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TECHNOLOGICAL SIMULATION PROCESS OF FORMING GRINDING MIXES BY LINEAR PROGRAMMING

The article discusses the method of linear programming (simplex method) as the method of systematic improvement and quality management, in particular the formation of grinding compounds, and the use of the resulting models to predict, control and optimize the process as a whole.
Keywords: *planning; production quality management; grinding mixture; simplex method.*

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МОДЕЛЮВАННЯ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ФОРМУВАННЯ ПОМОЛЬНИХ СУМІШЕЙ МЕТОДОМ ЛІНІЙНОГО ПРОГРАМУВАННЯ

У статті розглянуто метод лінійного програмування (сімплекс-метод) як метод систематичного поліпшення і управління якістю виробництва, зокрема, формуванням помольних сумішей. Запропоновано використання отриманої моделі для прогнозування, управління та оптимізації технологічного процесу в цілому.
Ключові слова: *планування; управління якістю виробництва; помольна суміш; сімплекс-метод.*
Табл. 3. Рис. 3. Форм. 5. Літ. 10.

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МОДЕЛИРОВАНИЕ ТЕХНОЛОГИЧЕСКОГО ПРОЦЕССА ФОРМИРОВАНИЯ ПОМОЛЬНЫХ СМЕСЕЙ МЕТОДОМ ЛИНЕЙНОГО ПРОГРАММИРОВАНИЯ

В статье рассмотрен метод линейного программирования (симплекс-метод) как метод систематического улучшения и управления качеством производства, в частности, формированием помольных смесей. Предложено использование полученной модели для прогнозирования, управления и оптимизации технологического процесса в целом.
Ключевые слова: *планирование; управление качеством производства; помольная смесь; симплекс-метод.*

Problem statement. Economic and mathematical methods can be used to solve a large range of economic problems. Targets may be different depending on manufacturing conditions and the nature of tasks. In economics such problems arise in practical implementation for the optimality of planning and management. The requirement for the use of the optimal approach to planning and management (the principle of "optimality") is flexible to alternative production and economic situations when it is necessary to take planning and management decisions. Such situations typically constitute everyday practice of economic entities (production program selection, attachment to suppliers, preparation of mixtures etc.) (Fedoseyev, 2002; Baltrashevich, 2001; Karasev, 1987; Garnaev, 2000; Kantorovich, Gorstko, 1968).

However, the performance of professional tasks under the current conditions is associated with the use of mathematical apparatus, as the method of systematic production improvement and quality management, and the use of the resulting model to predict, control and optimize consumer properties of existing and new products (Berestnev, 2008).

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Among the universal methods for linear programming, simplex is the most common method, developed by American scientist George Dantzig (Fedoseyev, 2002). However, linear programming methods were also executed by the Soviet scholar L.V. Kantorovich in the late 1930s. Unfortunately, these methods were not popular at that time and therefore are not widely known. Having developed the simplex method in the late 1940s, Dantzig was unaware of the works by Kantorovich.

The use of linear programming methods has significant advantages over the traditional ones:

– if the solution by conventional methods is, as a rule, obtained by developing one version of a plan (rarely 2–3), then by linear programming all real options of the plan are taken into account and the best is chosen (Fedoseyev, 2002; Vashkevi, 2009);

– thanks to the clear solution scheme linear programming is easily automated, saving labor.

Thus, to solve the problem it is appropriate to apply linear programming methods (Moore, 2004), which allow calculating, comparing and varying the basic components of the grinding mixture.

Recent research and publications analysis. Key aspects of the research are discussed by scientists of the neighboring countries, among which are A.N. Mertsalov (2009) and V.O. Novitskiy (2010).

Unresolved issues. The Republic of Kazakhstan has diverse soil and climatic areas, which in turn affect technological properties of grains and, therefore, in general, the organization and delivery of the process. Proper formation of grinding mixtures provides an output of quality products and process optimization. Analytical methods for calculating grinding mixtures are a tool for modelling, forecasting, and optimizing the process as a whole. Many facets of this problem determined the choice of the theme and the purpose of this study.

