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EFFECTIVENESS OF ARTILLERY SYSTEMS

The essence of the problem of artillery system effectiveness factors determination has been disclosed in the paper. On the base of the hypothesis of presentation possibility of effectiveness factors of artillery systems as linear combination of performance characteristics, the method of effectiveness factors calculation for the new artillery systems of the same category it has been offered. By this model using the effectiveness factors for the several artillery systems have been calculated, by compare of obtained data with their effectiveness factors, the adequacy of constructed mathematical model has been shown. At the same, with purpose of investigation of the "discrepancy" between the linear combination coefficients and the influence feature on effectiveness factor of relevant performance characteristic, the correlation between performance characteristics and the correlation between each performance characteristic and performance characteristic have been investigated, also Pirson's linear correlations coefficients have been calculated. The efficiency coefficient dependence on battle characteristics (artillery firepower, mobility, durability and applicability) and on the performance characteristics has been modelled. The "discrepancy" in the signs and the values of the performance characteristics coefficients has been explained by various impacts on the combat characteristics of artillery sets.

Keywords: artillery system; combat properties; performance characteristics; efficient factor; neural networks; least-squares method; linear correlation factor.

Introduction

The effectiveness of artillery systems is an integral characteristic of battle capabilities expressed by main functional futures based on the performance characteristics [1, p.4]. The effectiveness factors of artillery systems define a unit's battle potential, are initial data for calculation of the battle capabilities against enemy's armored machineries. These factors are presented in manuals' tables as known values. However, the list of presented artillery systems in these manuals is not full and there are only effectiveness factors of some artillery systems presented as examples in these manuals. It should be noted that in various references the same artillery system has a different value. In addition, there is a problem of effectiveness factors determination for the new obtained artillery systems, and a long time these effectiveness factors are impossible to get. On the other hand, these factor calculation methods indicated in these tables have not references. In spite of the calculation methods of effectiveness factors are offered in some references [1, 2, 3], the presence of some lacks of these methods do not allow to determine effectiveness factors of the new artillery systems adopted to armoury. There are some of them below:

- the calculated by various methods factors for the same artillery system are differed much;
- the formules, graphs and tables used in these methods are not justified;
- these methods use such numerical coefficients (system reliability, probability of target hit etc.) which are not presented by producer as performance characteristic.

In addition, for calculation of the effectiveness factors of artillery systems the offered methods are mainly based on the expert's reports and the results of stand experiments. For determination of effectiveness factors of the new artillery systems it is necessary to have many expert's reports and to carry out many experiments. In paper the dependence of effectiveness factors on the performance characteristics for the artillery systems has been investigated and for calculation of effectiveness factors of the new artillery systems of the same category the method has been offered.

Distinctive features of artillery systems' effectiveness

It is clear, that the value of effectiviness factor must be determined by the impact of arms performance characteristics on the combat properties [4, p.65]. Let us analyse of the main performance characteristics defining of the artillery system category from the point of view of impact on combat properties [5, p.92-95; 6, p.71-73]. "The fire power", "the mobility", "the durability" and "applicability" are considered as the main combat properties for artillery systems. In spite of that the purposes of all artillery systems are the same, they have various construction, fire and maneuver posibilities and battle applicability methods. Therefore, artillery systems can be divided into below subsystems: mortars, howitzers and cannons, volley fire rocket weapons (VFRW) and self-propelled artillery sets (SPAS). Taken for determination of combat effectiveness the performance characteristics of these subsystems weapons are different:

1) for mortars: calibre, maximum gunfire range, vertical and horizontal rotation angle of gun tube, weight of shell, fire rate, shell initial velocity, weight of ordnance, number of operating staff, ammunition equipment;

2) for howitzers and cannons: calibre, maximum gunfire range, rotation angle of gun tube, weight of

shell, fire rate, shell initial velocity, weight of ordnance, number of operating staff, ammunition equipment and size of ordnance;

3) volley fire rocket weapons: calibre, maximum gunfire range, rotation angle of gun tube, weight of shell, fire rate, weight of ordnance, number of operating staff, ammunition equipment, size of ordnance, number of tubes and maneuver possibilities;

4) self-propelled artillery sets: calibre, maximum gunfire range, rotation angle of gun tube, weight of shell, fire rate, weight of ordnance, number of operating staff, ammunition equipment, size of ordnance and movement possibilities.

