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APPLIED ECONOMIC-MATHEMATICAL ANALYSIS OF FIRE-RESISTANT PRODUCTS SINTERING PROCESSES: EFFICIENCY MANAGEMENT OF PRODUCTION PLANS PJSC «ZAPORIZHVOGNETRYV»

The article addresses the problem of applied economic-mathematical analysis of interrelated processes in the production, sintering, and material-resource support of fire-resistant product manufacturing. A conceptual approach to modeling the distribution of raw materials for obtaining an optimal charge is substantiated, considering the criterion of minimizing the total production cost of material and raw material expenses for fulfilling the order portfolio of PJSC «Zaporizhvognetryv». The author's modeling concept is based on the principles of a systemic approach, employing research methods such as economic-mathematical modeling, correlation-regression analysis, and groups of statistical data processing and summarization methods. This is used to create and implement a modeling toolkit – a complex of economic-mathematical and information models of a specific structure (developed in MS Excel electronic spreadsheets). These models collectively realize the functionality of the "Charge Optimization" and "Raw Material Price Forecasting" modules. This ensures effective operational and tactical regulation and management of the efficiency of production plans at the level of the main links of the production activities of PJSC «Zaporizhvognetryv». A human-machine dialogue procedure has been developed for calculating the demand for raw materials in conditions of multivariate combinations of acceptable rational variants of charges. To implement this procedure, an integrated information model was developed on the MS Excel platform, automating decision support for the distribution of charge materials among different charge variants for the production of fire-resistant products, in compliance with technological norms and aligned with the volume of the planned order portfolio of PJSC «Zaporizhvognetryv». The proposed mathematical and informational support enables the automated operational verification of the compiled production plan for its resource balance and adherence to contractual business obligations through a dialog system on the MS Excel platform, using the developed economic-mathematical model for charge optimization. The directions for applied economic-mathematical analysis of management decisions based on the developed toolkit are outlined. The model-algorithmic complex was tested on the statistical data of PJSC «Zaporizhvognetryv» to assess the effectiveness of the compiled production plan (planning horizon – one month). The obtained economic effect is justified, indicating a conditional reduction in total costs (model calculations) by 8,6 million UAH compared to actual expenses. This allowed practical recommendations to be made for further improvement of the efficiency management of production plans for PJSC «Zaporizhvognetryv» based on the calculations.

Key words: sintering, model, optimization, information data model, economic-mathematical analysis.

Problem Statement. PJSC "Zaporizhvognetryv" is a leader among Ukrainian enterprises in the production of fire-resistant products. The company specializes in the production of refractory, high-alumina, magnesia, and unshaped products used by enterprises in the metallurgical, cement, glass, chemical, and thermal power industries for lining their own units and furnaces. It is evident that during the post-war recovery period of the Ukrainian economy, there will be a surge in demand for the products of these enterprises, and consequently, for the fire-resistant products of PJSC "Zaporizhvognetryv". Under these conditions, the guarantee of competitiveness for PJSC "Zaporizhvognetryv" in the refractory products market is its competitive price (acceptable to business partners), directly correlated with its production cost. The most significant share (over 80%) in the production cost of refractories is occupied by the cost of its material and raw material component (raw materials, charge materials, semi-finished products, components, etc.).

Therefore, from the perspective of the systemic management of PJSC "Zaporizhvognetryv's" activity efficiency, the most crucial subsystems are those responsible for the rhythmic flow of business processes in the production of refractory products and the corresponding material and technical support of this production. This is because high economic efficiency in the procurement, delivery, and transfer of raw materials (charge components) and components into production is the main factor and, simultaneously, a reserve for reducing the cost of material expenses in the overall production cost of refractory products.

During the technical-technological processes of producing a range of refractory products and the associated processes of material-technical support and logistical inventory management of charge materials, the management services of PJSC "Zaporizhvognetryv" encounter a series of objective problematic situations directly or indirectly related to the planning, accounting, and control of expenses to fulfill the enterprise's planned order portfolio (hereinafter – POP) [8]:

1. The management of PJSC "Zaporizhvognetryv" adheres to a strategy focused on orders, requiring the production units to fully implement the planned order portfolio (POP) for refractory products. In this context, a significant and current task is the constant reduction of material costs in the production of refractory products through the optimization of charge variants based on the criterion of their minimum cost.

2. The peculiarity of refractory production lies in the diversity of material flows characterized by a wide range of diverse nomenclature of charge materials used in the production cycle.

