Structural-Parametric Modeling in Human Healthy Nutrition System

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***Abstract*—The article presents a fragment of the generalized structural and parametric model of adequate nutrition of a healthy person, describing in a matrix form a priori known data and knowledge about characteristics of a person's condition and their relationship with environmental factors and dietary and nutritional parameters. The algorithm of identification of an abnormal condition of a person and search for the root cause of deviation from norm is shown. To assess the adequacy of diet options in the information technology of its structural optimization, it is proposed to use a quality functional reflecting the weighted average total deviation of actual values of the chemical composition parameters from FAO/WHO norms. The use of information technologies implemented by multicriteria optimization and mathematical programming methods will make it possible to adjust and optimize diets according to various quadratic criteria of minimum deviation from the reference structure of a variety of indicators of nutritional, biological and/or energy value. The resulting set of alternative dietary options shall be structured to establish an optimal diet of a given quality, composition and properties, taking into account biomedical requirements addressing parameters of a certain group of people, structural relationships and limitations at the component, elemental and monostructural levels.**

Keywords—structural-parametric model, adequate diet, functional, partitioned matrix, identification algorithm, multicriteria optimization, criteria, healthy nutrition, database, information technologies

I. INTRODUCTION

According to the World Health Organization [1], adult overweight and obesity rates are increasing in almost all countries and regions; in 2016, 1.3 billion people were overweight, of whom 650 million (13% of the world population) were obese. Obesity is a serious risk factor for diabetes; cardiovascular diseases (mainly heart disease and apoplectic attack); musculoskeletal disorders (especially osteoarthritis, a degenerative joint disease with severe disabilities); and certain forms of cancer (including endometrium, breast, ovary, prostate, liver, gallbladder, kidney and colon cancer).

According to a WHO report [2], increased attention must be paid to ensuring optimal diet at every stage of human life. It is estimated that 3.7 million lives can be saved by 2025 by allocating necessary resources to address nutrition problems. In the human body, there is practically no organ or system which normal functioning does not depend on nutrition.

The Russian Federation has a number of legislative documents that provide guidelines for the organization and monitoring of the nutritional status of the country's population. Support and promotion of human health is impossible without adequate nutrition. Constant disruption of dietary regimen inevitably leads to pathological changes in vital functions. This is due to the deep influence of nutrition on all biochemical and physiological processes in the human body. It is this fundamental influence that underlies any diet therapy – therapeutic nutrition – for the treatment and prevention of various diseases. When recommending a diet, a nutritionist should use not only biochemistry data (protein, carbohydrate and lipid statuses, immune indicators, biochemical blood analysis), physiology (weight deficit, activity and injury factors), nutrition hygiene (volume, weight, consistency and temperature of food), but also take into account individual parameters (age, anthropometric data).

The mathematical apparatus is widely used in the analysis of nutrition problems [3 - 9], principles of food combinatorics in the design of combined food products [10, 11]. To solve the issue of adequate nutrition, corresponding to the needs and capabilities of the human body and balanced in all indicators of nutritional and biological values it is necessary to process large data sets.

Actual and reliable information on the chemical composition of food products and dishes should be stored in databases. The structure of a database should provide for the division into clusters, for example, “Porridge”, “Soups”, “Vegetables”, etc. Clusters are necessary for the subsequent distribution of food and dishes included in the diet into individual meals according to the time. Along with this, it is necessary to take into account the division into clusters according to different characteristics, for example, allergenicity (does the product contain an allergic component), etc.

This article presents the methodology of construction of the structural and parametric model of adequate nutrition, reflecting the variety of existing known and unknown links between the factors of a person's health condition and characteristics of his/her diet; development of information technologies in the system of healthy adequate nutrition for defined groups of people taking into account the metabolism of nutrients (ethnic affiliation, cultural preferences, health status, lifestyle, and clinical factors) of the available traditional products for the region. Creation (selection) of an individual (personal) diet and dietary regime is carried out on the basis of models and methods of multicriteria structural and parametric optimization and objective evaluation of the adequacy of proposed options with the help of computer technologies of processing and formalization of knowledge with finding optimal solutions.

