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JUSTIFICATION OF THE PRODUCTION LINES ARRANGEMENT BASED ON QUANTITATIVE AND GRAPHIC METHODS FOR ASSESSING THE LEVEL OF EQUIPMENT EXCELLENCE

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Abstract: *On the example of the estimation of technical and economic indicators of machines for the production of burger products, the task of multicriterial choice of equipment for the production lines arrangement by methods of spectral analysis, Pareto and distance to the goal was solved.*

The method of spectral analysis is based on the apparatus of dead-end tests, involves comparing all the definite combinations of features which describe the object, has advantages over Pareto and motion to the goal methods, because it provides a generalized mathematical evaluation of the specimens which are considered.

After analyzing five indicators (productivity, capacity, capacity of the feeding bin, weight, overall dimensions) of eight samples of equipment for the burger products production from different manufacturers, it has been established that according to the chosen parameters, the preference should be given to the machine Laminerva C/E 653 1ph.

The correctness of a decision primarily depends on the correct choice of indicators to be compared. In their composition, in the future it is necessary to include indicators of reliability and durability, as well as quality indicators of finished products.

Keywords: *Multicriterial choice, Method of spectral analysis, Pareto front, Equipment.*

INTRODUCTION

The production lines arrangement for the food industry is associated with certain difficulties, caused by the need to choose the appropriate equipment reasonably. The methods of the justified choice of equipment were actively developed at the end of the 20th century, but were not widely used. The situation has not changed significantly in recent years, although some publications related to the assessment of the equipment technical level in various industries, particularly food industry (Orlov, V., Petrunina, E., 2013), mining industry (Skotnicka-Zasadzień, B., Biały, W., 2011) and energy sector (Hennen, M., Voll, P. Bardow, A., 2014) appear.

The technical level of equipment is a relative characteristic of its quality and is based on the comparison of the indicators that characterize its technical perfection, in comparison with the basic values. When evaluating alternative equipment variants, each of which is characterized by a set of parameters, we have a multicriteria task. The most common are two types of tasks - optimization and choice, which differ, first of all, in decision rules.

Deterministic methods of functions optimization with many variables are used if single criteria, for each of which the weight is determined, can be reduced to one generalized (integral) one (Belton, V., & Stewart, T., 2002). In the case of the assessment of the equipment technical level, it is not possible to develop such a generalized criterion, taking into account various technical and economic aspects, and to ensure the sensitivity of the multifactorial model. Therefore, it is advisable to pay attention to the methods of multicriterial choice of the best variant from the set of those that are considered. Despite the presence of a large number of developed methods, in the mathematical theory of choice and decision making, currently there is no common strategy for solving practical engineering problems and clear criteria for comparing the choices methods themselves.

EXPOSITION

Possibilities of using three methods of multicriteria choise - methods of spectral analysis, Pareto and distance to the goal - were demonstrated by the example of the choice of the best variant of the machine for the burger products forming. For eight variants of equipment a complex assessment of technical characteristics was fulfilled (Table 1).

Table 1. Technical characteristics of machines for burger products forming

Characteristics of machines	Machine brand							
	ABM F-2000	La Minerva C/E 653 1ph	Planus	Formatic R3000	AK2M-40	IPKS - 123	Gaser A-2000	GPM AK-MR 400
Variant number	1 S_1	2 S_2	3 S_3	4 S_4	5 S_5	6 S_6	7 S_7	8 S_8
k_1 Productivity, pcs/h	2000	3900	2100	3000	3900	1680	1900	2100
k_2 Power, kW	0,75	0,7	0,37	0,75	0,55	0,55	0,75	0,37
k_3 Feed pan capacity, *l*	20	23	32	15	20	50	20	32
k_4 Volume occupied by the machine, m^3	0,189	0,166	0,297	0,29	0,373	0,312	0,183	0,6
k_5 Net weight, kg	67	50	75	95	90	90	66	100

The spectral analysis method

The degree of objects convergence by the method of spectral analysis is calculated not by the sequential comparison of individual features, but by the comparison of all possible (or definite) combinations of features included in the object description. Let's consider a number of design fulfillment variants of equipment in the form of a making decision matrix:

$$M_{md}(S) = \begin{matrix} \\ S_1 \\ S_2 \\ \\ S_j \end{matrix} \left\| \begin{matrix} k_1 & k_2 & & k_n \\ k_{11} & k_{12} & & k_{1n} \\ k_{21} & k_{22} & & k_{2n} \\ & & & \\ k_{j1} & k_{j2} & & k_{jn} \end{matrix} \right\|, \qquad (1)$$

S_1, S_2, ..., S_j – alternative design fulfillments that are compared; k_1, k_2, ..., k_n – characteristics of alternative variants; k_{im} – the value of the characteristic k_m for the variant S_i (i = 1..j, m = 1..n).

