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DETERMINISTIC FAILURE RATE MODEL FOR THE ASSESEMENT OF THE RELIABILITY IMPACT ON THE LIFE CYCLE COST ANALYSIS APPLICABLE TO THE COMPLEX TECHNICAL SYSTEMS

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Abstract: *The paper presents the mathematical apparatus of the deterministic failure rate model as well as a study case consisting in its application to the specialized wheeled vehicle systems. Deterministic failure rate model could be used to asses the achievement the full readiness status of the specialized wheeled vehicle systems from the inventory. Thus in order to ensure the operational efficiency of the technical systems this model could contribute at the problem of solving of an increased number of requirements with reduced resources.*
Key words: *Deterministic failure rate model, reliability, specialized wheeled vehicle systems.*

1. INTRODUCTION

A technical system is "reliable" when it is able to accomplish its function in a secure and efficient way throughout its life cycle. Thus the key aspect of the term reliability is related to the operational continuity.

When a technical system begins to be affected by a large quantity of accidental failure events (low reliability), this scenario causes high costs, associated mainly with the recovery of the function (direct costs) and with growing impact in the operational process (penalization costs).

The total costs of non-reliability [6,12] can be characterized as follows:

- costs for penalization regarding the downtime (operational losses, impact on quality, impact on security and environment).
- costs for corrective maintenance:
  - manpower: direct costs related with the manpower in the event of an unplanned action;
  - materials and replacement parts: direct costs related to the consumable parts and the replacements used in the event of an unplanned action.

In the technical literature [2] are presented three basic models related to the non- reliability cost within the life cycle cost analysis (LCCA): constant failures rate, deterministic failures rate and Weibull distribution failures rate. These models include in their evaluation processes the quantification of the impact that could cause the diverse failure events in the total costs of a production asset.

In the followings will be presented the deterministic failures rate model and its application to the case of the specialized wheeled vehicle systems.

2. DETERMINISTIC FAILURE RATE MODEL

The deterministic failures rate model proposes the following steps [5]:

1. Define the system/equipment to be evaluated;
2. Identify the possible alternatives that will cover the operational requirements for the evaluated systems;
3. Define, for each alternative, the detailed cost structure. The method classifies the costs in five categories:
   - Research and development costs;

- Construction and production costs;
- Preventive maintenance costs;
- Corrective maintenance cost: costs for non-reliability;
- Disassembly / withdrawal costs.

4. Quantify, for each alternative, the costs for each one of the defined categories;
5. Identify, for each alternative, the factors with higher cost contribution per cost category;
6. Propose strategies, for each alternative in order to minimize the impact on cost of the selected factors;
7. Quantify, for each alternative, the total costs, in annual equivalent value for a discount rate *i* and a number of years of expected service *t*;
8. Select the alternative that generates the lowest costs throughout the system/equipment expected useful life period.

This method is based on the followings characteristics:

- the total cost is estimated in equivalent annual values;
-the frequencies of failures may vary, in a deterministic way, for the different periods of time of the system/equipment life cycle.

In order to quantify the costs of non-reliability, this model proposes to evaluate the impact of the failures as follows:

1. Identify, for each alternative, the main failure modes *f* where *f=1…F*, for *F* failure modes;
2. Define, in a deterministic way and for each failure mode, the expected frequency of failures $\delta_f^{\,t}$ for the year *t*. The frequency of failures per year is considered deterministic, due to the fact it is defined starting from failures records, databases and/or experience of maintenance and operations personnel.
3. Calculate the failures cost C_f (in monetary units/failure). These costs include: costs of replacement parts, manpower, production loss penalization and operational impact;
4. Calculate the costs per failure mode per year CP_f^t [2]

$$CP_f^{\,t} = \delta_f^t C_f \qquad (1)$$

5. Convert, to present value, the costs for failure type per year $NPV(CP_f^t)$. Given a future value CP_f^t, the present value is calculated for every year (*t*) to a discount rate and for a specific period of time [2]:

$$NPV(CP_f^{\,t}) = CP_f^{\,t}\,\frac{1}{(1+i)^t} \qquad (2)$$

6. Calculate the total costs per failure in present value $NPV(TCP_f^t)$. All the costs for failure types, in present value, are added until the expected number of years of useful life (T) [2]:

$$NPV\left(TCP_f^t\right) = \sum_{t=1}^{T} NPV\left(CP_f^t\right) \qquad (3)$$

7. Calculate the annual equivalent total cost *AETC*. Given a present value $NPV(TCP_f^t)$, calculate its annual equivalent total cost *AETC* for the expected number of years of useful life T and the defined discount rate *i* [2]:

$$AETC = NPV\left(TCP_f^t\right)\frac{i(1+i)^T}{(1+i)^T - 1} \qquad (4)$$

Finally, the rest of the evaluated costs (investment, planned maintenance, operations, *etc*.) are added to the cost calculated by non-reliability, and the total cost is calculated in annual equivalent value. The result obtained is then compared for the different options.