The objective research is to compare graphical and analytical methods for calculating the grinding mixture and to develop a mathematical model for calculating the composition of the mill batch, based on specified constraints on quality, yield, price and weight of a grain mix to reflect the selected optimization criterion using the simplex-method in the application package MS Office (search for solutions), as well as the analysis and selection of the components of the grinding mixture of the most successful set of the best options in the calculations based on the current production requirements.

To achieve this goal the following objectives are identified:

– to develop a mathematical model for calculating the composition of the mill batch;

– to solve the problem graphically;

– to solve the problem by using an analytical method (simplex-method);

– to compare the results obtained by graphical and analytical methods;

– to choose the best option for grinding mixture.

The key research findings. The calculation of the optimum recipe of grinding grain mixtures is based on the current balances of raw materials at the plant, represented in its silo board and price data. If business has an automated accounting for grain quality, then the silo board data are automatically downloaded from the accounting system, otherwise they may be entered manually. In case the elevator has partial accounting, the cost of grain is treated as a weighted average for each silo. In other case, the price of raw material is put into classes (or other classification) based on consolidated accounting data (Berestnev, 2008).

Simplex-method used by the facility "Search for solutions" in Microsoft Excel, is the method of finding the extremum. The program finds a certain angular solution, and then looks through all neighboring angles of the feasible region and finds out whether the value of the objective function will improve when moving the function in one of these angles. In case of a positive answer the solution moves to such a corner, and the program re-examines its adjacent angles – is it possible to further improve? If the answer is negative, the program exits (Moore, 2004).

The mathematical model for calculating the mill batch is written as follows and is seen as the system of linear inequalities:

In this case, the objective function becomes:

$$F = f(\overline{X}) = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n \rightarrow \max, \min, const.$$
$$F = f(\overline{X}) = \sum_{j=1}^{n} c_j x_j \rightarrow \max, \min, const. \quad (1)$$

where c_J – given constants.

Subject to (conditions) in the unfolded state:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \{\le, =, \ge\} b_1, \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \{\le, =, \ge\} b_2, \\ \ldots\ldots\ldots\ldots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{m\overline{1n}}x_n \{\le, =, \ge\} b_m, \end{aligned} \quad (2)$$

$$x_j \ge 0; \; j = 1, n. \quad (3)$$

Subject to conditions in general form:

$$\sum_{j=1}^{n} a_{ij} x_j \le b_i, \; i = \overline{1, m},. \quad (4)$$

$$x_j \ge 0, \; b_j \ge 0, \; i = \overline{1, m}, \; j = \overline{1, n} \quad (5)$$

where a_{ij}, b_i, c_J – the defined constants.

Conditions (2, 3) are the function restriction. As initial parameters for calculating the grinding mixture composition, the restrictive conditions for grain quality are used (the amount of gluten, gluten quality in terms of the DCO, drop number, vitreousness, nature, ash content (or whiteness), the content of trash and grain impurities, moisture etc.) yield, the number of components in the mixture , as well as the marginal cost of grinding mixture. It is also possible, if necessary, to limit the percentage of wheat input of various types and classes (Berestnev, 2008).

General data to calculate the mill batch are recorded in Table 1.

Table 1. **Indicators of components and grinding mixture**

Group of parameters	Specified rate	Value of component parameters					Mixture restrictions
		1-st	...	i-th	...	n-th	
Quantitative	Quantity of grain in the mixture, %	m_1	...	m_i	...	m_n	$M = \sum_{i=1}^{n} m_i = 100\%;$ $m_i \ge 0$
Qualitative	Vitreousness, % Gluten content (Gl), % Ash content, %	V1 Gl1 Z1	... ...	Vi Gli Zi	... ...	Vn Gln Zn	≥V ≥Gl ≤Z

Continuation of Table 1

Economic	Price, KZT	P_1	...	Pi	...	P_n	P_{min}

Note: The sign «≥» is used for quality parameters, the increase of which leads to the improvement of grinding mixture. These are: vitreousness, gluten quantity and the like; the sign «≤» for quality parameters, the reduction by which also leads to grinding mixture improvement. For example, ash content, moisture etc.
Source: Authors.

