IRSTI 55.53.29

B. Togizbayeva[1], B. Suleyev[2], Zh. Kuanyshuly[1], A. Kenesbek[1]

[1]L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan
[2]Karaganda technical university, Karaganda, Kazakhstan
E-mail: baglant099@gmail.com, culeev_bahtiyar@mail.ru, zkuanyshuly@gmail.com, kenesbekanuar@bk.ru

Determination of the technical level of excavator structures based on parametric analysis

Abstract. The article is devoted to the definition of promising excavator designs. The paper presents current models of excavators operating on the territory of the Republic of Kazakhstan. The main technical characteristics of the machines are considered. Statistical analysis and processing in the software environment were carried out. Summary statistics for each of the selected data variables are provided. It includes measures of central tendency, measures of variability and measures of form. Based on the correlation matrix of indicators, it was revealed that the weight of the excavator has the greatest relationship with the digging depth, its capacity and bucket volume. Cluster analysis was carried out using the software package. As a result of cluster analysis, it was determined that the existing excavator designs can be divided into three groups. Histograms of the distribution are constructed. With their help, modal intervals and the middle are determined. The criterion of significance and the weighting coefficient for each indicator are determined. The coefficient of the technical level is calculated. Based on the results of the technical level, promising indicators of power values, digging depth, bucket volume and excavator weight are proposed.
Keywords: excavator, construction, cluster analysis, histogram, technical level.

DOI: doi.org/10.32523/2616-7263-2022-138-1-67-75

Introduction

In our republic, the volume of construction of buildings, structures, and highways is growing annually. According to the state policy in the field of construction and social protection, the volume of construction of social facilities is growing. It is impossible to perform an increasing amount of work without the use of special machinery and equipment.

The excavator is designed for digging the soil and its subsequent movement. A modern excavator is an indispensable equipment for road construction work. The range of application of the machine is quite wide, including the excavation of hard rocks, soil and bulk materials, ore extraction, excavation of pits, maintenance of engineering structures and landscaping.

Despite the variety of machines presented, their various designs such as single-bucket, multi-bucket excavator, single-bucket excavator with hydraulic drive of working equipment has found greater use in construction.

This machine which is unique in its design is used both for digging ditches and trenches and for planning slopes and erecting embankments for the roadway.

If in the construction of automobile roads, machines with a tracked propulsion are widely used, then in the construction of buildings and structures carried out in urban conditions, machines with a wheeled propulsion are widely used, since this facilitates the delivery process (the equipment arrives at the work site independently), maneuverability increases, and the possibility of use in cramped urban conditions.

Literary review

Both domestic and foreign researchers are engaged in the development of the excavator design. Among them, we can mention the work of a group of researchers engaged in the development of completely new machine design and control systems.

The author's article [1] presents the results of numerical and experimental analysis of the stability of hydraulic excavators. The author's article [2] considers the issue of developing the design of the machine taking into account the conditions of its operation. The paper presents information about the development of an excavator control system [3].

Materials and methods of research

The modern excavator market is represented by a wide range of equipment. Among this large variety, it is extremely difficult to single out exactly the technique that needs to be used. For this purpose, an indicator – the technical level - can be used to determine trends and promising models.

To apply the assessment of the technical level of products, you must perform the following actions:

1. Collect parametric information, namely numerical data on the main characteristics of machines or their working equipment;
2. Perform factor analysis to determine the relationship of indicators;
3. Perform cluster analysis to determine homogeneous groups;
4. Formation of the structure of the coefficient of technical level;
5. Proposals for the use of the coefficient of technical level

To assess the technical level of excavators, it is necessary to process statistical data in the «Statgraphics centurion XV» application software package.