II. MATERIALS AND METHODS

Structural and parametric modeling of systems [12, 13] of any physical system and social nature is reduced to the development of interaction matrices between the grouped parameters of state and purpose of individual functional blocks of the system similarly to the parametric adjacency

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matrix. At that, the main task is to find comparable characteristics of the relationship between parameters of a person’s condition of health with the subsequent development of a situational model of the state of the system with the algorithmization of procedures for its identification and forecasting.

The structural and parametric model of adequate nutrition reflects the functional relationship between characteristics (parameters) of a person's condition and his/her diet, reflecting many specific factors and links that determine the goals, purpose and use of developed diets and dietary regimes for specific defined consumer groups.

Classification of population groups in combination with characteristics of physiological condition, anthropometric data, parameters of motor activity and biomedical requirements allows developing the information map of the condition of a person, reflecting his/her parametric description with selected groups of characteristics and properties.

All physiological characteristics can practically be determined in the process of medical examination of a particular person or a specialized group of people. For example, biochemical blood test is necessary to determine carbohydrate, lipid and protein metabolism.

Finding all the indicators within the limits of the permissible norm indicates that a person receives necessary and sufficient amount of food substances, nutrients and energy with food.

The parametric description of a diet contains a set of parameters of food, biological and energy values, as well as indicators of carbohydrate, vitamin and mineral compositions.

III. Results and Discussion

Fig. 1 presents a fragment of the structural and parametric model of adequate nutrition in the form of partitioned matrix for subsets of controlled and most interrelating factors.

		Human condition parameters $x_1 \div x_{16}$																Diet parameters $x_{19} \div x_{29}$													
																		the nutritional value $x_{17} \div x_{19}$			Vitamin composition $x_{20} \div x_{25}$						Mineral composition $x_{26} \div x_{28}$				
	№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Height	1	1																•												•	
Carbohydrate metabolism	2		1																		•	•	•							•	
Heart functions	3			1																	•						•		•	•	
Lung functions	4				1																•									•	
Amino acid metabolism	5					1																		•						•	
Fatty acid metabolism	6						1																	•							
Nervous system function	7							1											•					•	•		•		•		
Erythrocyte maturation	8								1																•	•					
DNA synthesis	9									1															•	•					
RNA synthesis	10										1															•					
Immunity	11											1							•												
Energy production	12												1					•	•									•			
Cell recovery	13													1				•													
Blood coagulation	14														1												•				
Muscle function	15															1											•		•		
Acid-base condition	16																1											•			
Protein, g.	17	•											•	•				1	•												•
Fat, g.	18							•				•	•					•	1												•
Carbohydrates, g.	19																	•	•	1											•
Vitamin B_1, mg.	20		•	•	•																1										•
Vitamin B_2, mg.	21																					1									
Nicotinic acid, mg.	22																						1								
Vitamin B_6, mg.	23					•	•	•																1							
Vitamin B_{12}, mcg.	24							•	•	•															1						
Folic acid, mcg.	25								•	•	•															1					
Calcium	26			•				•							•	•											1	•	•		
Phosphorus	27												•				•										•	1			
Magnesium	28			•				•								•											•	•	1		
Energy value	29	•	•																											1	
Quality functionality	30																	•	•	•	•	•	•	•	•	•	•	•	•	•	

Fig. 1. Fragment of structural and parametric model of adequate nutrition.

The parameters of two main blocks of the system of adequate nutrition – health condition of a person $x_1 \div x_{16}$ and his/her diet $x_{17} \div x_{29}$ in the form of main integral characteristics, indicators of chemical composition and properties are placed along the main diagonal.

If the state parameters are independent or if there is no reliable information about possible relationship between them, the corresponding non-diagonal cells of the matrix remain empty. If there is relationship between the parameters, the non-diagonal elements marked in Fig. 1 by points reflect the presence of links between the parameters of a particular person's condition (height, weight, heart function, etc.) and the characteristics of the nutrition system, both within the group and between groups (non-diagonal blocks). Expert estimates, correlation and multiple regression coefficients; impact estimates found in the result of active experiments, as well as possible functions, ratios and conversion algorithms may be used as formalized characteristics of relationships.