3. There are objective constraints on the availability of charge materials in the warehouses of PJSC "Zaporizhvognetryv," directly related to the high variability of prices for the assortment of charge materials in raw material markets and limited warehouse space. The current volume of available charge materials in the warehouse fluctuates, making it impractical to constantly maintain inventory for the charge of a single or a few most acceptable variants. In a prolonged period, there may be an economically unjustified surplus of certain charge materials and a shortage of others. This will inevitably lead to unforeseen significant financial losses, either due to unplanned storage cost increases (in case of surplus) or the need for additional urgent procurement of materials at inflated prices, or even disruptions in the production plan and failure to meet commitments to business partners (in case of shortage).

Thus, there is a problem in selecting a set of rational charge variants for the range of refractory products, which is associated with the multivariability of available methods (variants) of charging. This complexity is further compounded by the lack of always effective management of purchasing charge raw materials and their storage at the enterprise. This underscores the need to search for ways to effectively (optimally) distribute charge materials, taking into account the production plan of the enterprise and the contracts concluded with business partners.

Review of Recent Research and Publications. Formulating a multi-component charge is one of the key stages in the production cycles of industrial enterprises [1; 10]. The essence of sintering lies in mixing individual components (charge materials containing certain percentage ratios of specific chemical elements) according to an established technological scheme in strictly regulated proportions. The goal is to obtain a mixture (charge) of specified quality, with the necessary chemical composition and predefined physical properties. The specificity of modern refractory production lies in the diversity of material flows, primarily the flows of raw resources of a wide nomenclature, which are used as charge materials. The cost (market price) of these charge materials varies within fairly broad boundaries, explained by their chemical characteristics, quality, demand on raw material markets, transportation and storage costs, and other factors. When the quality of individual components changes, their partial participation may be adjusted to ensure that the key indicator in the charge remains at a specified level that should not exceed permissible fluctuation limits.

The rational proportions of charge materials in the blend are determined by technologists a priori, in accordance with established standards to allow for the chemical composition within the permissible limits. This is done considering the cost of charge materials and their availability in the enterprise's warehouses. The pursuit of the optimal ratio of charge materials in the blend based on a posteriori assessments is a crucial direction for continuously improving production processes. This aims to reduce the cost of the blend and, consequently, enhance the economic efficiency of the entire production cycle of the enterprise. In the classical formulation, this task is expressed as follows: it is necessary to calculate the optimal (most cost-effective) composition of a multi-component charge, where the charge contains certain percentage ratios of specified chemical elements (in accordance with technological standards), and certain requirements are imposed on the composition of charge materials [1; 10].

The experimental method of searching for the optimal structure of a blend for enterprises is typically unacceptable because it is high-risk and, as a result, expensive due to the potential for obtaining unforeseen and inefficient blend variations, essentially resulting in random exploration. An alternative is analytical methods for calculating the blend, among which the optimization method (with its theoretical foundation being economic-mathematical modeling) is recognized as progressive [9; 12], demonstrating superior and more relevant results. Therefore, the ability to conduct necessary numerical calculations to find optimal mass ratios of charge materials in the blend with specified chemical and physical characteristics, perform economic-mathematical cost analysis of the production plan, and forecast the final sintering results is a prerequisite for developing effective production plans for metallurgical enterprises in general and refractory plants in particular.

The formulation of the problem for applied economic-mathematical analysis of the interconnected processes of production, sintering, and material-resource provision in the production of refractory products involves the theoretical justification of the structural-logical scheme and the analytical toolkit of a modeling algorithm for a human-machine interactive system for managing the efficiency of production plans in the short-term and long-term horizons.

The goal of the conducted scientific-practical research is the development of mathematical support and logical-algorithmic procedures for dynamically searching for optimal blends during the production of a range of refractory products. This includes considering the need for charge materials and efficiently managing their inventory in the warehouses of the enterprise, taking into account the diversity of combinations of used types of charge materials (illustrated with the example of PJSC "Zaporizhvognetryv").