In this regard, the issues of modernization of existing designs and the development of new ones are particularly relevant. In order to determine the trend in the development of machine designs and determine promising indicators, it is necessary to conduct an analysis

Research results

To assess the technical level of excavators, we will use statistical data processed in the Stat Graphics Centurion application package, presented in Table 1. The table shows that most of the weight of excavators is in the range from 14 to 19 tons, the bucket volume is in the range from 0.5 to 0.95 m^3, the digging depth is from 4 to 6.5 meters, the power internal combustion engines from 90 to 110 kW. Based on the analysis, the following data were obtained (Table 2).

This procedure is designed to summarize several columns of quantitative data. It will calculate various statistics, including correlations, covariances, and partial correlations. Also included in the procedure are a number of multivariate graphs, which give interesting views into the data. Use the Tabular Options and Graphical Options buttons on the analysis toolbar to access these different procedures.

Table 1

Technical characteristics of excavators

№	Brand	Weight, t	Bucket volume m^3	Digging height, m	Power, kW
1	Caterpillar m 313 d	16,2	0,84	5,75	95
2	Doosan\daewoo s 180 w5	17,7	0,93	6,00	112
3	Hitachiex 160 w	16,9	0,82	5,84	90,2
4	Hyundai r 170 w	16,2	0,76	5,42	94
5	J.C.B. js 160 w	17,7	0,70	6,23	97
6	Komatsu rw160-7	16,5	0,75	5,96	90
7	Liebherr a 314	16,6	0,75	5,45	90

ISSN: 2616-7263, eISSN: 2663-1261

8	New holland mh plus	16,8	0,80	5,70	192
9	Terex tw 170	16,2	0,90	5,70	110
10	Volvo ev 160 b	17,5	0,80	6,20	103
11	Case WX95	9,85	0,28	4,3	74
12	Case WX125	12,4	0,57	4,84	84
13	Case WX145	15,3	0,95	5,5	90
14	Cat M315D	18,3	0,9	5,8	101
15	Cat M316D	19,8	1,3	6,1	118
16	Cat M318D	20,1	1,3	6,4	124
17	Caterpillar M315D2	15,2	0,76	5,3	101
18	Hitachi ZX130W	14/9	0,7	5,5	89
19	Hitachi ZX140W-3	16	0,5	4,38	110
20	Hitachi ZX160W	17,3	0,8	5,8	90

To date, the number of excavator models on the market is quite wide and is represented by various models, both with a wheeled and tracked propulsion, with a reverse and straight shovel and in various other modifications.

Table 2

Summary Statistics

	Excavator weight	Excavator power	Digging dept h	Excavator speed	Bucket volume
Count	20	20	20	20	20
Average	16,5225	102,71	5,6085	32,25	0,8055
Standard deviation	2,27691	24,2695	0,563637	4,32709	0,229679
Coeff. ofvariation	13,7807%	23,6291%	10,0497%	13,4173%	28,5138%
Minimum	9,85	74,0	4,3	20,0	0,28
Maximum	20,1	192,0	6,4	38,0	1,3
Range	10,25	118,0	2,1	18,0	1,02
Stnd. skewness	-2,51043	5,09688	-2,02438	-2,23519	0,519473
Stnd. kurtosis	3,08557	9,08907	0,909523	2,07591	1,71593

This table shows summary statistics for each of the selected data variables. It includes measures of central tendency, measures of variability, and measures of shape. Table 3 shows the correlation matrix of indicators.

Table 3

Correlation matrix of excavator indicators

	Excavator weight	Excavator power	Digging depth	Excavator speed	Bucket volume
Excavator weight		0,3847	0,8085	-0,0682	0,7970
		(20)	(20)	(20)	(20)
		0,0939	0,0000	0,7752	0,0000
Excavator power	0,3847		0,2781	-0,0589	0,3613

	(20)		(20)	(20)	(20)
	0,0939		0,2351	0,8051	0,1175
Digging depth	0,8085	0,2781		-0,0838	0,7722
	(20)	(20)		(20)	(20)
	0,0000	0,2351		0,7254	0,0001
Excavator speed	-0,0682	-0,0589	-0,0838		-0,0666
	(20)	(20)	(20)		(20)
	0,7752	0,8051	0,7254		0,7803
Bucket volume	0,7970	0,3613	0,7722	-0,0666	
	(20)	(20)	(20)	(20)	
	0,0000	0,1175	0,0001	0,7803	

As can be seen from the table, the weight of the excavator has the greatest relationship with the digging depth k (0.8085), the weight of the excavator and its power k (0.3847), and the weight of the excavator and the bucket volume k (0.7970). This finds logical confirmation.

