
16	2/S13	1/S22	1/S34	4	4/108=1/27
17	1/S13		3/S34	4	4/108=1/27
18	1/S13;2/S11		1/S34	4	4/108=1/27
19	3/S13		1/S34	4	4/108=1/27
20	2/S13	1/S22	1/S34	4	4/108=1/27
21	1/S13	1/S22	2/S34	4	4/108=1/27
22	1/S13	2/S22	1/S34	4	4/108=1/27
23	3/S13		1/S34	4	4/108=1/27
24	1/S13		3/S34	4	4/108=1/27
25	1/S13	1/S21;1/S22	1/S34	4	4/108=1/27
26	1/S13	2/S22	1/S34	4	4/108=1/27
27	2/S13		2/S34	4	4/108=1/27
Total				108	1

It is assumed that the values of the replacement maintenance costs are C_c=300 monetary units respectively C_p=90 monetary units.

OUTPUT DATA

The goal is to compute the optimum time t_p in order to minimize the total expected cost per unit time $CTU(t_p)$ for the maintenance of the system/equipment in the case of the Constant Time Interval Replacement policy utilization.

The expected number of failures for the time interval t_p is given by

$$N(t_p) = \int_0^{t_p} \lambda(t)dt = \int_0^{t_p} \frac{f(t)}{1-F(t)}dt$$

Thus after the integration the expected number of failures will be

$$N(t_p) = \int_0^{t_p} \lambda(t)dt = \int_0^{t_p} \frac{f(t)}{1-F(t)}dt = \ln\frac{27}{27-t_p}$$

where

$$F(t) = \int_0^t f(t)dt = \int_0^t \frac{1}{27}dt = \left|\frac{t}{27}\right|_0^t = \frac{t}{27} - \frac{0}{27} = \frac{t}{27}$$

The total expected cost per unit time $CTU(t_p)$, for the interval t_p, is defined by

$$CTU(t_p) = \frac{C_p + C_c N(t_p)}{t_p} = \frac{90 + 300\ln\frac{27}{27-t_p}}{t_p}$$

Based on the values of the $CTU(t_p)$, where t_p belong the interval [1, 27], is obtained the graphic representation from Figure 4.

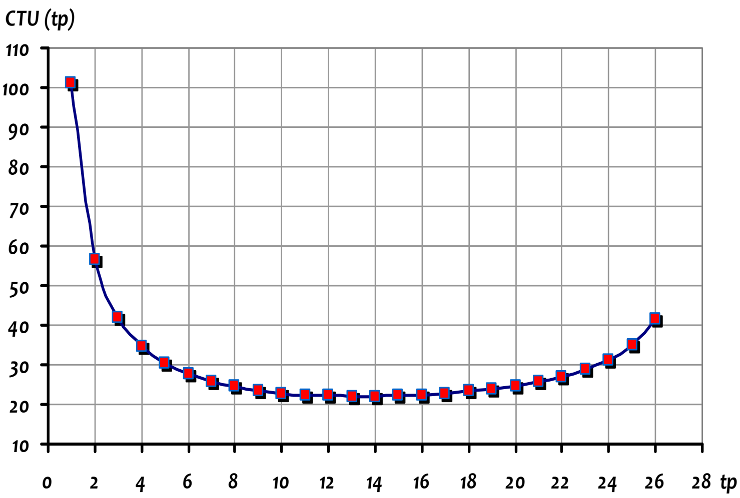

Figure 4. Constant Time Interval Replacement Maintenance

The minimum value for $CTU(t_p)$ is obtained for t_p=13 months with a value CTU(13)=22.07 monetary units per month.

CASE STUDY 2 – INPUT DATA

Will be used the same input data like in the Case study 1.

OUTPUT DATA

The goal is to calculate the optimum t_p which minimizes $CTU(t_p)$.

The length of the failure cycle can be estimated as follows

$$TD(t_p) = \frac{\int_0^{t_p} tf(t)dt}{F(t_p)} = \frac{\int_0^{t_p} t\frac{1}{27}dt}{\frac{1}{27}t_p} = \frac{t_p}{2}$$

The total expected cost per unit time $CTU(t_p)$, for the interval t_p, is defined by

$$CTU(t_p)=\frac{90\left(1-\frac{1}{27}t_p\right)+300\frac{1}{27}t_p}{t_p\left(1-\frac{1}{27}t_p\right)+\frac{t_p}{2}\frac{1}{27}t_p}=\frac{90+\frac{210}{27}t_p}{t_p-t_p^2\left(\frac{1}{54}\right)}$$

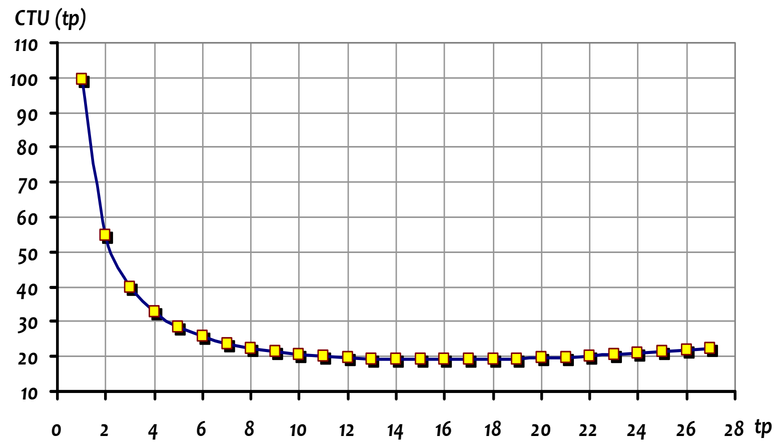

Figure 5. Preventive Age Based Replacement Maintenance

Based on the values of the $CTU(t_p)$, where t_p belong the interval [0, 27], is obtained the graphic representation from Figure 5.

The minimum value for $CTU(t_p)$ is obtained for t_p=16 months with a value CTU(16)=19.04 monetary units per month.

CONCLUSIONS

The paper introduces and applies the models for the total replacement maintenance of the remote control systems in order to be used at the optimization of the decisions in that field. These can be applied to the remote control systems with fixed mission lengths and limited time between missions for maintenance. The calculus examples emphasized strong points and weak points of the presented methods as follows:

- *in the case of Constant Time Interval Replacement Maintenance if the failures number is high it is possible to conduct some preventive replacements when the operating time of the system/equipment is less than t_p .These will influence the efficiency of the maintenance policy in terms of technical, operational and economical aspects.*
- *in the case of Preventive Age Based Replacement Maintenance it is possible to ensure flexibility in terms of achieving the readiness status of the system/equipment with reduced costs.*

The models for the total replacement maintenance concept could contribute to the enhancement of the remote control system performances as well as to the cost reducing during the life cycle system belonging to the current inventories.

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