Let us analyse above indicated performance characteristics:

- The calibre – the large shell (mine) calibre the large degree of fire destruction, it acts positively on the fire power, the measurement unit is *mm*.
- The maximum gunfire range – the large gunfire range the further destruction distance and the more hit of enemy targets, it acts positively on the fire power; also, the large gunfire range the low probability to hit own objects, it acts positively on the durability; the measurement unit is *m*.
- The rotation angle of gun tube – the large angle the less time of fire maneuver and of take aim, it acts positively on the fire power. The vertical rotation angle provides a shooting range and the horizontal one provides a broad battlefront of take aim; the measurement unit is *a degree*.
- The number of tube (for VFRW) – the more number the much volley intensity and the large bombardment area, it acts positively on the fire power; the measurement unit is *a piece*.
- The weight of shell (mine) – the large weight the large destruction degree of target, it acts positively on the fire power; the measurement unit is *kq*.
- The fire rate – the high rate the many affected targets in unit time, it acts positively on the fire power; the measurement unit is *1/min (shoot/min).*
- The shell initial velocity – the high velocity the less dispersion angle of shells and the high shooting accuracy and target hit probability, it acts positively on the fire power; the measurement unit is *m/san*.
- The weight of ordnance – the more weight the less maneuver possibilities, it acts negatively on the mobility and applicability; the measurement unit is *kq*.
- The size of ordnance – the large size the less maneuver possibilities on the battle field, it acts negatively on the mobility, the much revealing probability on the enemy part, it acts negatively on the durability; the measurement unit is m^3.
- Number of operating staff – the more number the much probability revealing and hitting probability on the enemy part; if the ordnance is destroyed then the loss of staff is more, therefore it acts negatively on the durability. This impact is proportional to staff number.
- Ammunition equipment – the many equipment the more duration of uninterrupted fight activities on the battle field, it acts positively on the fier power and durability; the measurement unit is *a piece*.
- Movement possibility (for SPAS) – it acts positively on the movement on the battlefield. It is an integrated factor of the velosity movement and one fuelling determined of passed distance; the measurement unit is $km^2/hour$.

In framework of study for determination of the effectiveness digital value of artillery systems let us adopt a hypothesis considered in [6]: *The effectiveness of artillery systems can be calculated as linear combination of above considered performance characteristics. The factors of this combination can be determined based on investigation of the correlation between known weapons' effectiveness and known performance characteristics.*

Information concerning artillery system's category has been taken from [2, p.76, p.80-81] (see tables 1 – 4, here: 0 – calibre (mm), 1 – maximum gunfire range (*m*), 2 – vertical rotation angle of tube (*degree*), 3 – horizontal rotation angle of tube (*degreee*), 4 – shell weight (*kq*), 5 – fire rate (*shoot/min*), 6 – ordnance weight (*kq*), 7 – shell initial velocity (*m/sec*), 8 – staff number (*men*), 9 – ammunition equipment (*piece*), 10 – effectiviness factor).

Table 1 – **Mortars performance characteristics**

Mortars	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
i	x_{i0}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	x_{i8}	x_{i9}	E_i
1. L9A1	51	800	85	4	1.02	8	6.27	106	1	120	**18.00**
2. M19	60	1830	85	4	1.46	30	10.5	156	1	120	**26.61**
3. UT-1	81.4	5900	81	5	3.2	15	71.2	250	3	120	**98.07**
4. NT-1	81.4	3800	81	5	4.2	20	58.85	250	3	120	**87.02**
5. E-44	81.4	5900	81	5	3.2	30	40.9	250	3	100	**115.45**
6. BM-38	82	3040	85	3	3.1	30	48	211	4	120	**98.32**
7. 2B9 automatic	82	4570	85	4	3.1	120	435	250	4	228	**130.00**
8. M30	106.7	5650	80	3	12	18	305	293	6	100	**119.48**
9. PM-37	120	5700	80	3	15.9	6	282	272	4	80	**180.95**
10. 2S12	120	7100	80	3	16	12	210	240	6	48	**190.00**
11. MT-13	160	5100	80	5	49	3	1170	245	6	40	**185.00**
12. M-240	240	9700	80	8	130.7	1	4230	245	5	40	**197.77**
13. 2B14-1	82	4020	85	4	3.1	24	42	232	4	120	**85.55**
14. M29	81	4730	80	3	3.1	30	48	223	4	100	**98.12**
15. MO-120	120	4200	80	4	16	15	94	238	3	80	**150.95**

Table 2 – **Howitzers and cannons performance characteristics**

Mortars	0	1	2	3	4	5	6	7	8	9	10
i	x_{i0}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	x_{i8}	x_{i9}	E_i
1. M1942/ZİS-3 cannon	76.2	13290	48	6.20	25	1116	14137	680	6	100	**211.97**
2. D-44 cannon	85	15650	48	9.54	15	1725	20488	793	5	120	**138.93**
3. Q.F. Mk-2 cannon	87.6	12250	25	11.34	5	1800	27718	532	6	100	**130.47**
4. MT-12 cannon	100	8200	26.5	5.65	14	3050	35820	1575	7	80	**178.76**
5. M101 howitzer	105	11270	58.5	14.97	10	2030	34 479	472	8	86	**231.36**
6. D30 howitzer	122	15400	218.5	21.76	8	3150	21461	690	6	80	**191.6**
7. M46 cannon	130	27150	48.75	33.40	6	7700	73283	930	9	80	**249.48**
8. M114 A2 howitzer	155	22000	58	43.88	4	7163	58999	684	11	60	**344.51**
9. M2 155/45 cannon	155	23220	63.5	42	4	12600	38892	853	11	60	**306.03**
10. TR (GIAT) cannon	155	24000	68.5	43.2	6	10750	56 760	810	7	50	**540.38**
11. M1 howitzer	155	23221	63.5	43.10	2	13860	97440	653	14	40	**260.62**
12. Б-4M howitzer	203.2	17890	34	100	0.5	21900	85593	607	14	16	**217.69**
13. M101A1 howitzer	105	11270	58.5	14.97	10	2030	20 365	472.4	8	80	**246.72**
14. D20 howitzer/ cannon	152	17410	63	43.51	6	5650	50805	655	10	80	**287.57**
15. M198 howitzer	155	22000	61	43.88	4	7163	75786	684	11	60	**346.64**