For the transition to the dimensionless characteristics of alternative variants, it's need to carry out the normalization:

$$\overline{k_{im}} = \begin{cases} \dfrac{k_{im}}{k_{im}^{/}}, \text{ if an increase in the characteristics improves the quality of the alternative variant} \\ 1 - \dfrac{k_{im}}{k_{im}^{/}}, \text{ if an increase in the characteristics worsens the quality of the alternative variant} \end{cases}, \qquad (2)$$

$k_{im}^{/} = \max(k_{im})$ by the column m of the matrix (1).

Using expressions (2), the transition from the making decision matrix $M_{md}(S)$ to the decision matrix $M_d(S)$ is carried out. Then the degree of severity of the characteristic **g** is determined: if the characteristic exceeds a given level, then it is considered $g_{im} = 1$, otherwise $g_{im} = 0$ (i = 1..j, m = 1..n). The critical level is chosen so that in the received spectral matrix (Mc) there are no rows and columns that consist only of zeros. $g_{im}=1$ at $k_{im} \geq k_m^{кр}$, $g_{im}=0$ at $k_{im} < k_m^{кр}$ (i = 1..j, m = 1..n).

$$M_d(S)=\begin{Vmatrix} \overline{k_{11}} & \overline{k_{12}} & \overline{k_{1n}} \\ \overline{k_{21}} & \overline{k_{22}} & \overline{k_{2n}} \\ \\ \overline{k_{j1}} & \overline{k_{j2}} & \overline{k_{jn}} \end{Vmatrix}, (3) \qquad M_c(S)=\begin{Vmatrix} g_{11} & g_{12} & g_{1n} \\ g_{21} & g_{22} & g_{2n} \\ \\ g_{j1} & g_{j2} & g_{jn} \end{Vmatrix}, \quad (4)$$

$\overline{k_{11}},\ \overline{k_{12}},..,\overline{k_{jn}}$ – dimensionless characteristics of alternative variants.

The influence of characteristics on the functioning efficiency and the quality of the investigated design fulfillments of equipment is determined based on the load of the rows (the object significance) and the columns (the significance of the object characteristics) of the spectral matrix $M_c(S)$. According to the theory of the blind alley tests, the load of rows (π) is determined by taking into account the load of the columns (ω), and the load of the columns – by taking into account the load of the rows. For the row: $\pi(\omega)_i^l=\sum_{m=1}^{n} G_{\omega m}^{l-1}\cdot g_{im}$, $i=1...j$; for the column: $\omega(\pi)_m^l=\sum_{i=1}^{j} G_{\pi i}^{l-1}\cdot g_{im}$, $m=1...n$, were l – the iteration number; G_ω, G_π – normalized column and rows weights respectively.

The initial weights of rows and columns are determined:

$$G_{\pi i}^0=\sum_{m=1}^{n} g_{im}, \quad i=1...j; \ G_{\omega m}^0=\sum_{i=1}^{j} g_{im}, \quad m=1...n \qquad (5)$$

Calculations are stopped when a given convergence of the iterative process is obtained.

In the course of the work, a making decision matrix $M_{md}(S)$, a decision matrix $M_d(S)$ and a spectral matrix $M_c(S)$ are constructed, in which the rows represent the equipment brands under consideration, and the columns – their technical characteristics. The matrix of decisions $M_d(S)$ is obtained by normalizing the characteristics using formulas (2). From the listed characteristics an increase of characteristics k_1 (productivity) and k_3 (capacity of a loading bunker) improves the quality of the alternative variant, while an increase of parameters k_2 (power), k_4 (dimensions), k_5 (weight) worsens them.

