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OPTIMIZATION OF THE NUMBER OF EXECUTANS IN MAINTENANCE WORKS

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Abstract One direction in order to improve the maintenance works, integrated in the maintenance strategy focused on reliability, is the optimized configuration of the human resources needed for the maintenance. The operationalization of the criteria: ”minimal total costs” was made by adapting the Monte Carlo simulation method and the expertons method for computing the optimal staff number. Within the article there are presented case studies for the transportation system and preparation of the solid fuel from the termofication electrical power station from Oradea [1-6].

1. INTRODUCTION

The optimum criterion ”total minimum costs” [1,2], that corresponds to a certain number of necessary executing personnel, is established by equation

$$C_t = C_d + D, \tag{1}$$

where: C_t is the total cost - $m.u/t.u$ (monetary units / time units); C_d costs for the payment of existing executing personnel (available) in the maintenance activity - repating of TPSSF, in certain frame of time - $m.u/t.u$; D is the damage inflicted by the absence (lack, unavailable) of a certain number of personnel that does not participate, although it is necessary to perform the work.

For establishing the two components of total costs we use equations

$$C_d = c \cdot M, \tag{2}$$

$$D = q \cdot E(\Delta M), \tag{3}$$

where: c is the average income of an executant (salary, pay rise, bonuses) - $m.u/t.u.$; M is the number of available personnel (that exists in that activity); q the damage inflicted due to the absence of an individual in the production process - $m.u/t.u.$; $E(\Delta M)$ is the average number of personnel deficit 4 (mathematic expectance of shortage - lack of personnel)

$$E(\Delta M) = \sum_{K} \Delta M_K \cdot p_K, \tag{4}$$

where: ΔM_K represents the shortage of personnel in the case that a certain number of personnel is available M_K, and p_K is the probability to have this shortage. Regarding the unit costs q and q, the financial records and other papers recommend using for medium qualification personnel equation

$$q = (2 \div 5)c \tag{5}$$

and equation

$$q = (5 \div 10)c \tag{6}$$

for high qualification personnel.

2. METHODS TO DETERMINE THE OPTIMAL NUMBER OF EXECUTANTS

2.1. MONTE CARLO SIMULATION METHOD [3-6]

For solving this problem we will present - based on the analysis of a case study - regarding the substantiation of the optimum number of personnel in the maintenance activity specific to the maintenance and repairing activity in a TPSSF (transport and preparation system of solid fuel) - three techniques of the "Monte-Carlo simulation method":

- one process concerns the random "selection" of the moments that data is recorded;
- the second will be used for building an artificial sample, that is statistically representative;
- the third is used for establishing iteratively the "minimum total costs" and, as a consequence, the "optimum number of locksmiths in the maintenance work".

Case study: determining the optimum number of personnel in the maintenance activity of a TPSSF at CET I Oradea (power and heating station).

Let $T_r = 120$ working days (one semester) be the reference time frame, $\theta = 50$ working days "selected" randomly. Using the random number N_r that is formed with the first five digits of the ratio θ / T_r we obtain out of table 1 - extracted from the set of one milion random numbers of Rand Corporation - those numbers of lower or at most equal value with the number of items N_r.

The order of recording the personnel necessity is given by the succession in which the numbers are read. This personnel necessity if appreciated by the work coordinator (head of repairs) and corresponds to a degree of employment of $(70 \div 80\%)$.

It follows: $\frac{\theta}{T_r} = \frac{50}{120} \Longrightarrow \frac{\theta}{T_r} = 0.41666$. So, $N_r = 41666$.

We will record the first 50 numbers $N_0 \leq N_r$, and we select the date of the recording the personnel necessity as a function of the reading order. The volume of the statistic sample is $n = 50$.

In Table 2 is presented the number of necessary personnel for the maintenance work execution with a percent of employment of locksmiths of $G_0 = (70 \div 80)\%$.