Table 3 – **VFRW performance characteristics**

Mortars	0	1	2	3	4	5	6	7	8	9	10
i	x_{i0}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	x_{i8}	x_{i9}	E_i
1. Tip-63	107	8500	45	12	18	540	611	4368	5	150	**178.69**
2. LARS 1	110	14700	205	36	34	1325	17480	61893	3	300	**923.89**
3. LARS 1	110	19000	205	36	34	1325	17480	61893	3	300	**1000.28**
4. LARS-2	110	25000	205	36	34	1325	17480	61893	3	300	**1106.77**
5. MLRS (ATACMS)	240	35000	115	12	258.5	2700	24560	54226	3	315.25	**757.98**
6. SAKARYA	122	40000	137.5	40	65.9	1150	30000	71300	5	727.5	**1516.76**
7. BM-21	122	20750	113.5	40	66.4	1210	13700	54507	7	562.5	**1187.94**
8. BM-21	122	33000	113.5	40	66.4	1210	13700	54507	6	637.5	**1345.41**
9. RM-70	122	20500	111	40	66	1060	33700	63800	6	480	**1033.60**
10.BM-21	122.4	15000	117.5	36	66.4	1210	11500	42780	3	680	**766.73**
11. BM-21	122.4	30000	117.5	36	66.4	1210	11500	42780	3	680	**1032.80**
12. BM-21	122.4	20100	117.5	12	66.4	650	6000	33115	2	743.75	**758.36**
13. M-77 Oganj	128	21000	111	32	67.1	810	22000	62250	5	300	**804.88**
14. HADİD-Noor	122	18000	110	40	45	1210	13700	71300	6	375	**857.95**
15. MLRS	240	40000	117.5	12	307	2700	24560	54226	5	315.25	**1230.56**

Table 4 – **SPAS performance characteristics**

Mortars	0	1	2	3	4	5	6	7	8	9	10
i	x_{i0}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	x_{i8}	x_{i9}	E_i
1. M108 howitzer	105	11500	219	15.00	10	20900	68127	5	86	196	**423.85**
2. 2S1/M1974 howitzer	122	21900	216.5	21.76	8	22200	47175	4	40	305	**471.75**
3. DANA/M-77 howitzer	152	18700	149.5	43.56	9	29250	95418	5	60	592	**628.01**
4. 2S3/M1973 howitzer	152.4	18500	211.5	43.56	4	27500	83265	4	46	300	**464.34**
5. M44T howitzer	155	24700	65	43.50	4	32000	86657	8	30	341	**635.38**
6. MkF3 cannon	155	20050	50	43.54	3	17400	35274	8	56	180	**586.89**
7. M-109G howitzer	155	15100	220	43.54	4	28849	137390	6	28	192	**302.63**
8. PzH 2000 howitzer	155	40000	213.7	43.5	12	55300	138067	5	60	256	**1004.5**
9. ZUZANA howitzer	155	39600	96.7	43.5	6	28450	138039	4	40	600	**820.30**
10. M-107 cannon	175	32700	63.5	66.78	2	28200	130889	8	30	252	**670.07**
11. M-110 A2 howitzer	203	22900	63.5	92.53	1	28350	106164	5	8	287	**606.00**
12. 2S7/M-1975 howitzer	203	37500	45	110.0	2.5	46500	133949	7	8	300	**896.16**
13. 2S1/M1974 howitzer	122	15200	216.5	21.76	8	15700	47175	4	40	305	**344.71**
14. M44T howitzer	155	24000	65	43.50	4	29500	93555	8	30	350	**587.72**
15. 2S3/M1973 howitzer	152.4	24000	212	43.56	5	28000	83265	4	46	300	**557.48**

Mathematical model of effectiviness factor calculation

Thus, it is considered that effectiviness factors of artillery systems can be defined by linear combination of the above presented performance characteristics, that is, this dependence will be constructed in shape of neural network [7]. Let us admit that the performance characteristics and effectiviness of N artillery systems are known. For simplicity, we number these arms as

i = 1, 2, 3, ..., N. It should be noted that we shall use for calculations only data for the first 12 arms presented in tables 1, 2, 3 and 4, that is, N = 12. Let us denote the performance characteristic of i arm by x_i (j = 1, 2, ..., 10), and arm effectiviness by E_j.