Presenting main material. The analysis of the network of business processes of PJSC "Zaporizhvognetriv" allowed us to highlight its fragment, which directly relates to batching in the manufacture of a given range of refractory products (planned PZP) and its material and technical support, including the marketing component. The selected fragment is represented by a separate virtual management business process, which we tentatively named *"Analysis of bottlenecks in the process of developing a production plan",* with the following key functional blocks: "Formation of a portfolio of orders → Technical and technological maps for the manufacture of refractory products → Compilation of a production plan → Evaluation of the profitability (economic efficiency) of the production plan → Production" (for details, see [4]). At separate links of this business process, "problematic" aspects from the point of view of information transparency and managerial control are highlighted, which are related to the processes of planning, accounting and control of costs for the implementation of the planned PZP, taking into account the criterion of the minimum cost of material costs for the production of refractory products and principles effective management of the purchase of bulk raw materials, its storage in the company's warehouses, as well as due to the optimization of batch options.

Further decomposition of functional blocks and analysis of "problematic" aspects in the link *"Development of a production plan → Evaluation of profitability"* made it possible to reveal hidden reserves for increasing the manageability and efficiency of this business process by minimizing the cost of resource costs, taking into account the multiplicity of available batches (batching options). We consider it expedient to consistently increase the efficiency and reliability of planned management decisions taking into account the principles of system analysis with the involvement of economic and mathematical modeling tools.

The problem set outlined in the insights was solved on the basis of the economic-mathematical model we built for the task of multivariate selection of the optimal batch for the production of an assortment of refractory products in the conditions of the course of business processes of PrJSC "Zaporizhvognetriv".

Below is a brief description of the logic, mathematical functionality and economic content of the basic structural components of the economic-mathematical model (hereinafter – EMM).

Model indexes:

$i = \overline{1, I}$ – identifier of refractory products (product type number);

$j = \overline{1, J_i}$ – identifier of the variant of the charge (number of the manufacturing method);

$k = \overline{1, K}$ – resource type identifier (number of batch material);

$s = \overline{1, S}$ – identifier of the resource provider (business partner);

$t = \overline{1, T}$ – identifier of the calendar period (number of the week, decade, month, etc.).

The coefficients (constants) and notation in the model are fixed for the period t (known numbers/calculated indicators):

a_{ijk}^t – the consumption rate of the k-th charge material (in tons) for the production of the i-th type of refractory products using the j-th charge option;

$A_i^t = \{a_{ijk}^t\}, i = \overline{1, I},$ – matrix of consumption rates of charge materials for the production of the i-th type of refractory products with the use of available charge options;

c_{ij}^t – standard cost (in conv. units: USD, UAH) of the cost of charge materials for the production of 1 ton of the i-th type of refractory products with the use of the j-th option of charge – the variable part of the cost of 1 ton of finished products;

$C^t = \{c_{ij}^t\}$ – matrix of normative costs of charge materials for the production of 1 ton of an assortment of refractory products with the use of available charge options;

p_{ks}^t – the current price for period t (in conv. units: USD, UAH) for a ton of the k-th batch material assigned by the s-th supplier;

$P^t = \{p_{ks}^t\}$ – matrix of prices (in conv. units: USD, UAH) per ton from suppliers of bulk materials.

Model parameters calculated/updated for period ***t****:*

V_i^t – volume of the production order of the i-th type of refractory products (in tons) for the planned period *t*;

$V^t = \{V_i^t\}$ – production order vector for an assortment of refractory products (in tons) for the planned period *t*;

$\bar{p}_k^t$ – average price (in conv. units: USD, UAH) for a ton of the k-th batch material stored in the company's warehouse;

$\bar{D}_k^t$ – the average daily balance (in tons) of the k-th batch material in the company's warehouse, taking into account current consumption and planned (expected) delivery;

$\mathfrak{t}^t$ – number of days in the planning period ($\mathfrak{t}^t$ =30 days).

Controlled variable models are updated for period t:

x_{ij}^t – the number of tons of the i-th type of fireclay products, which, according to the production plan, should be produced using the j-th variant of the filler;

y_k^t – the amount of deficit ("+") or surplus ("-") of the k-th batch material (in tons) for the production of a range of fireclay products according to the production order plan V^t.