The purpose of cluster analysis, which is performed using the Stat Graphics program (Special | Multivariate Methods | Cluster Analysis). The Euclidean distance was used as a measure of similarity in the cluster analysis procedure. Results of cluster analysis showed on figure 1.

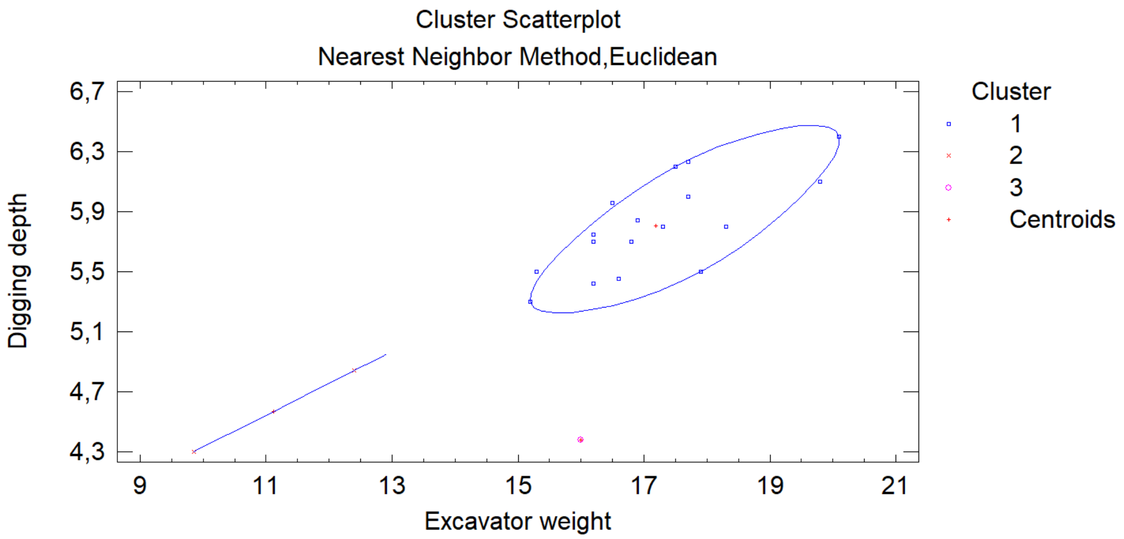
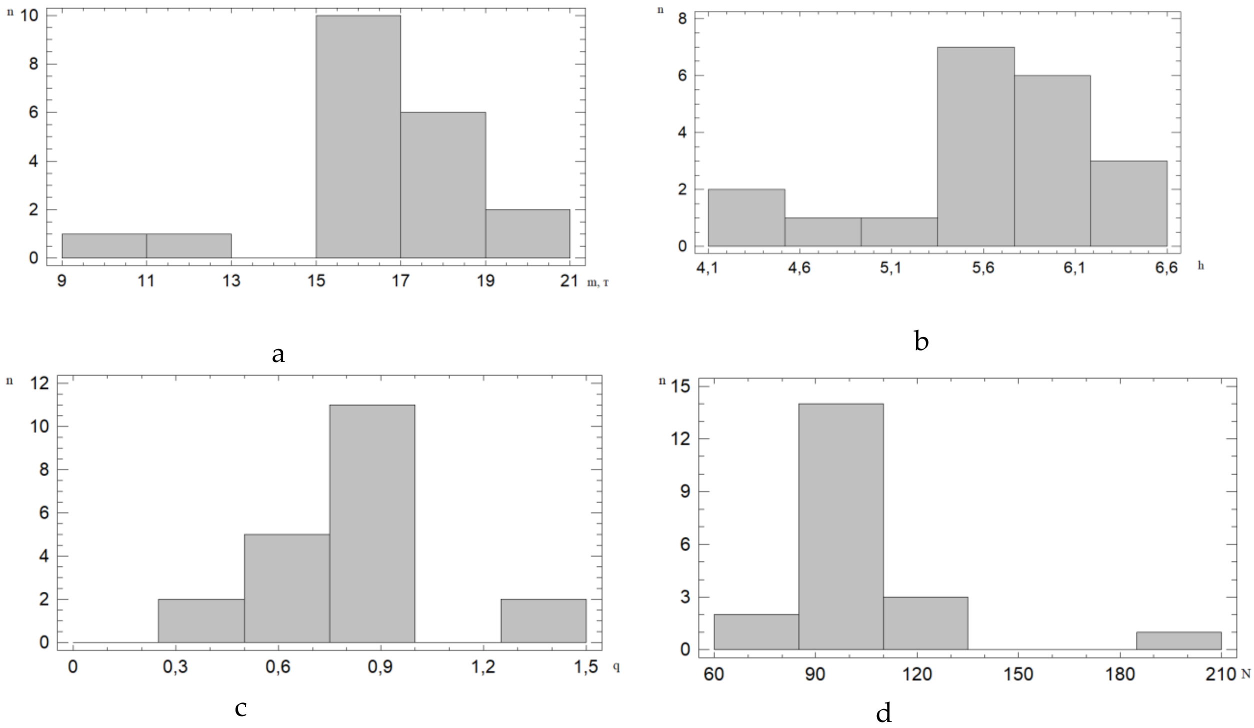