For example, Fig. 1 demonstrates that the metabolism of carbohydrates, heart and lungs functions depend on the intake of vitamin B_1; the content of vitamin B_6 influences the metabolism of amino acids and fatty acids and the functions of the nervous system; folic acid (folate) influences the maturation of red blood cells, synthesis of DNA and RNA; calcium makes impact on blood clotting, functions of the nervous and muscle systems, heart function; phosphorus influences functions of the muscle and nervous systems; magnesium - energy generation, acid-base balance, etc.

From [14] it was established, for example, that parameters of nutritional value $x_{17} \div x_{19}$ affect a person's anthropometric data, performance, functions of the central nervous system, immunity and recovery (renewal) of cells.

Energy value has an impact on all factors of a person's condition $x_1 \div x_{16}$.

A. Identification algorithm

Identification of the state of a person's nutrition system comes down to diagnosing the causes of its occurrence, predicting its further state, analyzing and evaluating possibilities of achieving the goal.

The identification algorithm contains (Fig. 2) a block of formation of the situation matrix and the procedure for finding the causes of the anomalous state of the system.

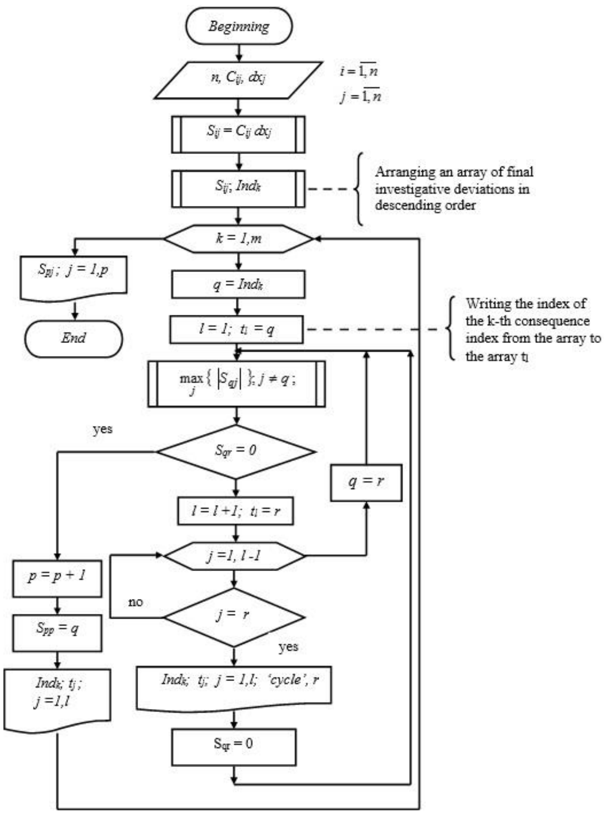

Fig. 2. Block diagram of the algorithm for diagnosing the abnormal state of nutrition system.

The procedure is a cycle of iteration of independent deviations, within which the maximum element in a line is searched for, its ordinal number *p* is remembered and transition to the *p*-th line takes place followed by a new search for the maximum element of this line [13].

To detect possible looping of cause-effect relationships, an array of t_l indices of diagonal elements included in the interaction trajectory is formed, and when two elements of this array match, it is followed by a "cycle" signal. In this case, the cause may be inside or outside the cycle circuit. To exit the cause-effect cycle and continue to search for the original cause, the last link of feedback is broken, i.e. element $S_{gp}=0$, with its value $f_g=S_{gp}$ and addresses memorized in index arrays Ind_{g1}; Ind_{g2}. Then when iterating over the elements of the *g*-th line, the procedure will either stop at the last link of the cycle (if the reason lies within the cycle circuit) or go further through the steps of a new cycle (Fig. 2). When moving to the detection of the causal chain of the next $k+1$-th consequence, the interrupted link of the *j*-th cycle of the previous trajectory of the links is restored, i.e. $S_{Indj1,\, Indj2}=f_j$.

To find the influence of other factors on the next *k*-th consequence, the first maximum contribution to its deviation is set equal to zero and the next largest element of the *k*-th line is selected, i.e. the next largest contribution to the *k*-th consequence.

All abnormal values of indicators are kept in the array of deviations from the norm and based on the knowledge base a person is provided with the initial selection of products in the recommended diet, which compensates for existing deviations taking into account individual characteristics of the patient and social conditions (personal perception of certain product, presence of allergies, as well as availability of specific products due to material or geographical factors).