The target function of the model is the minimization of total costs for the production of the planned volume of fireclay products:

$$F^t = \sum_{i=1}^{I} \sum_{j=1}^{J_i} (c_{ij}^t \cdot x_{ij}^t) \to min, \tag{1}$$

or taking into account the expression for the normative value ($c_{ij}^t = \bar{p}_k^t \cdot a_{ijk}^t$) of bulk materials per 1 ton of fireclay products, we get:

$$F^t = \sum_{i=1}^{I} \sum_{j=1}^{J_i} \sum_{k=1}^{K} [(\bar{p}_k^t \cdot a_{ijk}^t) \cdot x_{ij}^t] \to min. \tag{2}$$

System of limitations of the model:

1. Restrictions on the performance of the planned task from the assortment of fireclay products*:*

$$\sum_{j=1}^{J_i} x_{ij}^t \geq V_i^t, i = \overline{1, I}. \tag{3}$$

2. Balance limit on the use of bulk materials for the production of a planned order of an assortment of fireclay products:

$$\sum_{i=1}^{I}\sum_{j=1}^{J_i}\left(x_{ij}^{t}\cdot a_{ijk}^{t}\right)+y_k^t=\tau^t\cdot\overline{D}_k^t,\ k=\overline{1,K}. \tag{4}$$

3. Restrictions on the admissibility of the marginal deficit of bulk materials, if $y_k^t<0$, , and the marginal surplus of charge materials, if $y_k^t>0$:

$$Y_k^{min}\le y_k^t\le Y_k^{max},\ Y_k^{min}<0,\ Y_k^{max}>0, \tag{5}$$

where Y_k^{min}, Y_k^{max} – set maximum permissible values for the amount of "managed" deficit and surplus.

4. The condition of non-negativity of variables:

$$x_{ij}^t\ge 0,\ i=\overline{1,I},\ j=\overline{1,J_\iota}. \tag{6}$$

Thus, the EMM of the problem of multivariate selection of the optimal charge for the production of an assortment of refractory products, taking into account the planned PZP, takes the following form:

$$F^t=\sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{k=1}^{K}\left[\left(\bar{p}_k^t\cdot a_{ijk}^t\right)\cdot x_{ij}^t\right]\to min \tag{7}$$

$$\begin{cases}\sum_{j=1}^{J_i}x_{ij}^t\ge V_i^t,i=\overline{1,I},\\ \sum_{i=1}^{I}\sum_{j=1}^{J_i}\left(x_{ij}^t\cdot a_{ijk}^t\right)+y_k^t=\tau^t\cdot\overline{D}_k^t,\ k=\overline{1,K},\\ Y_k^{min}\le y_k^t\le Y_k^{max},\\ x_{ij}^t\ge 0,i=\overline{1,I},j=\overline{1,J_\iota}.\end{cases} \tag{8}$$

The economic-mathematical model (7)-(8) belongs to the class of linear programming problems; when using it, well-known methods of linear programming are used, in particular, the simplex method, which is implemented in the program "Search for a solution", which is included in the functionality of the standard MS Excel package [2; 9; 12].

Information model of data for the economic-mathematical model of charge optimization. The numerical solution of the problem (7)-(8) requires obtaining an array of relevant statistical information, in particular, data on the consumption rates of bulk materials, their average balances in the warehouses of the enterprise, current prices for their purchase, information on business partners of suppliers of raw materials and components, etc. It is expedient to form such a statistical base and digitize it in the infospace in the form of a complex of special information data models (hereinafter – IMD), which create an informational (digitized) image of the object and at the same time are a "road map" for the structured placement of local information content (data about the object object) on a certain hardware or software platform [6; 7]. This actualizes the task of developing a human-machine dialog system to support decision-making regarding the management of the effectiveness of production plans in the short-term and long-term horizon.

Complex IMD for the implementation of the developed model-algorithmic complex is a relational model (it is easy to understand and use; does not require specialized knowledge or professional programming skills from users), where the relationships between attributes reflecting the relationship of various parameters and variables in models (7)-(8), implemented through the formulas of the functionality of the standard package of electronic spreadsheets MS Excel. According to the field of use, this IMD is a game model that is configured to study the possible behavior of an object in programmed or unforeseen situations. Thus, IMD includes the possibility of modeling technical-technological, economic, marketing or management force majeure, which is connected, in particular, with a shortage/surplus of batch components in the warehouse, unpredictable changes in the production plan for marketing or technological reasons, etc. [3] (a full description of IMD exceeds the maximum scope of the article; the full text will be available later from other works of the authors).