So, $M_n \in [20; 40]$.

We deduce the length of the grouping interval, by STURGESS equation

$$L = \frac{M_n^{max} - M_n^{min}}{1 + 3.322 \lg n} \Longrightarrow L = 3, \tag{7}$$

13407	62899	78937	90525	46460	97660	23490	19853	06933	69767
50230	63237	94083	93634	53166	41836	28205	28215	47766	03076
84980	62458	9703	078397	55048	23912	81105	68517	67954	16570
22116	33646	17545	31321	73520	40050	90553	59002	26619	02930
68645	15068	56898	87021	64838	92133	44221	92531	70313	24969
26518	39122	96561	56004	17704	47400	30837	74348	66239	32704
36493	41666	27871	71329	43920	11199	36521	96194	15831	08968
77402	12994	59892	85581	01041	46662	98897	39588	57825	36521
83679	97154	40341	84741	41628	78664	80727	18313	82950	12335
71802	39356	02981	89107	19722	7045	028808	68012	52485	55139
57494	72484	22676	44311	79942	98351	10265	29761	39565	45332
73364	38416	93128	10297	75287	74989	58152	42467	23339	55311
14499	83965	75403	18002	82712	5590	064941	65510	77763	33684
40747	03084	07734	88940	15656	37895	94559	01332	33101	64795
42237	59122	92855	62097	76116	76977	94570	49799	41080	48621
1291	068707	45427	82145	74644	53625	10791	21789	14093	06268
48472	18782	51646	37564	70812	98331	9611	012424	98601	19089
35365	13800	83745	40141	38817	63835	13486	19526	27122	42515
43618	42110	93402	93997	67721	75037	70444	1695	047720	88646
29966	38144	62556	07864	41681	95285	44153	31709	13358	04626
56938	54729	67757	68412	88842	35676	49766	19159	95355	98213
34262	15157	27545	14522	25940	47239	93425	55467	47030	42545
91819	60812	47631	50609	72433	91514	79333	87127	45581	00185
37612	15593	73198	99287	83677	26442	97346	69649	57964	97149
54289	07147	84313	51938	14458	91409	79369	49514	89820	41310
19403	53756	4281	98022	41018	31937	84761	49105	06777	31998
95704	75928	21811	88274	45321	04207	34438	13524	03023	18046
01805	23906	96559	06785	85188	64339	27460	19037	002831	36558
74678	21859	98645	72388	32298	08662	54552	51553	12158	14668
08623	32752	40472	05470	73430	74306	85960	00755	17817	22757
39551	18398	36918	43543	13671	69405	11186	83682	21989	63268
11120	28638	72850	03650	81275	08602	03508	89028	00290	93766
83851	77682	81728	52157	77092	32490	40345	75076	58202	58038
70955	59693	26838	96011	56555	84390	12982	09083	33398	29974
47386	17462	18874	74210	29555	83653	07742	79452	91472	12611

Table 1 Extracted from the set of one million random numbers of Rand Corporation.

	26	30	23	33	30	26	30	33	25	30
	30	21	36	30	26	32	23	28	30	31
$M_n \in$	33	36	28	36	20	30	30	25	32	28
	24	29	35	28	35	29	25	37	21	31
	27	32	30	40	25	32	38	28	34	40

Table 2 The number of necessary personnel for executing maintenance work.

where: M_n^{max}, M_n^{min} are the maximum and minimum number of necessary personnel estimated by the manager.

In Table 3 we present the appearance frequencies of necessary personnel for the execution of maintenance work in certain time frames.

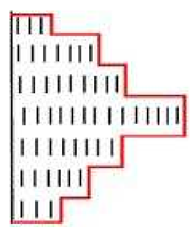
K	Interval	Frequency	
		*	f_K
1	$(20 \div 22)$		3
2	$(23 \div 25)$		7
3	$(26 \div 28)$		9
4	$(29 \div 31)$		14
5	$(32 \div 34)$		8
5	$(35 \div 37)$		6
7	$(38 \div 40)$		3
$\sum_K f_K$			50

Table 3 The appearance frequencies of personnel.