If there is insufficient compensation for deviations by selecting the desired products and dishes included in the diet, a search should be made for their optimal quantitative ratios (structural optimization) with the possible introduction of additional products and dishes depending on the current deviations of parameters from the norms or the development of an individual combined product that minimizes residual deviations.

B. Quality functional

The structural and parametric model (Fig. 1) includes the adequacy functional (x_{30}), which assesses the degree of deviation of the current diet from the reference models of a particular type of diet: children, school, student, adult, elderly nutrition, etc. Taking into account the breakdown of many factors into groups of properties, the adequacy functional of the diet is as follows:

$$G = \prod_{k=1}^{m_k} \left(1 - z_k^2\right) \cdot \left[\sum_{i=1}^{m} a_i \left(1 - \sqrt{\frac{1}{n} \sum_{j=1}^{n_j} b_{ij} z_{ij}^2} \right) \right] \quad (1)$$

$$z_{ij} = \frac{x_{ij} - x_{ij}^0}{\Delta x_{ij}^0}$$

where z_{ij} is the relative deviation of the *j*-th factor in the *i*-th group; $x_{ij}, x_{ij}^0, \Delta x_{ij}^0$ is the actual, reference and permissible deviation from the norm of the *j*-th parameter in the *i*-th group, respectively; a_{ij}, b_{ij} are the factors of significance of the *i*-th group of factors and the *j*-th factor in the *i*-th group, determined by methods of expert estimates or by factor experiment; z_k is the relative deviation of the *k*-th factor of the critical group, which deviation beyond the tolerance turns the functional to 0.

The functional varies from 1 with full adequacy of the diet to 0 at the limit of the allowable area and turns to 0 when any parameter of the critical group exceeds the maximum allowable value.

Thus, the structural and parametric model of adequate nutrition reveals the structure of links between parameters and factors affecting the health of a particular person, the use of which is necessary to develop or correct certain indicators of the daily diet and recommendations for a person's dietary regime.

The procedure for assessing the diagnosis of a person's condition comes down to the formation of the structural and parametric situational model [12] of an abnormal condition of a person and the search for reasons for deviations of his/her condition parameters from the FAO/WHO standards.

Based on the maximum deviation of the parameter of condition from the norm (for example, Δx_7 - function of the nervous system), it is necessary to identify all causes of this deviation (for example, fat, vitamin B_6, vitamin B_{12}, calcium, magnesium) and choose the most significant one (e.g. fat). This is followed by a change in diet with a selection of foods and dishes that minimize the identified imbalance with maximizing the functional adequacy of the diet.

C. Mathematical problem statement of adequate diet structural-parametric multicriteria optimization

As the objective function a hierarchy of quadratic criteria of the minimum deviation from the reference structure of a variety of indicators of food, biological and/or energy values presented in a generalized form as an adequacy criterion is used:

$$\sum_{k=1}^{n}\left(B_k^0 - \sum_{j=1}^{m} b_{kj}\, y_j\right)^2 \to \min \qquad (2)$$

where y_j is mass fraction (volume) of the j-th product in the diet; b_{kj} is specific content of the k-th chemical composition component in the j-th product; B_k^0 is standard content of the k-th component in the diet;

under limitations:

- by total volume of daily ration V

$$\sum_{j=1}^{m} y_j = V \qquad (3)$$

- by allowable change of the mass fraction (volume) of the j-th product in the diet

$$y_j^{\min} \le y_j \le y_j^{\max}; \quad j = \overline{1, m} \qquad (4)$$

As criteria or limitations one can also use digestibility, action selectivity, adequacy of chemical composition and energy value of nutrition to the volume of diet and age-related needs of human body, etc. as follows:

- **protein digestibility criterion**

$$P(\pi) = \left(\pi^0 - \frac{\sum_{j=1}^{m} \pi_j b_j y_j}{\sum_{j=1}^{m} b_j y_j}\right)^2 \to \min \qquad (5)$$

where π_0 is protein digestibility in a reference product, *mg. of tyrosine/g. of protein*; π_j is digestibility of the j-th component protein, *mg. of tyrosine/g. of protein;*