Figure 1. Cluster analysis

This procedure created 3 clusters out of 20 observations provided. Clusters are groups of observations with similar characteristics.

Cluster analysis revealed classificationally homogeneous groups of machines. This will allow us to draw conclusions with confidence from the histograms of the distribution. The histogram of the distribution of excavator indicators is shown in the figure 2.



a) excavator weight, tons; b) digging depth, m; c) bucket volume, m^3; d) engine power, kW

Figure 3. Distribution of values of excavator indicators

The modal interval for the excavator mass indicator is in the range from 15 to 17 with the middle equal to 16, the modal interval for the digging depth indicator is in the range from 5.35 meters to 5.76 meters with the middle of the modal interval equal to 5.55 meters, the excavator power is in the range from 85 kW to 110 kW, with the value of the middle equal to 97.5 kW

When determining the coefficient of the technical level of the excavator, promising indicators are the bucket volume, power and depth of digging, these indicators significantly affect the performance of the machine.

To determine the coefficient of the technical level, we will use the known equations

$$k_{TLE} = \gamma_q \frac{q_i}{q_{бi}} + \gamma_N \frac{N_i}{N_{bi}} + \gamma_h \frac{h_i}{h_{бi}} + \gamma_m \frac{m_{бi}}{m_i} \quad (1)$$

where γ_q, γ_N, γ_h, γ_m are, respectively, the weighting coefficients of the bucket volume, power, digging depth, mass;

$q_{бi}$, $N_{бi}$, $h_{бi}$, $m_{бi}$ - respectively, the basic values of the bucket volume, power, digging depth, mass.

The criterion of significance is determined by the formula 2

$$m_i = \frac{\sum m_{+-i}}{N} \quad (2)$$

where $\sum m_{+-i}$ is the number of models that fell into the modal interval on the histogram;

N is the number of models included in the histogram.