Post-optimization economic-mathematical analysis of the results of computer modeling of the optimal charge for the production of refractory products. A test run of the model-algorithmic complex was carried out on the statistical base, which was formed using a group of statistical observation methods. Omitting the optimal solution of the problem detailed by the assortment positions of the production plan and the corresponding charging options (the optimal values of x_{ij}^t of the model (7)-(8)) are found, we state only the generalized results, namely [3]:

- model calculations were carried out based on the range of products produced by three main workshops, namely: fireclay, high-alumina and magnesium products;
- the model built for these three shops in the form (7)-(8) contains: 49 types of refractory products, including 226 different filling options for them – x_{ij}^t (controlled variables); 69 parameters that correspond to the values of the "rational deficit" in relation to stocks of bulk materials in the company's warehouses, – y_k^t (controlled variables); 69 linear inequalities-constraints in the form of expression (4), which formalize the balance conditions for the use of charge materials; 49 linear inequalities-constraints in the form of expression (3) on the fulfillment of business obligations of the enterprise regarding the production of refractory products; 69 linear inequalities-constraints in the form of expression (5) on the permissible limits regarding the permissible deficit/surplus of bulk materials in the warehouse;
- the calculated optimal (maximum) value of the objective function (7) for the conditionally optimal production plan of the model shows that the total cost of batch components for its implementation (planning horizon – calendar month) reaches UAH 50.938 million, and for the implementation of the compiled production plan of PrJSC "Zaporizhvognetriv" for the same period – UAH 59.575 million. So, the conditional savings of total costs for the production plan is UAH 8.637 million. or 14.50% per month.

The described model (7)-(8) can be expanded by taking into account additional information about expected and/or forecasted events when calculating/determining its component parameters. It is, in particular, about market prices p_{ks}^t for bulk materials, their consumption rates a_{ijk}^t in case of equipment reconfiguration, etc. Here, market prices are peculiar indicators of the effectiveness of management decisions, when the person who makes the decision (hereinafter referred to as the OPR) includes in the production plan of the enterprise one or another method of charging with a certain intensity x_{ij}^t for the production of an assortment of refractory products and actually forms its planned cost price. A "successful" or "unsuccessful" choice of batching methods in the aggregate of the assortment of refractory products leads to a significant discrepancy in the total cost of the manufactured products due to a significant variation in the prices of different batching materials over time. This makes it possible to emphasize the following: the actual cost of the charge for refractory production is under the determining influence of the variability of market prices for the relevant charge materials.

These or other probable events are associated, in particular, with the following scenarios:

- a transition from one method of charging to another is carried out within the planned period under conditions of force majeure or other technical-technological or marketing-logistical necessity or expediency;
- costs for bulk materials are saved due to a "successful" purchase on the raw materials market at an attractive price (or obtaining significant discounts), which is connected with an effective system of forecasting prices for these raw materials;
- change of the supplier of bulk materials in connection with the degree of reliability and timeliness of delivery;
- others.

We propose the additional inclusion of the following parameters in the model (7)-(8) taking into account the issues outlined above (for the planned period t):

$l=\overline{1,L}$ – unit identifier (shop number): let l=1 – Aluminosilicate Department #1, l=2 – Aluminosilicate Department #2, l=3 – Magnesium Products Department;

b_{ij}^t – costs (in U.S. dollars, hryvnias), which are associated with the need to switch from the current charging option to some new j-th option for the production of the i-th type of refractory products, are included as a component in the calculation of the indicator cost price c_{ij}^t;

$B^t=\{b_{ij}^t\}$ – cost matrix (in U.S. dollars, hryvnias) for reconfiguring the equipment when switching from one charging variant to another for the production of the i-th type of refractory products;

n_{ij}^t – the number of batches of the i-th type of fireclay products (weighing 1 ton each), which are planned to be manufactured using the j-th option of charging, taking into account the production capacity of the workshop – is taken into account when calculating the indicator b_{ij}^t;

$N^t = \{n_{ij}^t\}$ – the matrix of the necessary production capacities of the shop for the execution of the planned task taking into account V_i^t.

M_{ks}^t – marketing costs (in U.S. dollars, hryvnias) for ordering and delivery from the s-th supplier to the company's warehouse of the ordered volume D_k^t (in tons) of the k-th batch material – included as a component in the calculation price index p_{ks}^t;

$M^t = \{M_{ks}^t\}$ – matrix of marketing costs (in U.S. dollars, hryvnias) for placing an order and delivering bulk materials from suppliers to the company's warehouse, taking into account the ordered volumes D_k^t (in tones);

D_k^t – placed (paid to the supplier) volume of the order (in tons) of the k-th batch material (scheduled or unscheduled delivery), which is expected to arrive at the company's warehouse in the period t;

$\bar{\tau}_k^t$ – the average delivery time (in days) of the required (planned) volume (in tons) of the k-th batch material from suppliers from the rated list of business partners – is taken into account when calculating the indicator M_{ks}^t;