- **protein nutrition adequacy criterion**

$$PBA = \frac{AZOT_M}{AZOT_{OB}} \cdot 100\ (\%) \to \max \qquad (6)$$

under

$$AZOT_M = \left(AZOT_{BAL} - \frac{BELOK_{VVED}}{6.25} + 4\right) \to \max \qquad (7)$$

where PBA is protein activity indicator (*%*); $AZOT_M$ is blood urea nitrogen (*g*); $AZOT_{OB}$ is total nitrogen (*g*); $AZOT_{BAL}$ is nitrogen balance (*g/day*); $\text{BELOK}_{\text{VVED}}$ is introduced protein;

- **albumin deficiency criterion**

$$\sum_{i=1}^{n}\left(alb_0 - alb_i\right)^2 \to \min \qquad (8)$$

where n is number of patient observations; alb_0 is standard albumin levels in a patient's blood; 30 (*g/l*) ≤ alb_0 ≤ 35 (*g/l*) - mild deficiency; 25 (*g/l*) ≤ alb_0 ≤ 30 (*g/l*) - moderate deficiency; alb_0 < 25 (*g/l*) - severe deficiency; alb_i is albumin levels in a patient's blood at the i-th observation (*g/l*);

- **transferrin deficiency criterion**

$$\sum_{i=1}^{n}\left(Trf_0 - Trf_i\right)^2 \to \min \qquad (9)$$

where n is number of patient observations; Trf_0 is standard transferrin levels in a patient's blood; 1.8 (*g/l*) ≤ Trf_0 ≤ 2.0 (*g/l*) - mild deficiency; 1.6 (*g/l*) ≤ Trf_0 ≤ 1.8 (*g/l*) - moderate deficiency; Trf_0 < 1.6 (*g/l*) - severe deficiency; Trf_i is transferrin levels in a patient's blood at the i-th observation (*g/l*);

- **lymphocytes deficiency criterion**

$$\sum_{i=1}^{n}\left(Lmf_0 - Lmf_i\right)^2 \to \min \qquad (10)$$

where n is number of patient observations; Lmf_0 is standard lymphocytes count in a patient's blood; 80 ($10^6/l$) ≤ Lmf_0 ≤ 90 ($10^6/l$) - mild deficiency; 70 ($10^6/l$) ≤ Lmf_0 ≤ 80 ($10^6/l$) - moderate deficiency; Lmf_0 < 70 ($10^6/l$) - severe deficiency; Lmf_i is lymphocytes count in a patient's blood at the i-th observation ($10^6/l$);

In (7) - (10) cases, it is necessary to establish relationships between the criterion estimates and chemical composition parameters of the diet and the products included, similar to criteria (2) - (6).

Minimization of possible discrepancy between standard and proposed rations' parameters is reduced to multicriteria optimization with the formation of a Pareto-optimal set of solutions according to the above formalized criteria.

D. Algorithm of diet structured optimization

The algorithm of diet structured optimization by partial criteria:

$$B_k^0 - \sum_{j=1}^{n} b_{kj}\, y_j \to \min; \qquad k = \overline{1, m} \qquad (11)$$

includes a sequential determination of the imbalance by the k-th element under limitations (3)-(4) and its minimization (in case of deficiency) by increasing to the upper limit the mass fraction of one product y_l with a maximum specific content of b_{kl}^{max} of the deficient element and corresponding reduction to a minimum the mass fraction of another product with a minimum specific content of b_{kr}^{min} of the k-th element.

In case of redundancy, the structural shift is vice versa. By redistribution of mass fractions of the selected product pair to y_l^{max} and y_r^{min} we obtain a new improved value of the partial criterion (5). The size of redistribution of mass fractions of components is selected based on the limitation (4) by the given limits y_l^{max} and y_r^{min}, as well as restrictions on the total volume of the diet (3),

$$\delta = \min\left\{\Delta y_k, \Delta y_k^{\max}, \Delta y_k^{\min}\right\} \qquad (12)$$

where $\Delta y_k^{max} = y_l^{max} - y_l$ is permissible increase of the l-th product mass fraction; $\Delta y_k^{min} = y_p - y_p^{min}$ is permissible reduction of the p-th product mass fraction.

New values of mass fractions are determined as $y_l' = y_l + \delta$; $y_p' = y_p - \delta$; the procedure is repeated with the next pair of products being found to redistribute their mass fractions until a local minimum is found by the k-th element.