3. CASE STUDY

INPUT DATA

In the present study case will be applied the above presented method in order to analyze the costs generated by the low reliability of a specialized wheeled vehicle system (Figure 1). The main components of the system are presented in Table 1.

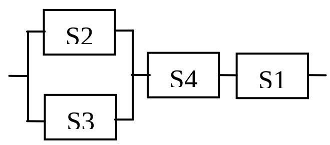

Figure 1. A schematic view of the specialized wheeled vehicle system

Table 1. Main components of the specialized wheeled vehicle system

System	Destination
S1	Vehicle platform

S2	Communication and information system
S3	Electrono-optic system
S4	Software interface system

The expected failures frequencies for a year is defined based on the recorded statistics data. (Table 2)

Table 2. The expected failure frequency

An	*S1*	*S2*	*S3*	*S4*	δ_f^t failures/year
1	1	1			2
2		1	1	1	3
3	1	1		1	3
4		1		1	2
5	1		1	1	3
6	1	1	1	1	4
7	1			1	2
8	1		1	1	3
9		1	1		2
10		1	1	1	3

OUTPUT DATA

The model proposes for the assessment of the failures impact the followings:

- Calculate the failures cost C_f (monetary units/failure)

C_f=1000 monetary units/failure

- Calculate the costs per failure mode per year CP_f^t (equation *1*)
- The values of CP_f^t for a 10 years expected useful life are presented in Table 2.
- Convert, to present value, the costs for failure type per year $NPV(CP_f^t)$ (equation *2*)

The present value is calculated for every year (*t*) for a discount rate *i=9%*. The results in present values are shown in Table 2.

Table 2. The present values of the costs for failure type per year $NPV(CP_f^t)$

An	CP_f^t	$1/(1+0.9)^t$	$NPV(CP_f^t)$
1	2000	0.917431193	2180
2	3000	0.84167993	3564.3
3	3000	0.77218348	3885
4	2000	0.708425211	2823.16
5	3000	0.649931386	4615.87
6	4000	0.596267327	6708.4
7	2000	0.547034245	3656
8	3000	0.501866279	5977.68
9	2000	0.460427779	4343.786
10	3000	0.422410807	7102.09

- Calculate the total costs per failure in present value $NPV(TCP_f^t)$, using equation 3. All the costs for failures types in present value are added for the expected years of useful life *T=10* years:

$NPV(TCP_f^t)$= 44856.28 monetary units

- Calculate the annual equivalent total cost *AETC*, using equation 4, for the expected years of useful life *T=10* years and the discount rate *i=9%*

$$AETC = 44856.28 \frac{0.09(1+0.09)^{10}}{(1+0.09)^{10}-1}$$

$$AETC = 6989.59 \quad monetary \quad units \ / \ year$$

4. CONCLUSIONS

The deterministic failure rate model could contribute to the enhancement of the specialized vehicle systems performances by diminishing the uncertainty within the process of total life cycle cost estimation.

The calculus example emphasized the strong points and weak points of the presented method as follows:

- the obtained annual equivalent total cost, represent the mean value of money that will be needed every year to pay for the problems of failures, during the 10 years of expected useful life, with a discount factor of 10%. The frequency of failures varies every year throughout the expected cycle of useful life.

- this method demands that the designer identifies failure frequency behavior patterns.

The main limitation of this model is related to the process of failure frequency information gathering. It is important that this information is based on suitable historical records and well sustained statistical databases.

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MODEL CU RATA DE DEFECTARE DETERMINISTĂ PENTRU EVALUAREA IMPACTULUI FIABILITĂȚII ASUPRA ANALIZEI COSTULUI PE DURATA DE VIAȚĂ APLICABIL SISTEMELOR TEHNICE COMPLEXE

Lucrarea prezintă aparatul matematic al modelului cu rata de defectare deterministă precum şi un studiu de caz prin care acest model a fost aplicat unui sistem complex de tip vehicul specializat pe roți. Modelul cu rata de defectare deterministă se poate utiliza pentru evaluarea obținerii unei operativități ridicate pentru sistemele complexe de tip vehicul specializat pe roți. Astfel pentru a se asigura eficiența operațională a sistemelor tehnice acest model poate contribui la rezolvarea unui număr ridicat de cerințe cu resurse limitate.

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