The statistic sample is representative to a Gauss type distribution. As a function of computing items in Table 2 we will construct a volume statistic sample $n' = 75$ (for a greater degree of veracity). We will proceed as follows: computing probabilities p_K based on frequencies f_K in Table 3, with equation

$$p_K = \frac{f_K}{\sum_K f_K}, \text{ with } \sum_K p_k = 1 \tag{8}$$

and the results are recorded in Table 4.

K	M_{sup}	f_K	p_K	p_K^{cum}
1	22	3	0.06	0.06
2	25	7	0.14	0.20
3	28	9	0.18	0.38
4	31	14	0.28	0.66
5	34	8	0.16	0.82
6	37	6	0.12	0.94
7	40	3	0.06	1.00

We take into account the upper limit of the interval M^{sup}; p_K^{cum} is the cumulated probability

Table 4 Probabilities p_K computed as a function of the frequencies f_K.

Now with each cumulated probability we associate an interval of random numbers having as lower limit the natural number of five digits given by the previous cumulated probability and, as an upper limit, the natural number given by the respective cumulated probability minus one. We read 75 random consecutive numbers of Table 1 and function of the associated interval in which they are, we obtain the artificial statistic sample of volume (Table 5).

In Table 6 we present the probability intervals associated to the value M_K.

As a function of the values M_{S_J} in Table 5 the frequency values may be computed (Table 7). Although the graph approximates the normal (Gaussian) form the artificial sample, in order to "correct" the influence of frequency $f_3(28) = 12 < f_2(25) = 16$, we will group the values M_K (Sturgess equation is only informative). The new grouping is presented in Table 8.

The iterative computing of the optimum number of personnel necessary to execute the maintenance work is presented next, in Table 9 (the computing items of Table 7 will be considered).

J	Random number	M_S	J	Random number	M_S	J	Random number	M_S
1.	13407	25	26.	19403	25	51.	68707	34
2.	50230	31	27.	95704	40	52.	18782	25
3.	84980	37	28.	01805	22	53.	13800	25
4.	22116	28	29.	74678	34	54.	42110	31
5.	68645	34	30.	08623	25	55.	38144	31
6.	26518	28	31.	39551	31	56.	54729	31
7.	36493	28	32.	11120	25	57.	15157	25
8.	77402	34	33.	83851	37	58.	60812	31
9.	83679	37	34.	70955	34	59.	15593	25
10.	71802	34	35.	47386	31	60.	07147	25
11.	57494	31	36.	62899	31	61.	53756	31
12.	73364	34	37.	63237	31	62.	75928	34
13.	14499	25	38.	62458	31	63.	23906	28
14.	40747	31	39.	33646	28	64.	21859	28
15.	42237	31	40.	15068	25	65.	32752	28
16.	01291	22	41.	39122	31	66.	18398	25
17.	48472	31	42.	41666	31	67.	28638	28
18.	35365	28	43.	12994	25	68.	77682	34
19.	43618	31	44.	97154	40	69.	59693	31
20.	29966	28	45.	39356	31	70.	17462	25
21.	56938	31	46.	72484	34	71.	78937	34
22.	34262	28	47.	38416	31	72.	94083	40
23.	91819	37	48.	83965	37	73.	09703	25
24.	37612	28	49.	03084	22	74.	17545	25
25.	54289	31	50.	59122	31	75.	56898	31

Table 5 First 75 random numbers in Table 1 and M_{S_J} values.

K	M_K	Associated interval
1	22	$(00000 \div 05999)$
2	25	$(06000 \div 19999)$
3	28	$(20000 \div 37999)$
4	31	$(38000 \div 65999)$
5	34	$(66000 \div 87999)$
6	37	$(82000 \div 93999)$
7	40	$(94000 \div 99999)$

Table 6 The probability intervals associated with the value M_K.

