OPERATIONAL ENTROPY, A CRITERIA FOR TECHNICAL EQUIPMENTS MAINTENANCE

CÂRLAN M.*, CSUZI. I.**, COSTEA M.***
* S.C. Formenerg S.A,
** S.C. Oradea Transport Local S.A,
*** Lumina -The University of South- East Europe
marius.costea@lumina.org

Abstract – This paper is presenting a method used to confirm the necessity of practicing maintenance works for two vehicles, tramways, whose operational statuses, defined by the levels of exploitation parameters, proved to be in precarious condition. Wear and tear has been the main cause leading to the occurrence of unnumbered moments when the vehicles were unavailable. Studies performed on data collected during a compelling enough period of time are highlighting, a tendency to increase the failure frequency with more than 10%. The wear and tear of the analyzed technical equipment is expressed by the status probabilities that are related to a later moment, and determined by using Markov chain theory, and entropic level - unit of measure for incertitude or chaos - phenomenons that are specific for system degradation - to be determined based on Shannon entropy concept[7],[11]. Based on these two sizes, the decision-maker may impose the optimal strategy regarding the maintenance works practice.[1]

Keywords: conditional probabilities, transition probabilities from one status to another, stochastic matrix, dynamic matrix, entropy.

1. INTRODUCTION

It is considered a compelling volume data sample, containing $n \geq 30$ elements, in order to obtain an efficient representativeness level [5], [10]. Depending on the temporal evolution of an equipment, from its functional status, O, to the out of order status F, the status probabilities that are associated with that particular event are determined . $p_O^{(0)}$, $p_F^{(0)}$ at the initial moment (0):

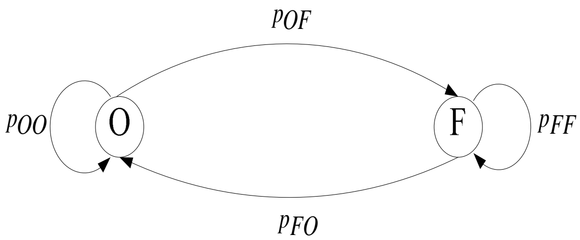

Fig. 1 - Graph transition probabilities of a technical entity

Further we consider the technical equipments that can be repaired: the equipment that is in functional status (O) is passing, after a certain cycle of statuses (F), in the out of order status (F); it is fixed (the damage which occurred is fixed) and it returns to the initial functional status (O). It is obvious that the cycle is repeating until that equipment, becoming unfixable, is put out of action. Table 1 presents the transition probabilities, concerning the evolution of a fixable technical system, during a T period of time.

Table 1. The transitions probabilities

State		O		O	
		f	p	f	p
O	followed:	n_{OO}	p_{OO}	n_{OF}	p_{OF}
F		n_{FO}	p_{FO}	n_{FF}	p_{FF}

In this table:

O, F - the two temporal evolution statuses of the technical system;

$n_{OO}, n_{O,F}, n_{FO}, n_{F,F}$ - the transition frequencies from a status to another;

$p_{OO}, p_{O,F}, p_{FO}, p_{F,F}$ - the corresponding transition inter-statuses probabilities.

The status probabilities for time (0) are determined based on the following relations:

$$p_O^{(0)} = \frac{n_O}{T} \quad (1)$$

$$p_F^{(0)} = \frac{n_F}{T}, \quad (2)$$

where:

n_O, n_F - the number of times when the equipment's status was functional(O) respectively in the out of order status (F);

T - the benchmark length of time.

Obviously,

$$T = n_O + n_F . \quad (3)$$

The calculation of the status probabilities, at a future time (later moment), is made using some theory elements from "Markov chains", as it follows [3], [4], [6], [8], [12]:

- the transition probabilities matrix (stochastic matrix) [M] is determined:

$$[\mathrm{M}] = \begin{bmatrix} p_{OO} & p_{OF} \\ p_{FO} & p_{FF} \end{bmatrix} \qquad (4)$$