τ_{ks}^t – delivery time (in days) of the required (planned) volume (in tons) of the k-th batch material from the s-th supplier – is included as a component in the calculation of the indicator $\bar{\tau}_k^t$;

$TS^t = \{\tau_{ks}^t\}$ – matrix of delivery time (in days) of bulk materials from suppliers;

ρ_{ks}^t – the rating of the sth supplier (from the list of business partners) of the kth batch material is taken into account when choosing the sth supplier and is indirectly included in the calculation of the indicator M_{ks}^t;

$RAT^t = \{\rho_{ks}^t\}$ – matrix of rating assessments of the enterprise's business partners who are suppliers of bulk materials.

Evidently, "understanding" the reasons for changes in prices for bulk materials and quantifying the "consequences" of these changes, as well as measuring their impact on possible price changes for other bulk materials, in particular for substitute raw materials, allows the ODA to apply effective flexible procurement policy schemes with taking into account rational expectations of prices on commodity markets. And therefore, the task of identifying the mutual dependence of prices for different charge materials-substitutes in the conditions of market volatility is extremely relevant during the implementation of the management activities of the enterprise, first of all for practical reasons of ODA. The implementation of this task is embodied in the solution of such an applied modeling problem, which is solved by econometric methods.

Formulation of an applied econometric problem. To establish the presence or absence of quantitative dependence between market prices for different pairs of charge materials included in the charge and which:

− are substitutes for each other (partial case);
− are not substitutes for each other (general case).

Assess the statistical significance of these dependencies and, if such dependencies are significantly significant, take into account the new information received about the possibility of technological mutual replacement of charge materials in the composition of the charge, taking into account the variability of prices in order to minimize the total cost of used charge materials in the production plan of the enterprise.

The formulated problem was solved using econometric methods in the following way (see [5] for more details on solution methods):

1. 12 parallel time series of prices for bulk materials were created (actual retrospective statistics for March 2021 (the pre-war period of stable prices on raw materials markets) were used for the 12 "most valuable" bulk materials – conventionally marked through RES_1-RES_{12} (see Table 1); the series are aligned in time intervals – 13 levels of the series are selected, taking into account that "empty" levels of time series are excluded from the calculations).

2. From the formed time series, all possible pairs were built, for which the density of the relationship was estimated using the indicator of the pairwise correlation coefficient "r", calculated according to the well-known formula using the standard MS Excel package [5]. The results of the calculations are presented in the table. 1 (different qualitative ranges of "r" values are highlighted in color):

Table 1 – Estimated values of correlation coefficients "r" for pairs of vectors of prices for bulk materials (statistical data for March 2021)

Bulk Materials	RES_1	RES_2	RES_3	RES_4	RES_5	RES_6	RES_7	RES_8	RES_9	RES_{10}	RES_{11}	RES_{12}
RES_1	1											
RES_2	-0,161424	1										
RES_3	0,5600353	0,01524	1									
RES_4	0,3756596	-0,450628	0,483971	1								
RES_5	0,5952086	-0,388906	0,218713	0,6410082	1							
RES_6	0,4843309	-0,182581	0,31657	0,6470902	0,866354	1						
RES_7	-0,660033	0,034938	-0,438912	0,0449903	-0,3327	-0,18522	1					
RES_8	-0,280094	0,317213	-0,140259	-0,679964	-0,65015	-0,389225	0,046289	1				
RES_9	-0,340724	-0,161175	0,009168	0,5562048	0,101308	0,192102	0,591177	-0,53357	1			
RES_{10}	0,2620036	-0,172606	0,256929	0,1130844	0,509109	0,494382	-0,29305	0,000583	-0,11263	1		
RES_{11}	0,0081229	-0,405967	-0,143081	0,2622481	0,647122	0,653219	0,007325	-0,12963	0,104825	0,7664602	1	
RES_{12}	-0,274884	0,245462	0,08162	0,1374154	-0,44313	-0,345645	0,490148	-0,22394	0,556093	-0,6087874	-0,636667	1

Source: calculated by the authors

3. An assessment of the density of connection ("strength of connection") between the prices of different charge materials was carried out using the calculated correlation coefficients using the Chaddock scale [11], which is presented in a generalized form in the table. 2.