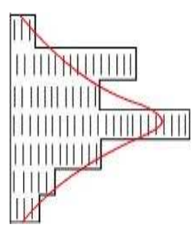
K	M_K	Frequency		Probability
			f_K	p_K
1	22		3	0.04000
2	25		16	0.21333
3	28		12	0.16000
4	31		24	0.32000
5	34		12	0.16000
6	37		5	0.06667
7	40		3	0.04000
$\sum_K f_K$			75	1.0000

Table 7 Probabilities p_K computed as a function of the frequencies f_K

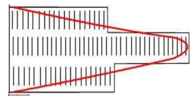
K	M_K	Frequency		Probability
			f_K	p_K
1	$(22 \div 27)$		19	0.25333
2	$(28 \div 33)$		36	0.48000
3	$(34 \div 40)$		20	0.26667
$\sum_K f_K$			75	1.0000

Table 8 Probabilities p_K computed as a function of the frequencies f_K

Table 9 shows us that the optimum number of personnel that corresponds to total minimum costs is $M = 35$ locksmiths for maintenance activity.

2.2. EXPERTONS METHOD [3-6]

Let A_h^{inf} and A_h^{sup} the lower and upper limits for the appreciations of a group S of experts, be given numerically (linguistically) and let $[a_n^{inf}; a_n^{sup}] \subset [0; 1]$ the intervals associated with these appreciations transposed on a linear scale with seven levels. The experton is a statistical construction given as a two column table whose elements are the relative cumulated frequencies 9, $f_c^r(\alpha_K)$ associated with the appreciation intervals that correspond to the α_K levels

$$f_c^r(\alpha_K) = [f_c^{r\ inf}(\alpha_K); f_c^{r\ sup}(\alpha_K)] \tag{9}$$

The defining measure of an experton is the mathematical expectance, $E(Ex(Z))$ given by the equation

$$E(Ex(Z)) = [E^{inf}(Ex(Z)); E^{sup}(Ex(Z))], \tag{10}$$

where

$$E^{inf/sup}(Ex(Z)) = \frac{1}{n_t - 1} \sum_K f_c^{r\ inf/sup}(\alpha_K) \tag{11}$$

$Ex(Z)$ is some experton (Z).

Iteration	M_k	M	ΔM	p_K	$E(\Delta M)$	C	D	C_t	Obseravation
1.	22	30	-	-	1.83	30c	11c	41c	-
	25		-	-					
	28		-	-					
	31		1	0.32000					
	34		4	0.16000					
	37		7	0.06667					
	40		10	0.04000					
2.	22	**35**	-	-	0.33	35c	2c	**37c**	Total minimum costs
	28		-	-					
	31		-	-					
	34		1	-					
	37		2	0.06667					
	40		5	0.04000					
3.	22	36	-	-	0.23	36c	1.4c	37.4c	-
	31		-	-					
	34		-	-					
	37		1	0.06667					
	40		4	0.04000					
4.	22	37	-	-	0.12	37c	0.7c	37.7c	-
	28		-	-					
	31		-	-					
	34		-	-					
	37		-	-					
	40		3	0.04000					

Table 9 Computation of the optimum number of personnel necessary for executing the maintenance work.

Between the mathematical expectance of an experton and the average interval appreciation, $m(a)$ we have relation

$$m(a) = E(Ex(Z)), \tag{12}$$

where

$$m(a) = \left[\frac{\sum_n a_n^{inf}}{n}; \frac{\sum_n a_n^{sup}}{n} \right] \tag{13}$$

Table 10 presents the semantic of the 7th level scale, the simbol for each level, the level and the step.

n_t	Semantic	Simbol	Level (α)	Step ($\Delta\alpha$)
1	Dissatisfactory	D	0	0
2	Almost dissatisfactory	AD	0,167	0,167
3	Slightly satisfactory	SS	0,333	0,167
4	Satisfactory	S	0,5	0,167
5	Well	W	0,667	0,167
6	Almost very well	AVW	0,833	0,167
7	Very well	VW	1	0,167

Table 10 The semantic of the 7th level linear scale.