The dependence between these quantities can be written as neural network:

$$\sum_{j=1}^{10} \alpha_j x_{ij} \ , \ i = 1, 2, 3, ..., N. \qquad (1)$$

It is considered for above presented arms that x_{ij} and E_j are known, their values are given in table 1. If we apply the mathematical model given in [8] then we obtain below the values of neural network factors:

– mortar:

$$\begin{aligned} &\alpha_1=11.58123,\ \alpha_2=-0.01786,\\ &\alpha_3=-3.43018,\ \alpha_4=36.73646,\\ &\alpha_5=-39.32734,\ \alpha_6=-0.00416,\\ &\alpha_7=0.74021,\ \alpha_8=-1.25743,\\ &\alpha_9=-6{,}25943,\ \alpha_{10}=-1.98954; \end{aligned} \qquad (2)$$

– cannons and howitzers:

$$\begin{aligned} &\alpha_1=9.49153,\ \alpha_2=0.00660,\\ &\alpha_3=-1.25995,\ \alpha_4=-9.54496,\\ &\alpha_5=9.63352,\ \alpha_6=-0.00359,\\ &\alpha_7=0.00028,\ \alpha_8=-0.19277,\\ &\alpha_9=-43.78641,\ \alpha_{10}=-3.26425; \end{aligned} \qquad (3)$$

– VFRW:

$$\begin{aligned} &\alpha_1=-7.49242,\ \alpha_2=0.01774,\\ &\alpha_3=4.23441,\ \alpha_4=1.12569,\\ &\alpha_5=3.72270,\ \alpha_6=0.01039,\\ &\alpha_7=-0.00008,\ \alpha_8=0.00011,\\ &\alpha_9=96.0293,\ \alpha_{10}=0.48191; \end{aligned} \qquad (4)$$

– SPAS:

$$\begin{aligned} &\alpha_1=1.71139,\ \alpha_2=0.01149,\\ &\alpha_3=-1.19681,\ \alpha_4=-0.06277,\\ &\alpha_5=12.90055,\ \alpha_6=0.00769,\\ &\alpha_7=-0.00083,\ \alpha_8=17.29470,\\ &\alpha_9=2.65821,\ \alpha_{10}=-0.00002. \end{aligned} \qquad (5)$$

Thus, the effectiveness factor for any artillery systems can be calculated based on the performance characteristics by next formula

$$E = \sum_{j=1}^{10} \alpha_j x_j \ , \qquad (6)$$

here x_1, x_2, ..., x_{10} are the values of performance characteristics.

Verification of neural network factors adequacy

For this purpose, let us calculate the effectiveness factors of arms which are unused in calculations of neural network factors, and compare the calculated values with the effectiveness factors given in tables 1 – 4 (see table 5).

Thus, (6) formula can be applied successfully for calculation of artillery systems effectiveness based on the performance characteristics.

In addition to that, included in (3.6) formula and determined for a linear combination the values of α_j, j = 1, 2, ..., 10 factors aren't always directly proportional to performance characteristics and it creates disagreements.

On the other part, taking into account that α_2 and α_7 factors are less than other ones and are negligible in effectiveness assessment, it is doubtful that these α_2 and α_7 factors are reason for disagreements.

Table 5 –**The comparision of given and calculated effectiveness factors**

Artillery systems	Effectiveness factors		Error	
	Given in table	Calculated	Absolute	in %
2B14-1 mortar (table 1, row 13)	E_{13}=85.55	E_{13}=86.81	1,26	1,47
M29 mortar (table 1, row 14)	E_{14}=98.12	E_{14}=98.49	0,37	0,37
MO-120 mortar (table 1, row 15)	E_{15}=150.95	E_{15}=150.33	0,62	0,41
M101A1 howitzer (table 2, row 13)	E_{13}=246.72	E_{13}=246.72	0,00	0,00
D20 cannon/howitzer (table 2, row 14)	E_{14}=287.57	E_{14}=289.59	2,02	0,70
M198 howitzer (table 2, row 15)	E_{15}=346.64	E_{15}=345.63	1,02	0,29
M-77 Oganj VFRW (table 3, row 13)	E_{13}=804.88	E_{13}=807.96	3,08	0,38
HADİD-Noor VFRW (table 3, row 14)	E_{14}=857.95	E_{14}=860.19	2,24	0,26
MLRS VFRW (table 3, row 15)	E_{15}=1230.56	E_{15}=1229.89	0,67	0,05
2S1/M1974 howitzer -15 km (table 3, row 15)	E_{13}=344.71	E_{13}=344.79	0,08	0,02
M44T howitzer -24 km (table 3, row 15)	E_{14}=587.72	E_{14}=602.49	14,77	2,51
2S3/M1973 howitzer -24 km (table 3, row 15)	E_{15}=557.48	E_{15}=543.75	13,73	2,46

For the purpose of clarification of the significance of this task, let us:

- investigate the correlation factors for assessment of the dependence between arms effectiveness factors and performance characteristics;

- justify the objective character of disagreements concerning a mathematical model of implicit dependence between effectiveness and performance characteristics.