The paper discusses a three-component and a four-component mixtures. Tables 2, 3 show the basic data for calculating grinding batches.

Table 2. **Initial data for calculating a three-component mixture**

Parameters	Components			Mixture parameters
	first	second	third	
Weight of mixture (M), t				1750
Presence of components (m_{ie}), t	1200	1600	2800	$m_1 \le m_{1e}$, $m_2 \le m_{2e}$, $m_3 \le m_{3e}$
Vitreousness (V), %	48	60	50	≥50
Gluten content (Gl), %	23	28	24	≥24
Ash content (Z), %	1,73	1,77	1,82	≥1,76
Price (P), KZT/ton	22000	24000	21000	minimum

Source: Authors.

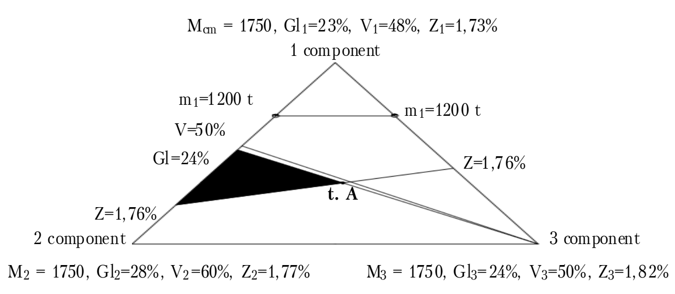
Table 3. **Initial data for calculating a four-component mixture**

Parameters	Components				Mixture parameters
	first	second	third	fourth	
Weight of mixture (M), t					1750
Presence of components (m_{ie}), t	1200	1600	2800	2000	$m_1 \le m_{1e}$, $m_2 \le m_{2e}$, $m_3 \le m_{3e}$, $m_4 \le m_{4e}$
Vitreousness (V), %	48	60	50	54	≥50
Gluten content (Gl), %	23	28	24	25	≥24
Ash content (Z), %	1,73	1,77	1,82	1,79	≤1,76
Price (P), KZT/ton	22000	24000	21000	23000	minimum

Source: Authors.

This paper presents the calculation of the mill batch by graphic and simplex methods and their comparative analysis is carried out.

Calculation of a three-component grinding mixture using the graphical method (Vashkevi, 2009) by weight and quality indicators is given on Figure 1. The vertices of the triangle correspond to 100% of the content of this component in grinding mixture (grinding mixture weight).



Source: Authors.

Figure 1. **Calculating of a three-component mixture based on weight and quality indicators**

Thus, point A meets all the conditions imposed by the quality and weight of a grinding mixture. Consequently, the mass of components at the point A is: m_1 = 430 tons (24.6%); m_2 = 410 tons (23.4%); m_3 = 910 tons (52%).

The price of the three-component grinding mixture is determined by the formula (1) and is:

F = 22000 x 0,246 + 24000 x 0,234 + 21000 x 0,52 = 21948 KZT.

Calculation of the three-component grinding mixture by analytical method (simplex-method) is shown on Figure 2. In the column "values" the mass of the components is given in %.

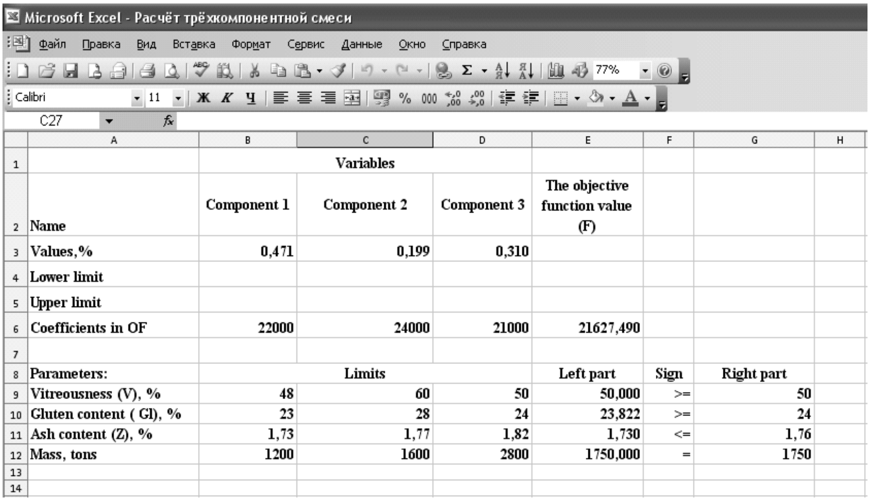
On the basis of formulas (1) and (2) one can write a mathematical model for three-component mixture (raw data are given in Table 2):