The procedure continues until all the possibilities of redistributing the mass fractions of the components are exhausted, resulted in obtaining an alternative diet with a minimum deviation of the k-th element from the specified standard value in the adequate nutrition assortment structure. The choice of the optimal alternative from the found Pareto-optimal solutions set corresponds to the minimum value of the global adequacy criterion (2) or the maximum of the quality functional, which estimates the total residual deviation of the resulting diet structure indicators from the standard option on a scale from 0 to 1.

E. Project for the development of a computer system of healthy diet

In order to support a healthy lifestyle and maintain health, it is necessary to develop a decision support system for the development and correction of adequate dietary regimes taking into account human metabolism. The authors propose the creation of a computer system of optimization of the current diet and preparation of a new diet for a person (user) based on the principles of adequate nutrition, mathematical methods and information technologies.

The information basis of the system is a database (DB) of products and dishes, being most common and sold in large cities and metropolises. The construction of multidimensional parametric models begins with the creation and filling of a database (DB) of reference information necessary both for constructing parametric and mathematical models of healthy food products and for assessing adequacy.

The database structurally displays physical and chemical parameters of raw materials, products of animal and plant origin, optimization criteria and adequacy assessment, recommendations and norms of food nutrients and energy consumption, ensuring the selection of raw materials that meet the specified requirements.

The structure of the information subsystem has been developed - a database of the main physicochemical characteristics of food products, such as calorie content, vitamin quantitative composition, chemical composition (proteins, fats, carbohydrates, and minerals), fatty acid compositions, and essential amino acids per unit mass of products, which is presented in Fig. 3.

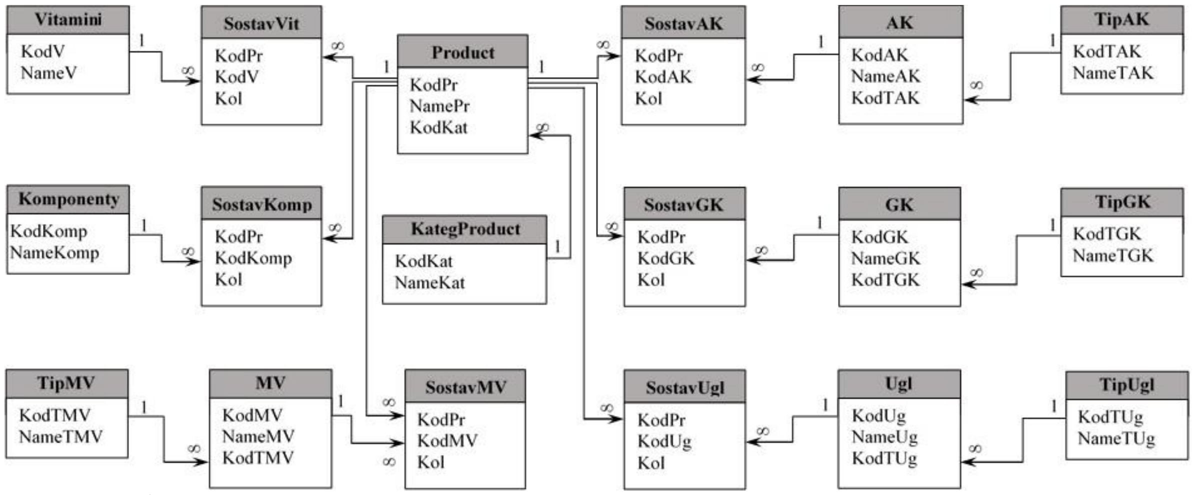

Fig. 3. Logical structure of the database.

IV. Conclusions

With each day, the integration of nutritional science with engineering sciences, in particular with food technology, is increasing, which creates opportunities for the development of new progressive methods and techniques for developing products with a given chemical composition, specialized products, as well as personalization of diets [15]. Application of information technologies implemented by methods of mathematical programming allows optimizing diets according to different criteria and making an informed decision in determining optimal composition of the diet, taking into account all specified properties and limitations. Analysis of the structural and parametric model of adequate nutrition of a healthy person in a matrix form allows assessing the diagnostics of a person's condition, revealing abnormal conditions and reasons for their occurrence.

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