The correlation between performance characteristics of the artillery systems is arised due to their meaning: the arm's calibre growth leads to growth of arm's weight, the arms's weight growth leads to increasing of staff number etc. Besides, as it is mentioned above, the small values of α_2 and α_7 coefficiens provide understanding how arms' fire shape and shell initial velocity impact to arm's effectiveness.

That is, when the hypothesis [5] is considered, it is arised necessity to justify of the correct choosing of performans characteristics of the artillery systems.

Thus, many factors impact to the correlation between various characteristics and so, the nature of the correlation between mentioned quantities is complex and without mathematical assessment it is difficult to make conclusion about correlation between these quantities.

For simplicity, let us use Pearson's linear correlation formula [7, p.13] for the pupose of calculation of the factors of linear correlation between performans characteristics:

$$r = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\left[\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2\right]\cdot\left[\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2\right]}}. \quad (7)$$

Here: n is a number of considered arms, $n = 12$; x_i and y_i are the values of i arm x and y performance characteristics; $\bar{x}$ and $\bar{y}$ are the average values of x and y performance characteristics, respectively.

Thereupon $n < 1000$, calculated by (7) formula the values of correlation factors should be corrected by below formula:

$$r' = r\cdot\left[1 + \frac{1 - r^2}{2\cdot(n-2)}\right]. \quad (8)$$

The calculated by (7) and (8) values of the factor correlation have been presented in tables 6÷9 (here: 0 – calibre, 1 – maximum gunfire range, 2 – vertical rotation angle of tube (degree), 3 – horizontal rotation angle of tube, 4 – shell weight, 5 – fire rate, 6 – ordnance weight, 7 – shell initial velocity, 8 – staff number, 9 – ammunition equipment, 10 – effectiviness factor).

For purpose of assessment of correlation between considered quantities let us use theses given in [7, p.12]:

$|r'| = 1$ – that is, there is a functional dependency between quantities;

$0.95 \le |r'| < 1$ – that is, this dependence is a very strong;

$0.75 \le |r'| < 0.95$ – that is, this dependence is strong;

$0.5 \le |r'| < 0.75$ – that is, this dependence is average;

$0.2 \le |r'| < 0.5$ – that is, this dependence is weak;

$0 \le |r'| < 0.2$ – that is, practically there is not a dependence.

If the sign of a correlation factor r' is positive then there are directly proportional quantities, if the sign is negative then there are inversely proportional quantities.

Table 6 – **Correlation factors of performance characteristics for mortars**

№	Mortars' performance characteristics	Linear correlation factor r'										
		0	1	2	3	4	5	6	7	8	9	10
1.	Calibre	-	0.781	-0.206	0.596	0.921	-0.366	0.888	0.408	0.659	-0.669	0.785
2.	Maximum gunfire range	0.781	-	0.091	0.578	0.741	-0.183	0.724	0.768	0.727	-0.460	0.873
3.	Vertical rotation angle of tube	-0.206	0.091	-	0.326	0.152	0.186	0.183	0.159	-0.021	0.302	0.040
4.	Horizontal rotation angle of tube	0.596	0.578	0.326	-	0.810	-0.174	0.834	0.204	0.073	-0.233	0.316
5.	Shell weight	0.921	0.741	0.152	0.810	-	-0.338	0.990	0.298	0.479	-0.550	0.650
6.	Fire rate	-0.366	-0.183	0.186	-0.174	-0.338	-	-0.222	0.071	-0.106	0.881	-0.138
7.	Ordnance weight	0.888	0.724	0.183	0.834	0.990	-0.222	-	0.282	0.423	-0.428	0.600
8.	Shell initial velocity	0.408	0.768	0.159	0.204	0.298	0.071	0.282	-	0.758	-0.113	0.756
9.	Staff number	0.659	0.727	-0.021	0.073	0.479	-0.106	0.423	0.758	-	-0.443	0.872
10.	Ammunition equipment	-0.669	-0.460	0.302	-0.233	-0.550	0.881	-0.428	-0.113	-0.443	-	-0.501
11.	Effectiviness factor	0.785	0.873	0.040	0.316	0.650	-0.138	0.600	0.756	0.872	-0.501	-

For purpose of application of the offered in [9] effectiviness factor calculation method and of determination of the importance of selected performance characteristics let us analyse row 11 in tables 6, 7, 8 and 9:

– for mortars: the influence of the calibre, the maximum gunfire range, the shell initial velocity and the staff number on the effectiviness factor is strong; the influence of the shell and ordnance weight is average; the influence of other performance characteristics on the effectiviness factor is weak or it is not practically;

– for howitzers and cannons: the influence of the calibre, the maximum gunfire range and ammunition equipment on the effectiviness factor is average; the influence of other performance characteristics on the effectiviness factor is weak or it is not practically;