Case study: establishing of the optimum number of locksmiths for the maintenance activity in TPSSF of CET I Oradea.

A group of four experts expose each of them their opinion - based of verification, measurements, functioning samples - regarding the operational capacity (the state of the respective equipment) and its availability (safetyness in operation), the appreciations being distinguished with the symbols of the scale steps (table 11).

We present the algorithm for constructing the expertons (Tables 12 and 13).

$\frac{E_\tau}{e_J}$	E_1 : 20 executants		E_2 : 24 executants	
	Appreciation	Interval	Appreciation	Interval
e_1	W; AVW	$(0,667 \div 0,833)$	W;AVW	$(0,667 \div 0,833)$
e_2	W	$0,667$	S;W	$(0,500 \div 0,667)$
e_3	W;VW	$(0,667 \div 1)$	AVW	$0,833$
e_4	W;AVW	$(0,667 \div 0,833)$	W;VW	$(0,667 \div 1)$
$m(ac)$	*	$(0,667 \div 0,833)$	*	$(0,667 \div 0,833)$

$\frac{E_\tau}{e_J}$	E_3 : 28 executants	
	Appreciation	Interval
e_1	S;W	$(0,500 \div 0,667)$
e_2	AVW;VW	$(0,833 \div 1)$
e_3	AVW;VW	$(0,833 \div 1)$
e_4	S;W	$(0,500 \div 0,667)$
$m(ac)$	*	$(0,667 \div 0,833)$

Table 11 The opinions of the four experts based on measurements and functioning samples.

We obtain the expertons of the couples
$(Ex(E_1)) \wedge (Ex(E_2)) = Ex(E_1 \triangle E_2)$;
$(Ex(E_2)) \wedge (Ex(E_3)) = Ex(E_2 \triangle E_3)$;
$(Ex(E_3)) \wedge (Ex(E_1)) = Ex(E_3 \triangle E_1)$;

It follows: $E_1 \triangle E_2$ - first place, $E_2 \triangle E_3$ - second place, $E_3 \triangle E_1$ - third place

So: E_1 first and third place, E_2 first and second place, E_3 second and third place

It follows that the classification is: E_2 - E_1 - E_3.

The optimium number of personnel for executing the maintenance work at CET I Oradea TPSSF it justifies to be: $M_optimum = 24$ executants.

E_τ	Scale	f^a	f_c^a	$f_c^r : E_x(E_\tau)$	$E[Ex(E_\tau)]$
	0	0	4	1	
	0.167	0	4	1	
	0.333	0	4	1	
E_1	0.500	4 1	4	1	[0,667;0,833]
	0.667	0	4	1	
	0.833	0 2	0 3	0 0.75	
	1	0 1	0 1	0 0.25	
	0	0	4	1	
	0.167	0	4	1	
	0.333	0	4	1	
E_2	0.500	1 0	4	1	[0,667;0,833]
	0.667	2 1	3 4	0.75 1	
	0.833	1 2	1 3	0.25 0.75	
	1	0 1	0 1	0 0.25	
	0	0	4	1	
	0.167	0	4	1	
	0.333	0	4	1	
E_3	0.500	2 0	4	1	[0,667;0,833]
	0.667	0 2	2 4	0.5 1	
	0.833	2 0	2	0.5	
	1	0 2	0 2	0 0.5	

Table 12 The method of constructing the expertons of the couples.