Based on the analysis of the characteristics of machines for the burger products forming, given in Table 1, we adopt the following critical levels of characteristics:

$$k_1^{kr}=0{,}6;\ k_2^{kr}=0{,}5;\ k_3^{kr}=0{,}7;\ k_4^{kr}=0{,}7;\ k_5^{kr}=0{,}1. \qquad (6)$$

Given the loads on rows and columns, weightedness of the objects characteristics is determined. In the solution, two iterations are carried out (Fig. 1, figures in circles denote the sequence of calculation steps), the iterative process converges to the values of the boundary loads. It has been established that the best integrated estimate of 1 is characteristic of the machine Laminerva C/E 653 1ph.

$$M_{dm}(S)=\begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ S_7 \\ S_8 \end{matrix}\overset{\begin{matrix} k_1 & k_2 & k_3 & k_4 & k_5 \end{matrix}}{\begin{Vmatrix} 2000 & 0.75 & 20 & 0.189 & 67 \\ 3900 & 0.70 & 23 & 0.166 & 50 \\ 2100 & 0.37 & 32 & 0.297 & 75 \\ 3000 & 0.75 & 15 & 0.29 & 95 \\ 3900 & 0.55 & 20 & 0.373 & 90 \\ 1680 & 0.55 & 50 & 0.312 & 90 \\ 1900 & 0.75 & 20 & 0.183 & 66 \\ 2100 & 0.37 & 32 & 0.600 & 100 \end{Vmatrix}} \quad M_d(S)=\begin{Vmatrix} 0{,}51 & 0 & 0{,}4 & 0{,}69 & 0{,}33 \\ 1 & 0{,}07 & 0{,}46 & 0{,}72 & 0{,}5 \\ 0{,}54 & 0{,}51 & 0{,}64 & 0{,}51 & 0{,}25 \\ 0{,}77 & 0 & 0{,}3 & 0{,}52 & 0{,}05 \\ 1 & 0{,}27 & 0{,}4 & 0{,}38 & 0{,}1 \\ 0{,}43 & 0{,}27 & 1 & 0{,}48 & 0{,}1 \\ 0{,}49 & 0 & 0{,}4 & 0{,}7 & 0{,}34 \\ 0{,}54 & 0{,}51 & 0{,}64 & 0 & 0 \end{Vmatrix} \quad M_c(S)=\begin{Vmatrix} 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{Vmatrix}$$

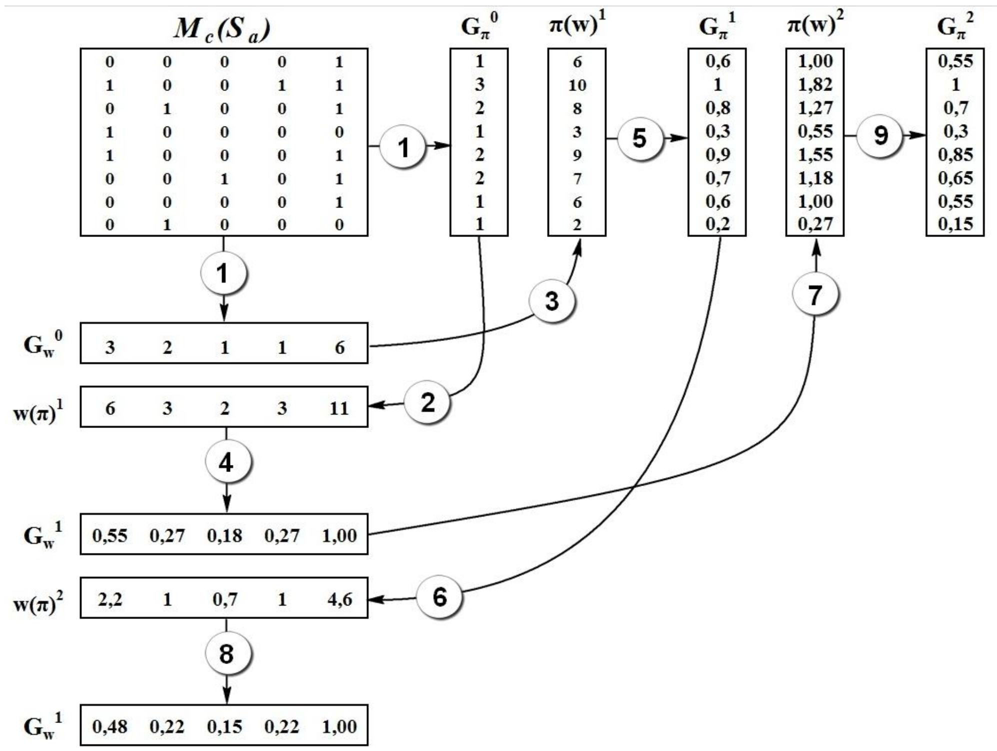


Fig.1 The calculation scheme of the choice of the optimal variant in accordance with the spectral approach to determining the importance of the object characteristics