– for VFRW: the influence of the number of tubes and ordnance size on the effectiviness factor is strong; the influence of the maximum gunfire range and the ordnance weight on the effectiviness factor is average; the influence of other performance characteristics on the effectiviness factor is weak or it is not practically;

Table 7 – **Howitzers and cannons performance characteristics**

№	Howitzers and cannons	Linear correlation factor r'										
		0	1	2	3	4	5	6	7	8	9	10
1.	Calibre	-	0,626	0,048	0,912	-0,804	0,911	0,782	-0,139	0,805	-0,953	0,532
2.	Maximum gunfire range	0,626	-	0,076	0,580	-0,549	0,626	0,685	-0,097	0,570	-0,477	0,659
3.	Rotation angle of tube	0,048	0,076	-	-0,050	-0,061	-0,118	-0,208	-0,167	-0,166	0,010	0,052
4.	Shell weight	0,912	0,580	-0,050	-	-0,687	0,959	0,791	-0,183	0,842	-0,849	0,406
5.	Fire rate	-0,804	-0,549	-0,061	-0,687	-	-0,689	-0,705	0,247	-0,663	0,724	-0,313
6.	Ordnance weight	0,911	0,626	-0,118	0,959	-0,689	-	0,842	-0,057	0,885	-0,884	0,432
7.	Ordnance size	0,782	0,685	-0,208	0,791	-0,705	0,842	-	-0,015	0,882	-0,789	0,403
8.	Shell initial velocity	-0,139	-0,097	-0,167	-0,183	0,247	-0,057	-0,015	-	-0,099	0,087	0,016
9.	Staff number	0,805	0,570	-0,166	0,842	-0,663	0,885	0,882	-0,099	-	-0,805	0,281
10.	Ammunition equipment	-0,953	-0,477	0,010	-0,849	0,724	-0,884	-0,789	0,087	-0,805	-	-0,511
11.	Effectiviness factor	0,532	0,659	0,052	0,406	-0,313	0,432	0,403	0,016	0,281	-0,511	-

Table 8 – **Correlation factors of performance characteristics for VFRW**

№	Volley fire rocket weapons	Linear correlation factor r'										
		0	1	2	3	4	5	6	7	8	9	10
1.	Calibre	-	0,479	-0,187	-0,483	0,990	0,871	0,324	0,102	-0,171	-0,103	-0,112
2.	Maximum gunfire range	0,479	-	0,113	0,224	0,547	0,533	0,556	0,575	0,112	0,481	0,731
3.	Rotation angle of tube	-0,187	0,113	-	0,461	-0,174	0,275	0,335	0,718	-0,411	-0,121	0,469
4.	Number of tubes	-0,483	0,224	0,461	-	-0,411	-0,071	0,463	0,708	0,425	0,324	0,783
5.	Shell weight	0,990	0,547	-0,174	-0,411	-	0,869	0,365	0,169	-0,132	0,038	-0,010
6.	Fire rate	0,871	0,533	0,275	-0,071	0,869	-	0,492	0,477	-0,189	-0,177	0,181
7.	Ordnance weight	0,324	0,556	0,335	0,463	0,365	0,492	-	0,837	0,242	0,078	0,608
8.	Ordnance size	0,102	0,575	0,718	0,708	0,169	0,477	0,837	-	0,122	0,215	0,853
9.	Staff number	-0,171	0,112	-0,411	0,425	-0,132	-0,189	0,242	0,122	-	0,093	0,346
10.	Movement possibilities	-0,103	0,481	-0,121	0,324	0,038	-0,177	0,078	0,215	0,093	-	0,564
11.	Effectiviness factor	-0,112	0,731	0,469	0,783	-0,010	0,181	0,608	0,853	0,346	0,564	-

Table 9 – **SPAS performance characteristics**

Sıra №	Self-propelled artillery sets	Linear correlation factor r'										
		0	1	2	3	4	5	6	7	8	9	10
1.	Calibre	-	0,481	-0,710	0,916	-0,709	0,418	0,522	0,345	-0,836	0,052	0,447
2.	Maximum gunfire range	0,481	-	-0,376	0,538	0,012	0,748	0,678	0,192	-0,341	0,355	0,928
3.	Rotation angle of tube	-0,710	-0,376	-	-0,635	0,708	0,024	-0,077	-0,624	0,567	-0,134	-0,381
4.	Shell weight	0,916	0,538	-0,635	-	-0,617	0,523	0,560	0,424	-0,760	0,056	0,537
5.	Fire rate	-0,709	0,012	0,708	-0,617	-	0,260	-0,060	-0,475	0,783	0,215	0,174
6.	Ordnance weight	0,418	0,748	0,024	0,523	0,260	-	0,728	0,137	-0,218	0,120	0,809
7.	Ordnance size	0,522	0,678	-0,077	0,560	-0,060	0,728	-	0,097	-0,410	0,286	0,560
8.	Staff number	0,345	0,192	-0,624	0,424	-0,475	0,137	0,097	-	-0,247	-0,312	0,223
9.	Ammunition equipment	-0,836	-0,341	0,567	-0,760	0,783	-0,218	-0,410	-0,247	-	0,000	-0,144
10.	Movement possibilities	0,052	0,355	-0,134	0,056	0,215	0,120	0,286	-0,312	0,000	-	0,379
11.	Effectiviness factor	0,447	0,928	-0,381	0,537	0,174	0,809	0,560	0,223	-0,144	0,379	-