$Ex(E_1)$		$Ex(E_2)$		$Ex(E_1 \triangle E_2)$	
1		1		1	
1		1		1	
1		1		1	
1	$\wedge$	1	$\Rightarrow$	1	$E[Ex(E_1 \triangle E_2)] =$
1		0.75 1		0.75 1	[0.625; 0.833]
0 0.75		0.25 0.75		0 0.75	
0 0.25		0 0.25		0 0.25	

$Ex(E_2)$		$Ex(E_3)$		$Ex(E_2 \triangle E_3)$	
1		1		1	
1		1		1	
1		1		1	
1	$\wedge$	1	$\Rightarrow$	1	$E[Ex(E_2 \triangle E_3)] =$
0.75 1		0.5 1		0.5 1	[0.625; 0.792]
0.25 0.75		0.5		0.25 0.5	
0 0.25		0 0.5		0 0.25	

$Ex(E_1)$		$Ex(E_1)$		$Ex(E_3 \triangle E_1)$	
1		1		1	
1		1		1	
1		1		1	
1	$\wedge$	1	$\Rightarrow$	1	$E[Ex(E_3 \triangle E_1)] =$
0.5 1		1		0.5 1	[0.583; 0.792]
0.5		0 0.75		0 0.5	
0 0.5		0 0.25		0 0.25	

Table 13 The method of constructing the expertons of the couples (cont'd).

3. CONCLUSIONS

The optimization of maintenance work consists in the optimized configuration of human resources for TPSSF maintenance, which materializes in:

- determining the optimum number of human resources destined to maintenance work, that we have determined in this paper;
- establishing the optimum make-up of equipment that operationalize the maintenance work;
-optimizing the number of teams that carry out the maintenance work;
- the optimum allocation of maintenance teams.

In establishing the optimum number of personnel that carry out maintenance work it is recommended to use "the minimum total cost" criterion, taking into account the contradictory fundamental components of costs: the component that corresponds to having the personnel and the component that corresponds to the damage caused by not doing the maintenance work at the proper time due to lack of personnel. In this paper the operationalization of the criterion was made by simulation and by applying the expertons method.

4. ACKNOWLEDGMENT

This paper is dedicated to anniversary of 65 years from birth of prof. dr. Adelina Georgescu (borne in Drobeta Turnu-Severin on April 25, 1942), a prominent personality and a dynamic promoter of the Romanian and international contemporary applied mathematics.

Professor Adelina Georgescu graduated the Faculty of Mathematics (Bucharest), section of fluid mechanics in 1965, with a thesis on subsonic aerodynamics. Under the supervision of Professor Caius Iacob she prepared a doctorate in hydrodynamic stability theory, a pioneering field for that period. In 1970 she defended her Ph. D. Thesis and became Doctor in Mathematics. Between 1965 and 1990 she worked at the Institute of Fluid Mechanics and Aerospatial Constructions, Bucharest, and at The Institute of Mathematics, Bucharest, alternatively, reaching all scientific degrees. In 1990 she was the initiator of

the project of a new research institute, the Institute of Applied Mathematics, of the Romanian Academy. The Institute was born in 1991 and Professor Adelina Georgescu held the function of Director (and Principal Researcher I) until 1995. Her intention was to create a strong group in nonlinear dynamics. In 1997, as the Institute was not lead in the scientific direction envisaged by Prof. Georgescu, she moved to the University of Piteşti, where she is acting so far.

Professor Adelina Georgescu is main founder (1992) and president (1992- up to the present) of the Romanian Society of Applied and Industrial Mathematics (ROMAI). Prof. A. Georgescu is founder (1993) and main organizer of the annual ROMAI Conference on Applied and Industrial Mathematics (CAIM, 1993- up to the present). Also, she is founder (2005) and Editor in Chief (2005- up to the present) of the ROMAI JOURNAL (an international journal edited by ROMAI Society). Congratulations and thank you professor Adelina Georgescu for your great endeavour and contributions in dissemination of Romanian research on applied and industrial mathematics and its integration in a global international knowledge society.

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