- the unit-matrix [I] is considered:

$$[\mathrm{I}] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (5)$$

- resulting the dinamic matrix [D]:

$$[\mathrm{D}] = [\mathrm{M}] - [\mathrm{I}] \qquad (6)$$

The status probabilities values in the established regime of the ergodic system, $p_O^{(\mathrm{F})}$, $p_F^{(\mathrm{F})}$ are resulting from solving the following equation system:

$$\begin{cases} (\mathrm{p}_{OO}-1)\,\mathrm{p}_O^{(\mathrm{f})} + p_{FO}\cdot p_F^{(\mathrm{f})} = 0 \\ p_{OF}\cdot p_O^{(\mathrm{f})} + (\mathrm{p}_{FF}-1)\,\mathrm{p}_F^{(\mathrm{f})} = 0\,. \\ p_O^{(\mathrm{f})} + p_F^{(\mathrm{f})} = 1 \end{cases} \qquad (7)$$

For solving this system containing three equations and two unknowns, there are used one of the first two equations (*) or (**) and the equation (***).

It results:

$$p_O^{(\mathrm{f})} = \frac{p_{FO}}{p_{FO} + p_{OF}} \qquad (8)$$

$$p_F^{(\mathrm{f})} = \frac{p_{OF}}{p_{FO} + p_{OF}} \qquad (9)$$

The entropy associated with the status probabilities $p_0^{(0)}, p_F^{(0)}, p_0^{(\mathrm{F})}, p_F^{(\mathrm{F})}$) is resulting from the relation:

$$H = -\frac{1}{\ln 2}(\mathrm{p}_O \cdot \ln \mathrm{p}_O + \mathrm{p}_F \cdot \ln \mathrm{p}_F) \qquad (10)$$

Entropy's evolution depending on the probability is presented in the figure 1.

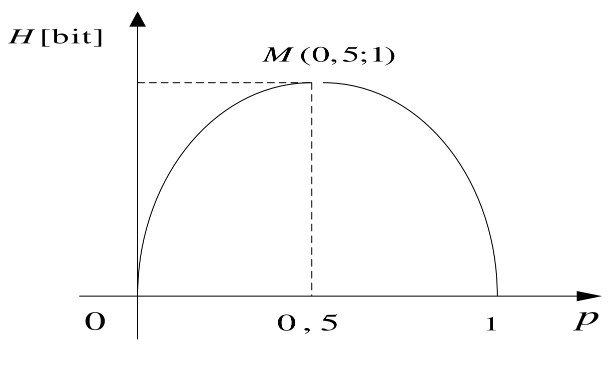

Fig. 2 - The graph of the function H=f(p)

2. CASE STUDY

Table two presents the temporal evolution of two trams within the company S.C. Oradea Transport Local S.A., during a period of time T= 200 consecutive days. It results that the status probabilities in the initial moment(0), for the two entities E1, E2, according the relations (1), (2), or,

$$p_O(\mathrm{o}) = \frac{n_O}{n_O + n_F} \qquad (11)$$

$$p_F(\mathrm{o}) = \frac{n_F}{n_O + n_F} \qquad (12)$$

Table 2. Temporal evolution of the tramways

i	E_1		E_2		Observations
	State		State		
1	O	-	O	-	
2	-	F	.	.	
3	O	-	.	.	
4	O	-	.	.	
5	-	F	.	.	
6	O	-	.	.	
7	-	F	.	.	
8	O	-	.	.	
. . .	. . .	. . .	. . .	. . .	
150	O	-	O	-	
151	-	F	-	F	*
152	F	-	O	-	
153	F	-	O	-	
154	-	F	O	-	
155	-	F	-	F	*
156	O	-	-	F	
157	O	-	-	F	
158	-	F	-	F	*
159	O	-	O	-	
160	O	-	O	-	
161	-	F	.	.	
162	O	-	.	.	
163	O	-	.	.	
164	-	F	.	.	
165	O	-	.	.	
166	-	F	.	.	
167	-	F	-	.	
168	O	-	O	-	
169	-	F	-	F	*
170	-	F	-	F	*
171	O	-	-	F	
. . .	. . .	. . .	O	-	
197	. . .	. . .	. . .	- - -	
198	O	-	-	F	
199	-	F	O	-	
200	O	-	-	F	

According both to the information presented in the previous table and to the relations (1) and (2), the status probabilities are obtained for the time (0), for each of the equipments - table 3:

Table 3. The status probabilities

E_k	$p_O^{(0)}(E_k)$	$p_F^{(0)}(E_k)$
E_1	0,93	0,07
E_2	0,95	0,05

Following the formerly provided calculation itinerary, the transition probabilities resulting are: $p_{OO}, p_{O,F}, p_{FO}, p_{F,F}$ table 4 and table 5 for these equipments:

Table 4. The transitions probabilities for E_1

State		O		F	
		f	p	f	p
O	followed:	174	0,94054	11	0,05946
F		11	0,78571	3	0,21429

Table 5. The transitions probabilities for E_2

State		O		F	
		f	p	f	p
O	followed:	185	0,97368	5	0,02632
F		4	0,44444	5	0,55556

Table 6 is presenting the probabilities' values in stabilized regime - the values are determined according to the equations system (7) or relations (8) and (9). There are also showed the percentage variations $\Delta p_O^{(-)}$, $\Delta p_F^{(+)}$ corresponding to the two technical entities.

Table 6. The probabilities' values in stabilized regime

E_k	Probabilities				Variation (%)		Observations
	Moment (0)		Moment (f)				
	State				$\Delta p_O^{(-)}$	$\Delta p_F^{(+)}$	
	O	F	O	F			
E_1	0,93	0,07	0,929	0,07	0,038	0,5	Slow degradation
E_2	0,95	0,05	0,932	0,067	1,873	35,58	Rapid degradation

An accelerated state of decay is noticed to the entity E2 operational potential, despite that in the time (0) the functioning probability percentage was superior compared to entity E1, with 2,15%. This functional depreciation will also be confirmed by the temporal evolution of the entropy - table 7.

The quantities $\Delta H^{(+)}$ is representing entropy's increase expressed in percentages.

Table 7. the temporal evolution of the entropy

E_k	H[bit]		$\Delta H(+)$	Observations
	Moment (0)	Moment (f)		
E_1	0,3655	0,3672	0,47	Slow degradation
E_2	0,2863	0,35762	24,89	Rapid degradation

3. CONCLUSION

E_2 entity's operational status, despite that in the beginning it outclassed the functionality level of E_1, the statistic protocol performed during a length of time T = 200 days, proved an intense-regressive evolution mode and the perspective of an advanced operational degradation. In this case, the deciding factor may decide between the following options:

- a major renewal (restoration) followed by a preventive verification regime type ERP (Eventual Replacement Policy [2], [9]);
- a temporary decommission, aiming to bring, eventually, a new technology (modernisation) for this tram. Obviously, a cost effective calculation, justified in terms of the conditions the unit is disposing of, will establish the best solution, whose opportunity is satisfying the beneficiary unit requirements.

REFERENCES

[1]. Ackoff, R.L., Sasieni, M.V. – Bazele cercetării operaționale (traducere din limba engleză), Editura Tehnică, București, 1975

[2]. Cătuneanu, V., Mihalache A.– Bazele teoretice ale fiabilității, Editura Academiei Române, București, 1983

[3]. Cârlan, M., – Probleme de optimum în ingineria electrică, Editura Academiei Române, Bucureşti, 1994

[4]. Cârlan, M., Demeni, I., Blaga, A. –Un model stochastic în mentenanță, Revista Tehnologiile Energiei, București, 2006.

[5]. Ciucu, G., Craiu V., Stefanescu A.– Statistică matematică și cercetari operationale. Editura Didactică și pedagogică, București, 1974

[6]. Csuzi, I.– The Life Cycle Cost Management Aspects of Maintenance in Public Transport System , Editura Științifică, București, 1968

[7]. Georgescu-Roegen, N. – Legea entropiei și procesul economic (traducere din limba engleză), Editura Politică, București, 1979

[8]. Kaufmann, A.- Metode și modele ale cercetării operaționale, vol 1. (traducere din limba franceză), Editura Tehnică, București, 1968.

[9]. Lyonnet, P. – La maintenance. Mathématiques et méthodes, TEC-DOC, Londres-New York, 1992

[10]. Onicescu, O., Ștefanescu, V.- Elemente de statistică informațională, Editura Tehnică, București, 1979

[11]. Silețchi, M., Lascu, A.- Informația, entropia și procesele economice. Editura Academiei Române, Bucureăti, 1978

[12]. Târcolea, C., Filipoiu, A., Bontaș, S. – Tehnici actuale în teoria fiabilității, Editura Științifica și Enciclopedică, București, 1989.