– for SPAS: the influence of the maximum gunfire range and the ordnance weight on the effectiviness factor is strong; the influence of the shell weight and ordnance size on the effectiviness factor is average; the influence of other performance characteristics on the effectiviness factor is weak or it is not practically.

The explanation of "discrepancy" between quantities. For purpose of understanding of importance of the task let us construct of the mathematical model of functional dependency between weapons performance characteristics, combat properties and an effectiviness factor. Let us adopt, that

$$A = A(x_1, ..., x_{10}),$$

$$M = M(x_1, ..., x_{10}),$$

$$Y = Y(x_1, ..., x_{10})$$

$$T = T(x_1, ..., x_{10})$$

are the functions expressed numerical values of firepower, mobility, durability and applicability, respectively, and are depended on $x_1, ..., x_{10}$ variables.

Here: $x_1, ..., x_{10}$ are normalized performance characteristic's coefficients of above mentioned artillery systems. Let us express an arm effectiviness factor via firepower, mobility, durability and applicability as

$$E = E(A, M, Y, T)$$

function and adopt that

$$E(0, 0, 0, 0) = 0.$$

Let us adopt that these functions are smooth. Let us extract the linear part of

$$E(x_1, ..., x_{10}) = E(A(x_1, ..., x_{10}), M(x_1, ..., x_{10}), Y(x_1, ..., x_{10}), T(x_1, ..., x_{10})) \quad (9)$$

equation and obtain [9, p.505]:

$$E(x_1, ..., x_{10}) = \sum_{i-1}^{10} a_i x_i + o\left(\sqrt{\sum_{i-1}^{10} x_i^2}\right),$$

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$$a_i = \frac{\partial E}{\partial A}\frac{\partial A}{\partial x_i} + \frac{\partial E}{\partial M}\frac{\partial M}{\partial x_i} + \frac{\partial E}{\partial Y}\frac{\partial Y}{\partial x_i} + \frac{\partial E}{\partial T}\frac{\partial T}{\partial x_i}. \quad (10)$$

In dependence of the signs and absolute values of included in (10) quantities the α_1 can be equal unexpected values and it helps to explane an above mentioned "discrepancy". For example, $a_i = -7/492$ for included in (1) arm's calibre, we have:

$$\frac{\partial E}{\partial A}\frac{\partial A}{\partial x_i} + \frac{\partial E}{\partial M}\frac{\partial M}{\partial x_i} + \frac{\partial E}{\partial Y}\frac{\partial Y}{\partial x_i} + \frac{\partial E}{\partial T}\frac{\partial T}{\partial x_i} = -7.492 \,. \quad (11)$$

We can see, that the increace of arm's calibre influenses positively on the firepower, but in the same time, the increace of ordnance weight and staff number influenses negatively on the arm's mobility, durability and applicability. In other words,

$$\frac{\partial A}{\partial x_i} > 0, \quad \frac{\partial M}{\partial x_i} < 0, \quad \frac{\partial Y}{\partial x_i} < 0, \quad \frac{\partial T}{\partial x_i} < 0. \quad (12)$$

The negative sign of α_1 indicates that in (10) the "weigth" of negative components sum is more than positively ones. If these logical reasoning are applied to other characteristics then the sense of discrepancy in signs of coefficients included in the effectiviness factor equation is understandable.

Conclusion

The essence of the problem of determination of effectiveness factors of artillery system has been disclosed in the paper. On the base of the hypothesis of presentation possibility of effectiveness factors of artillery systems as linear combination of performance characteristics, the method of effectiveness factors calculation for the new artillery systems of the same category it has been offered.

By this model using the effectiveness factors for the several artillery systems have been calculated, by compare of obtained data with their effectiveness factors, the adequacy of constructed mathematical model has been shown. At the same, with purpose of investigation of the "discrepancy" between the linear combination coefficients and the influence feature on effectiveness factor of relevant performance characteristic, the correlation between performance characteristics and the correlation between each performance characteristic and performance characteristic have been investigated, also Pirson's linear correlations coefficients have been calculated.

The efficiency coefficient dependence on battle characteristics (artillery firepower, mobility, durability and applicability) and on the performance characteristics has been modelled. The "discrepancy" in the signs and the values of the performance characteristics coefficients has been explained by various impacts on the battle characteristics of artillery piece.

In the paper, based on the neural network the mathematical model has been constructed for determination the dependence of effectiveness factors of the artillery systems on main performance characteristics.