The weighting coefficient for the i-th indicator is determined by the formula 3:

$$\gamma_i = \frac{m_i}{\sum_{i=1}^{n} m_i} \qquad (3)$$

where m_i is the criterion of significance of the i-th indicator;
n is the number of analyzed models.

The values of the basic indicators, the criteria for the significance of the weighting coefficient are presented in Table 4, and the calculated values of the technical level of the technical indicators of the excavators are presented in Table 5

Table 4

The value of the basic indicators

№	Indicator	Basic value	Significance criterion	Weighting coefficient
1	Bucket volume, m^3	0,875	0,65	0,220
2	Power, kW`	97,5	0,9	0,305
3	Digging height, m	5,55	0,8	0,272
4	Weight, t	16	0,6	0,203

Table 5

Calculated values of the excavator technical level indicator

Brand	Weight	Bucket volume	Digging height	Power	Total
Caterpillar m 313 d	0,200494	0,2112	0,2818	0,2972	0,9907
Daewoo s180w5	0,183503	0,233829	0,2941	0,3504	1,0617
Hitachiex 160 w	0,192189	0,206171	0,2862	0,2822	0,9667
Hyundai r 170 w	0,200494	0,191086	0,2656	0,2941	0,9513
J.C.B. js 160 w	0,183503	0,176	0,3053	0,3034	0,9683
Komatsu rw160-7	0,196848	0,188571	0,2921	0,2815	0,9591
Liebherr a 314	0,195663	0,188571	0,2671	0,2815	0,9329
New holland mh+a	0,193333	0,201143	0,2794	**0,6006**	1,2744
Terextw 170	0,200494	0,226286	0,2794	0,3441	1,0502
Volvoev 160 b	0,1856	0,201143	0,3039	0,3222	1,0128
Case WX95	**0,329746**	0,0704	0,2107	0,2315	0,8424
Case WX125	0,261935	0,143314	0,2372	0,2628	0,9052
Case WX145	0,212288	0,238857	0,2695	0,2815	1,0022
Cat M315D	0,177486	0,226286	0,2843	0,3159	1,0040
Cat M316D	0,16404	**0,326857**	0,2990	0,3691	1,1590
Cat M318D	0,161592	0,326857	**0,3137**	0,3879	1,1900
Caterpillar M315D2	0,213684	0,191086	0,2597	0,3159	0,9805
Hitachi ZX130W	0,217987	0,176	0,2695	0,2784	0,9419
Hitachi ZX140W-3	0,203	0,125714	0,2147	0,3441	0,8875
Hitachi ZX160W	0,187746	0,201143	0,2843	0,2815	0,9547

The calculated values of the coefficient of the technical level of each type of equipment allow us to identify the most promising version of the equipment.