Table 2 – Chaddock's scale for evaluating the "strength of connection" between a pair of random variables (by the value of correlation coefficients "r")

The range of values of the bond density indicator (for the correlation coefficient "r")	Qualitative characteristic of the connection force	Color identifier for "r" values in the table. 1
$\lvert\pm 0,1\rvert - \lvert\pm 0,3\rvert$	Practically absent	***red***
$\lvert\pm 0,3\rvert - \lvert\pm 0,5\rvert$	Low	***Orange***
$\lvert\pm 0,5\rvert - \lvert\pm 0,7\rvert$	Moderate	***Yellow***
$\lvert\pm 0,7\rvert - \lvert\pm 0,9\rvert$	Strong	***Cyan***
$\lvert\pm 0,9\rvert - \lvert\pm 0,99\rvert$	Very Strong	***Green***

Source: compiled by the authors based on [11]

A joint analysis of Tables 1-2 shows that:

– for most pairs of bulk materials, the correlation between their market prices is "practically absent" (48.50%) or "weak" (24.24%), that is, for almost three quarters (72.74%) of all combinations of bulk materials materials, the further application of econometrics tools in the defined context of the problem makes no sense;

– for almost a quarter of pairs of bulk materials, the correlation between their market prices is "moderate" (24.24%), and for two pairs or 0.02% of their total number it is "strong (dense)" (bulk materials: RES_5 "Fireclay scrap, imported" and RES_6 "Fireclay scrap, waste returned"; RES_{10} "Fireclay scrap, LSH UPOL" and RES_{11} " Fireclay scrap, LSH (CPS) UPOL"). In these cases, conducting a further correlation-regression analysis using appropriate econometric methods is appropriate, and the corresponding costs of labor and computing resources are economically justified, since the newly acquired information about the mutual dependence in the dynamics of prices for different charge materials allows making decisions on the management of the enterprise's activities more effective than in its absence. The expected economic effect is to reduce the total cost of production costs for the planned volume of the assortment of refractory products due to the mathematical optimization of the distribution of limited raw material resources (batch materials), which, as a result, makes it possible to use the developed economic and mathematical toolkit for searching on this statistical base optimal ("ideal" under the given conditions) production plans of the enterprise.

The built EMM (7)-(8), supplemented with mathematical tools for solving applied problems of marketing and econometric analysis of market prices, and the corresponding IMD are the basis of the developed computer dialogue decision support system for "management of deviations" from optimal resolution of the problem of multivariate selection of batching methods in the shops of PrJSC "Zaporizhvognetriv".

Conclusions. The conceptual approach to modeling the distribution of batch materials for obtaining the optimal batch according to the criterion of minimizing the total production cost of material and raw material costs for the fulfillment of the portfolio of orders of PrJSC "Zaporizhvognetriv" is substantiated. The author's concept of modeling is based on the principles of a system approach, the application of such research methods as: economic-mathematical modeling, correlation-regression analysis and groups of methods of statistical processing and generalization of data, for the creation and implementation of a model toolkit – a complex of economic-mathematical and information models of a special structure (created in MS Excel spreadsheets), which together implement the functionality of the "Batch optimization" and "Raw material price forecasting" modules. This ensures effective operational-tactical regulation and management of the effectiveness of production plans at the level of the main links of the production activity of PrJSC "Zaporizhvognetriv".

A dialogue man-machine procedure was developed for calculating the need for charge materials in conditions of multivariate combinations of permissible rational options for charge charges. For its implementation, an integral IMD was developed on the MS Excel platform, on the basis of which the automation of decision-making support for the management of the distribution of charge materials between different types of charges for the manufacture of refractory products was carried out in compliance with technological standards and was coordinated with the volume of the planned order portfolio of PrJSC "Zaporizhvognetriv". The proposed mathematical and information support allows for an operational automated check of the compiled production plan for its resource balance and compliance with contractual business obligations based on a dialog system on the MS Excel platform using the batch optimization developed by EMM.

Approbation of the developed model-algorithmic complex "EMM – IMD" on the MS Excel platform was carried out on the statistical database of three workshops of PrJSC "Zaporizhvognetriv", which produce refractory products, to check the effectiveness of the prepared production plan for March 2021, which made it possible to make, on the basis of calculations, , in particular, the following conclusions:

1. The prepared production plan is not perfect ("intuitive", not optimal according to the criterion of minimizing the cost of charge materials). The project of the best (savings of total costs – more than 8.5 million hryvnias) production plan, which was found according to the model (7)-(8), is recommended.