For determination of neural network factors, the performance characteristics and effectiveness factors of known artillery systems have been used.

The network factors have been calculated by method of least squares. For purpose of verification of the adequacy of calculated network factors the mathematical model has been applied for arms with known effectiveness factors and it confirms an appropriateness of calculations. By application of Pirson's linear correlations formula the analysis of calculated factors showed that for calculation of effectiveness factors the selected characteristics are sufficiently important.

One can think, that the constructed mathematical model for calculation of artillery systems effectiveness factors has not "discrepancy" and can be applied for assessment of effectiveness factors of the new artillery systems.

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Эффективность артиллерийских систем

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Предмет изучения: эффективность современных артиллерийских систем. **Цель статьи.** Разработка метода, который позволит определить коэффициенты эффективности артиллерийских систем. **Результаты работы.** На основе гипотезы о возможности представления коэффициентов эффективности оружия в виде линейной комбинации тактико-технических характеристик, предложен метод расчета коэффициента эффективности для нового оружия данной категории. Построена математическая модель на базе нейронной сети. Для определения параметров нейронной сети использовались характеристики и факторы эффективности известных артиллерийских систем. Синаптические коэффициенты нейронной сети были рассчитаны методом наименьших квадратов. Используя эту модель были рассчитаны коэффициенты эффективности для ряда образцов оружия. Сравнение полученных значений с известными коэффициентами эффективности показало адекватность построенной математической модели. Исследовано несоответствие между коэффициентами линейной комбинации и характером влияния на коэффициент эффективности соответствующих тактико-технических характеристик. Изучены корреляционные связи между тактико-техническими характеристиками; между каждой тактико-технической характеристикой и коэффициентом эффективности. Для рассчитанных показателей были вычислены коэффициенты линейной корреляции Пирсона. Была смоделирована зависимость коэффициента эффективности от боевых характеристик – огневой мощи оружия, мобильности, живучести и применяемости, а также, в свою очередь, их зависимость от тактико-технических характеристик. Наблюдаемое «несоответствие» в знаке и величине коэффициентов, характеризующих влияния тактико-технических характеристик, было объяснено различным характером их влияния на боевые характеристики оружия. **Выводы.** Предложенная математическая модель, базирующаяся на нейронной сети, позволяет определить зависимости коэффициентов эффективности артиллерийских систем от основных характеристик работы. Построенная математическая модель для расчета коэффициентов эффективности артиллерийских систем не «расходится» и может применяться для оценки эффективности новых артиллерийских систем.

Ключевые слова: артиллерийские системы; боевые характеристики; показатели тактико-технических характеристик; коэффициент эффективности; нейронные сети; метод наименьших квадратов; коэффициент линейной корреляции.

Ефективність артилерійських систем

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Предмет вивчення: ефективність сучасних артилерійських систем. **Мета статті.** Розробка методу, який дозволить визначити коефіцієнти ефективності артилерійських систем. **Результати роботи.** На основі гіпотези про можливість подання коефіцієнтів ефективності зброї у вигляді лінійної комбінації тактико-технічних характеристик, запропонований метод розрахунку коефіцієнта ефективності для нового зброї даної категорії. Побудовано математичну модель на базі нейронної мережі. Для визначення параметрів нейронної мережі використовувалися характеристики і фактори ефективності відомих артилерійських систем. Вагові коефіцієнти синапсів нейронної мережі були розраховані методом найменших квадратів. Використовуючи цю модель були розраховані коефіцієнти ефективності для ряду зразків зброї. Порівняння отриманих значень з відомими коефіцієнтами ефективності показало адекватність побудованої математичної моделі. Досліджено невідповідність між коефіцієнтами лінійної комбінації і характером впливу на коефіцієнт ефективності відповідних тактико-технічних характеристик. Вивчено кореляційні зв'язки між тактико-технічними характеристиками; між кожною тактико-технічною характеристикою і коефіцієнтом ефективності. Для розрахованих показників були обчислені коефіцієнти лінійної кореляції Пірсона. Була змодельована залежність коефіцієнта ефективності від бойових характеристик - вогневої потужності зброї, мобільності, живучості і вживаності, а також, в свою чергу, їх залежність від тактико-технічних характеристик. Спостережувана «невідповідність» в знаку і величині коефіцієнтів, що характеризують впливу тактико-технічних характеристик, була пояснена різним характером їх впливу на бойові характеристики зброї. **Висновки.** Запропонована математична модель, що базується на нейронній мережі, дозволяє визначити залежності коефіцієнтів ефективності артилерійських систем від основних характеристик роботи. Побудована математична модель для розрахунку коефіцієнтів ефективності артилерійських систем не «розходиться» і може застосовуватися для оцінки ефективності нових артилерійських систем.

Ключові слова: артилерійські системи; бойові характеристики; показники тактико-технічних характеристик; коефіцієнт ефективності; нейронні мережі; метод найменших квадратів; коефіцієнт лінійної кореляції.