The Pareto analysis method

Pareto optimality is intended to determine if the proposed change improves the overall level of the object. The principle of dominance is used to find effective (Pareto-optimal) variants. Assume that the variants that are compared are estimated by the vector of criteria: $\mathbf{k} = \{k_1, k_2, ..., k_n\}$, $k_i \in \mathbf{K}$, $i = 1...n$.. Then variant A dominates variant B, if each criterion k_i^A prevails or is equivalent to the corresponding criteria k_i^B, at least for one of them there is a strict preference k_i^A over k_i^B. It convenient to use the Pareto analysis method in graphical interpretation on a plane, alternately comparing two criteria. It gives the opportunity to go out an effective boundary that combines options that dominate others and do not have domination over them. Variants that lie on the effective boundary are called Pareto optimum.

For a visual representation of the solution for a number of alternatives, two criteria were considered alternately (Fig.2). First of all, for the eight design fulfillments of the equipment, we considered the indicators that have the highest weight - productivity, pcs./h and power consumtion, kW (Fig. 2a). The direction of the abscissa (power) axis is inversed, since optimization by the power criterion is associated with its minimization. Points 1 to 8 depict the variants of machines for burger products forming. In this case, the variants of the dominant machines are La Minerva C/E 653 1ph (point 2), Planus (point 3) and GPM AK-MR 400 (point 8), becouse above and right of them there are no variants for improvement by two characteristics at once. Since there are three variants of equipment on the effective border, the following characteristics should be considered. Leaving the most significant indicator – productivity, we take into account the feed pan capacity, which, if the forming process is periodicity, affects the duration of auxiliary operations and hygienic process. In this case, the variants of machines that are on the effective border - La Minerva C/E 653 1ph (point 2) and IPKS-123 (point 6). To obtain a more objective solution, the following characteristic is considered: the overall dimensions of the equipment, which are represented in generalized form by the volume occupied by the machine (Fig. 2 c).

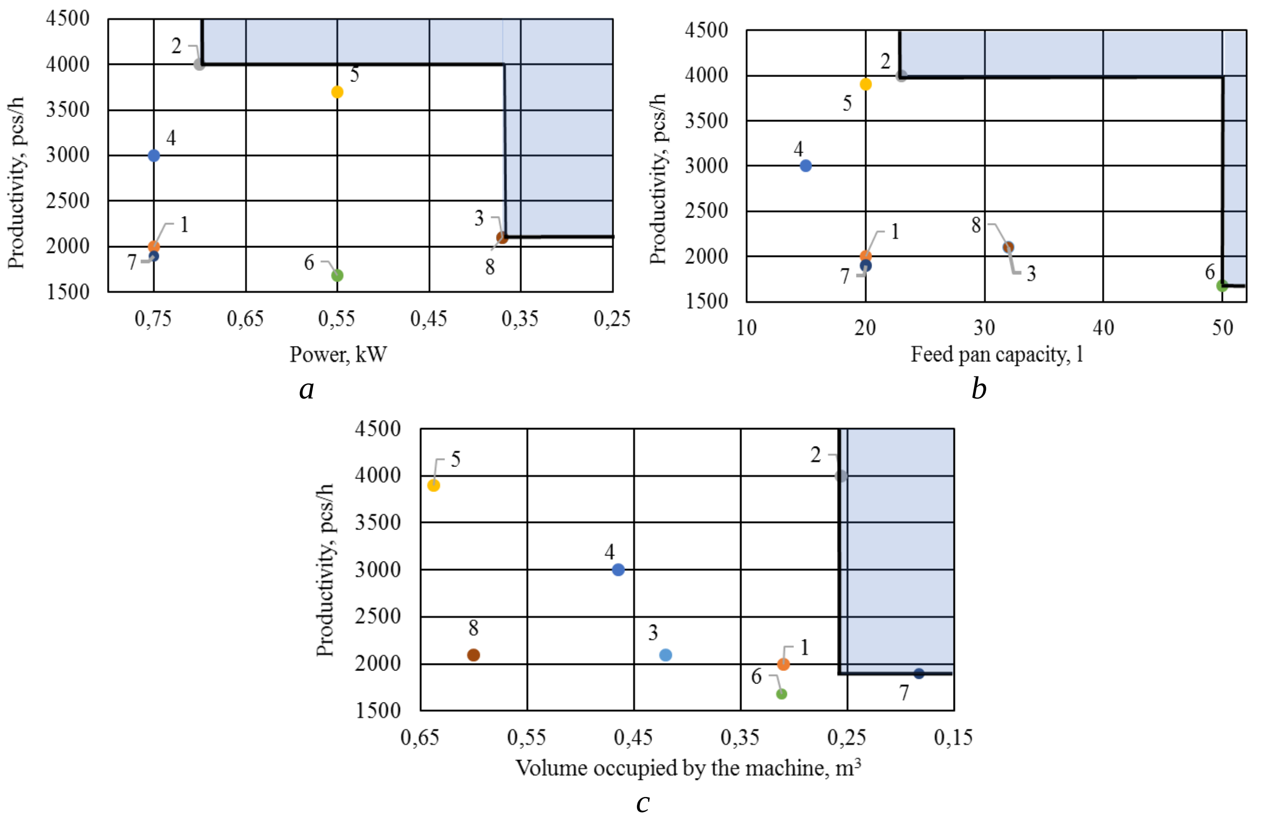
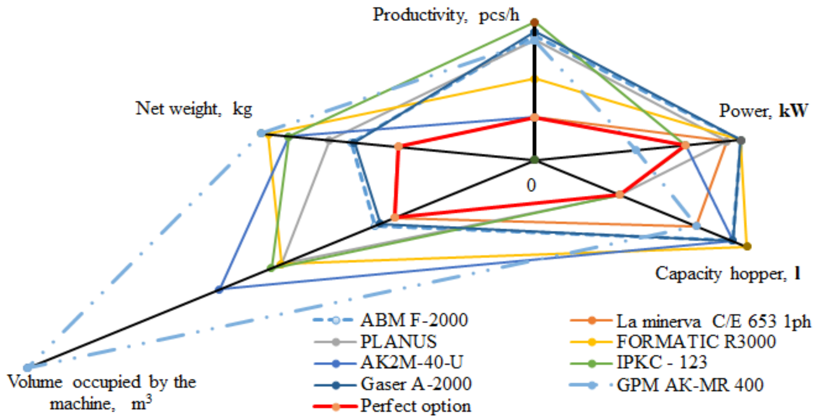