2. There is a threat of a shortage or a significant surplus of resources during the implementation of the prepared production plan. It is recommended to carry out dynamic maintenance of the balance of warehouse stocks of bulk materials for resource provision of the proposed optimal production plan using the methods of adaptive forecasting and scenario modeling.

3. The perspective and expediency of solving the above-mentioned problems through informatization of the procedures of complex economic-mathematical analysis of batching processes for the production of refractory products is based on the following recommendations regarding the further improvement of the management of the efficiency of production plans of PrJSC "Zaporizhvognetriv":

− apply the developed model-algorithmic complex for the operational audit of a set of rational (economically acceptable, optimal) charge options for the range of refractory products, taking into account various options for warehouse stocks of charge materials;

− use model variants of batching (optimal according to model (7)-(8)) as a basis for drawing up a schedule of costs of batching materials, taking into account their availability in the warehouse and a prospective plan for their additional purchase;

− integrate the developed computer dialogue system into the management mechanisms of PrJSC "Zaporizhvognetriv" for timely provision of relevant information on the possibility of interchangeability of individual components in the composition of the charge to support the decision-making of the ODR regarding the optimization of the technological regime of the selection of charge methods for the planned volume of the assortment of refractory products.

The direction of further investigations is the creation of an applied software product in the format of a dialog computer system such as a decision support system (DSS – Decision Support System).

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АНАЛІЗ ПРОЦЕСУ СПІКАННЯ ВОГНЕТРИВКИХ ВИРОБІВ: ЕФЕКТИВНЕ УПРАВЛІННЯ ВИРОБНИЧИМИ ПЛАНАМИ ПАТ «ЗАПОРІЖВОГНЕТРИВ»

У статті актуалізується задача прикладного економіко-математичного аналізу взаємопов'язаних процесів виробництва, шихтування та матеріально-ресурсного забезпечення виробництва вогнетривкої продукції. Обґрунтовано концептуальний підхід до моделювання розподілу шихтових матеріалів для отримання оптимальної шихти за критерієм мінімізації загальної виробничої собівартості матеріально-сировинних витрат на виконання портфеля замовлень ПрАТ «Запоріжвогнетрив». Авторська концепція моделювання спирається на принципи системного підходу, застосування таких методів дослідження, як: економіко-математичне моделювання, кореляційно-регресійний аналіз та групи методів статистичної обробки й узагальнення даних, для створення та реалізації модельного інструментарію – комплексу економіко-математичних та інформаційних моделей спеціальної структури (створено в електронних таблицях MS Excel), що разом реалізують функціонал модулів «Оптимізація шихти» та «Прогнозування цін на сировину». Це забезпечує ефективне оперативно-тактичне регулювання та управління ефективністю виробничих планів на рівні основних ланок виробничої діяльності ПрАТ «Запоріжвогнетрив». Розроблено діалогову людино-машинну процедуру для розрахунку потреби у шихтових матеріалах в умовах багатоваріантності комбінацій допустимих раціональних варіантів шихтовок. Для її реалізації розроблено інтегральну інформаційну модель даних на платформі MS Excel, на базі якої проведено автоматизацію підтримки прийняття рішень з управління розподілом шихтових матеріалів між різними варіантами шихтовок для виготовлення вогнетривкої продукції з дотриманням технологічних норм та узгоджено з обсягом планового портфеля замовлень ПрАТ «Запоріжвогнетрив». Запропоноване математичне та інформаційне забезпечення дозволяє здійснювати оперативну автоматизовану перевірку складеного виробничого плану на його ресурсну збалансованість і дотримання договірних бізнес-зобов'язань на базі діалогової системи на платформі MS Excel з використанням розробленої економіко-математичної моделі оптимізації шихти. Окреслено напрямки прикладного економіко-математичного аналізу управлінських рішень на базі розробленого інструментарію. Апробацію розробленого модельно-алгоритмічного комплексу здійснено на статистичній базі ПрАТ «Запоріжвогнетрив» для перевірки на ефективність складеного виробничого плану (горизонт планування – місяць) та обґрунтовано отриманий економічний ефект – умовне зниження загальних витрат (модельні розрахунки) у порівнянні з фактичними витратами на 8,6 млн. грн., що дозволило на підґрунті розрахунків зробити практичні рекомендації для подальшого вдосконалення управління ефективністю виробничих планів ПрАТ «Запоріжвогнетрив».

Ключові слова: спікання, модель, оптимізація, інформаційна модель даних, економіко-математичний аналіз.

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