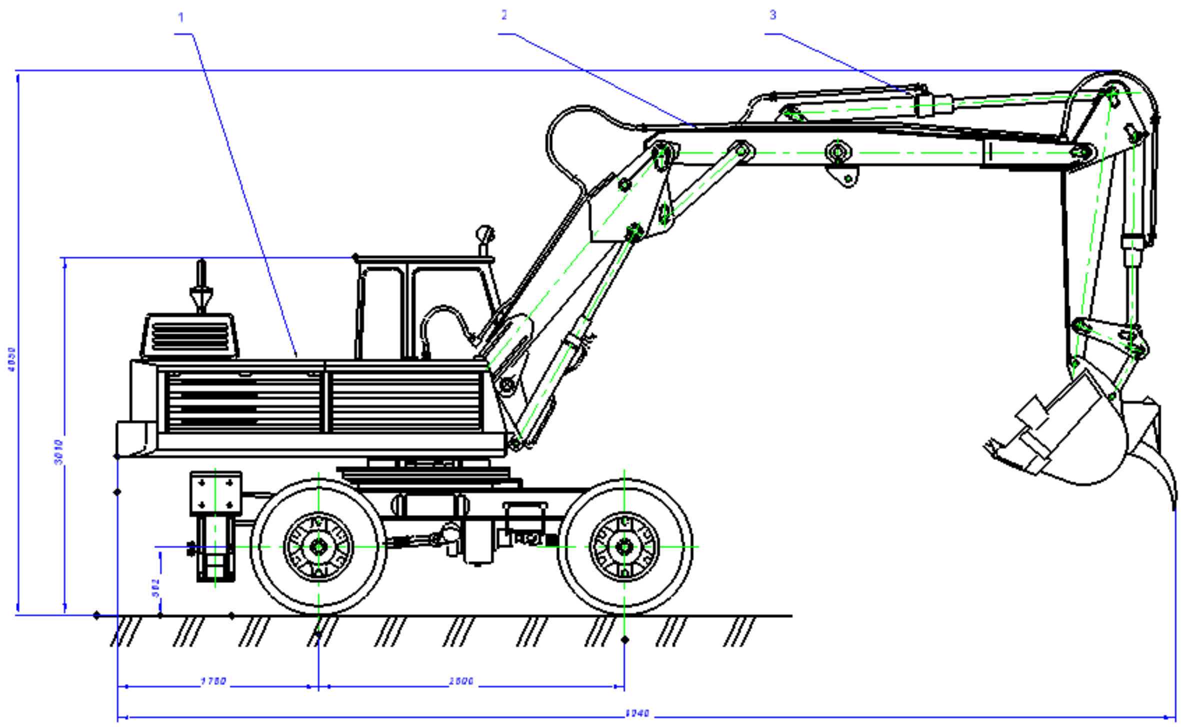
Discussion of the results obtained

The coefficient of the technical level obtained by calculation allows us to draw conclusions about the development trends and promising structures of machines.

So for excavators, promising models in terms of indicators are the following:

1. NEW HOLLAND MH+, wheeled excavator;
2. Cat M316D, wheeled excavator;
3. Cat M318D;
4. Case WX95.

According to the promising indicators of the machines, drawing works were carried out on the general types shown in Figure 2.



1-rotary platform; 2-boom; 3- hydraulic cylinder of the handle

Figure 2. General view of the excavator

Thus, the promising indicators of the excavator are the following:
- excavator weight from 16 to 19 tons;
- bucket volume from 0.8 to 1.3 m^3;
- digging depth from 5.7 to 6.4 meters
- power from 118 to 192 kW.

The conducted research will help to determine the level of technology development in the future.

References

1. Janosevic Dragoslav, Pavlovic Jovan, Jovanovic Vesna, Petrovic GoranA numerical and experimental analysis of the dynamic stability of hydraulic excavators // Factauniversitatis-series mechanical engineering – 2018. – T.16. - №2. – p. 157-170. DOI: 10.22190/FUME180404015J.

2. Tosun, a Determination of excavator type according to rock and excavator characteristics in soft formations that can be excavated directly // Journal of mining science – 2019. T.50. - №2. – p. 349-361. DOI: 10.1134/S1062739114020185.

3. Reginald, Niraj, Seo Jaho, Cha Moohyun Integrative Tracking Control Strategy for Robotic Excavation // International Journal of Control, Automation, and Systems – 2021. –T.19. - №7. – p. 3435-3450. DOI: 10.1007/s12555-020-0595-2.

Б.Тоғызбаева[1], Б.Д. Сулеев[2], Ж. Қуанышұлы[1], Ә. Кеңесбек[1]
[1]*Л.Н. Гумилев атындағы Еуразия Ұлттық университеті, Нұр-Сұлтан, Қазақстан*
[2]*Қарағанды техникалық университеті, Қарағанды, Қазақстан*

Параметрлік талдау негізінде экскаватор конструкцияларының техникалық деңгейін анықтау

Аңдатпа. Мақала экскаватордың перспективалық конструкцияларын анықтауға арналған.