$$F = 22000m_1 + 24000m_2 + 21000m_3 \rightarrow \min.$$

under the constraints:

$$\begin{cases} 48m_1 + 60m_2 + 50m_3 \geq 50 \cdot 100 \\ 23m_1 + 28m_2 + 24m_3 \geq 24 \cdot 100 \\ 1{,}73m_1 + 1{,}77m_2 + 1{,}82m_3 \leq 1{,}76 \cdot 100 \\ m_1 + m_2 + m_3 = 1750 \\ m_n \geq 0 \end{cases}$$

Thus, solving the system of inequalities by the simplex-method, we obtain the numerical values of the masses of the components that meet all the specified criteria.



	A	B	C	D	E	F	G	H
1			Variables					
2	Name	Component 1	Component 2	Component 3	The objective function value (F)			
3	Values,%	0,471	0,199	0,310				
4	Lower limit							
5	Upper limit							
6	Coefficients in OF	22000	24000	21000	21627,490			
7								
8	Parameters:		Limits		Left part	Sign	Right part	
9	Vitreousness (V), %	48	60	50	50,000	>=	50	
10	Gluten content (Gl), %	23	28	24	23,822	>=	24	
11	Ash content (Z), %	1,73	1,77	1,82	1,730	<=	1,76	
12	Mass, tons	1200	1600	2800	1750,000	=	1750	
13								
14								

Source: Authors.

Figure 2. **Calculation of a three-component grinding mixture by the simplex-method**

As it can be seen from Figure 2, the calculation of grinding batch by simplex-method is more accurate than the calculation by graphical method, and the price in this case is 21,627.5 KZT.

Similarly, a four-component grinding mixture is calculated. The results of the calculation are shown on Figure 3.

Microsoft Excel - Расчёт четырёхкомпонентной смеси

	A	B	C	D	E	F	G	H
1		Variables						
2	Name	Component 1	Component 2	Component 3	Component 4	The objective function value (F)		
3	Values,%	0	0,63	0,265	0			
4	Lower limit							
5	Upper limit							
6	Coefficients in OF	22000	24000	21000	23000	20685		
7								
8								
9	Parameters:	Limits				Left part	Sign	Right part
10	Vitreousness (V), %	48	60	50	54	51,05	>=	50
11	Gluten content (Gl), %	23	28	24	25	24	>=	24
12	Ash content (Z), %	1,73	1,77	1,82	1,79	1,5974	<=	1,76
13	Mass, tons	1200	1600	2800	2000	1750	=	1750

Source: Authors.

Figure 3. **Calculation of the four-component grinding mixture by the simplex method**

Conclusions. Thus, the proposed model of technological operations allows calculating the composition of grinding mixture without the knowledge of programming languages, but using Microsoft Excel.

The use of a graphical method is only available for two-and three-component mixtures, as for the four- and more component mixtures it is impossible to chart the calculation of grinding batch. The disadvantage of the graphical method is the presence of errors in such construction. Graphical method can eliminate a larger share of subjectivity than the method of inverse proportions.

When calculating by graphical method it is not always possible to correctly select the point with the minimum value of the objective function, therefore, errors occur when determining the cost of a grinding mixture.

Application of the simplex-method allows calculating the grinding mixture of any number of components more significantly, to analyze different options and choose the best option of grinding batch in charge of all the conditions on quality.

Between the values obtained by the graphical method and the simplex-method, the differences are about 30–35%.

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