Fig. 2. Choosing the best variant of the machine for burger products forming based on the Pareto principle at the parameters that are considered:
a - productivity - power, *b* - productivity - feed pan capacity, *c* - productivity - volume occupied by the machine

Variants of equipment, which dominate over others, are the machine La Minerva C/E 653 1ph (point 2) and Gaser A-2000 (point 7). The La Minerva C/E 653 1ph there is at an effective boundary for all of the considered combinations of parameters. Consequently, it is appropriate to choose it as one that has the largest productivity among the considered at moderate power consumption and small overall dimensions.

The method of distance to a goal

Another simple method for solving the problem of multicriteria choice is to apply an integral criterion of distance to a goal. The method essence is to justify the ideal and evaluate the degree of approach to it each of the variants of the original set. The ideal variant characterizes such a system, for which each criterion reaches its potentially possible best value, which can be theoretically substantiated or correspond to the best actually achieved value. The practical application of the method is presented on a graphical model (Fig. 3). For variants of the initial set of alternatives, criteria k_i are determined and put on a radially located scales. The scale is constructed so that the improvement of the criterion goes to the center (point 0). By connecting points on the scales for the j-th option, a polygon is obtained. At the best values of the criteria, a polygon of an idealized variant is constructed. A generalized criterion of distance to the goal μ is defined as the ratio of the area of j-th variant to the idealized area.



Variant	μ
S_1	2,86
S_2	1,51
S_3	2,61
S_4	3,63
S_5	3,20
S_6	2,94
S_7	2,86
S_8	4,98

Fig. 3. Multi-criteria assessment of machines technical level by a distance to the goal method

CONCLUSION

In order to assess the technical level of equipment it is expedient to use methods of multicriteria choice. The results obtained by the three methods of multicriteria choise (spectral analysis, Pareto and distance to the goal) are the same. After analyzing five characteristics of eight variants of equipment for the burger products forming by different manufacturers has been established, that according to the chosen parameters the advantage should be given to the machine La Minerva C/E 653 1ph.

In our opinion, the most expedient is the application of the spectral analysis method because it enables to take into account in a complex way all the criteria that characterize the technical level of equipment and the efficiency of its work. The method does not require special skills in working with graphic information and is the most formalized. The correctness of a decision primarily depends on the correct choice of indicators to be compared. In their composition, in the future it is necessary to include indicators of reliability and durability, as well as quality indicators of finished products.

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