Қазақстан Республикасының аумағында пайдаланылатын экскаваторлардың өзекті модельдері ұсынылған. Машиналардың негізгі техникалық сипаттамалары қарастырылады. Бағдарламалық ортада статистикалық талдау және өңдеу жүргізілді. Таңдалған деректер айнымалыларының әрқайсысы үшін жиынтық статистика келтірілген. Оған орталық тренд шаралары, өзгергіштік шаралары және форма шаралары кіреді. Көрсеткіштердің корреляциялық матрицасы негізінде экскаватордың салмағы қазу тереңдігімен, оның қуатымен және шөміш көлемімен ең үлкен байланыс бар екендігі анықталды.

Бағдарламалық пакеттің көмегімен кластерлік талдау жүргізілді. Кластерлік талдау нәтижесінде экскаваторлардың қолданыстағы конструкцияларын үш топқа бөлуге болатындығы анықталды. Таралу гистограммалары салынды. Олардың көмегімен модальды интервалдар мен орта анықталады. Әрбір көрсеткіш үшін маңыздылық критерийі мен салмақ коэффициенті анықталды. Техникалық деңгей коэффициенті есептелді. Техникалық деңгейдің нәтижелері бойынша қуат мәндерінің, қазу тереңдігінің, шөміш көлемінің және экскаватор массасының перспективалық көрсеткіштері ұсынылған.

Түйін сөздер: экскаватор, конструкция, кластерлік талдау, гистограмма, техникалық деңгей

Б. Тогизбаева[1], Б.Д. Сулеев[2], Ж. Қуанышұлы[1], А. Кенесбек[1]
[1]*Евразийский национальный университет им Л.Н. Гумилева, Нур-Султан, Казахстан*
[2]*Карагандинский технический университет, Караганда, Казахстан*

Определение технического уровня конструкций экскаваторов на основе параметрического анализа

Аннотация. Статья посвящена определению перспективных конструкций экскаватора. В работе представлены актуальные модели экскаваторов, эксплуатирующихся на территории Республики Казахстан. Рассмотрены основные технические характеристики машин. Проведен статистический анализ и обработка в программной среде. Приведена сводная статистика по каждой из выбранных переменных данных. Она включает в себя меры центральной тенденции, меры изменчивости и меры формы. На основе корреляционной матрицы показателей, выявлено, что наибольшую связь имеет вес экскаватора с глубиной копания, его мощностью и объемом ковша. При помощи программного пакета проведен кластерный анализ. В результате кластерного анализа определено, что существующие конструкции экскаваторов можно разделить на три группы. Построены гистограммы распределения. С их помощью определены модальные интервалы и середина. Определены критерий значимости и коэффициент весомости для каждого показателя. Рассчитан коэффициент технического уровня. На основании результатов технического уровня предложены перспективные показатели значений мощности, глубины копания, объема ковша и массы экскаватора.

Ключевые слова: экскаватор, конструкция, кластерный анализ, гистограмма, технический уровень

Information about authors:

Togizbayeva B. – professor of L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan.

Suleyev B. – Acting Director of the Department of science and innovation of the Karaganda technical university Kazakhstan, Karaganda, Kazakhstan.

Kuanyshuly Zh. – 2nd year doctoral student of L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan.

Kenesbek A. – L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan.

Тоғызбаева Б. – Л.Н. Гумилев атындағы Еуразия Ұлттық университетінің профессоры, Нұр-Сұлтан, Қазақстан.

Сулеев Б.Д. – Қарағанды техникалық университеті Ғылым және инновация департаментінің директорының міндетін атқарушы, Қарағанды, Қазақстан.

Қуанышұлы Ж. – Л.Н. Гумилев атындағы Еуразия Ұлттық университетінің 2-ші курс докторанты, Нұр-Сұлтан, Қазақстан.

Кеңесбек Ә. – Л.Н. Гумилев атындағы Еуразия Ұлттық университетінің аға маманы, Нұр-Сұлтан, Қазақстан.