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Justification of the mathematical model for describing the cross-cutting processes of functional food production with their enrichment

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ABSTRACT
Cross-cutting technological processes that reflect the relationship between the technological operations of raw materials production, stock formation, their transportation, processing of raw materials and the production of final products are typical for several industries. Of particular importance is the optimization of cross-cutting technological processes in agriculture and food industry to improve food security in the Northern territories of Russia. In this regard, this paper forms a model and structure of initial data for obtaining a tool for justifying the optimal location of enterprises for the production of functional food products and their optimal number for Russia's conditions. The authors in this study developed an original approach to the formation of a mathematical model to description of the production logistics of cross-cutting technology, which includes optimization of the transportation costs of functional food products with regard to their enrichment, which is a justification of economic efficiency of cross-cutting technology of procurement, transportation and production of functional foods. The authors of this study also defined the change in the cost of final products with an increase in the number of processing enterprises. It was found that the rational number of processing points – enterprises producing functional food products – is in the range of 7-12, while the optimal number is 7-9.

Keywords: Logistics, Agricultural food, Raw materials, Cross-cutting technological process, Transportation, Functional food products.

INTRODUCTION
Cross-cutting technological processes that reflect the relationship between the technological operations of raw materials production, stock formation, their transportation, processing of raw materials and the production of final products are characteristic to several industries. Such cross-cutting processes play a unique role for the Russian economy, given significant development of which it is necessary to provide it with scientifically based logistics territorial interregional and global world connections. Of particular importance is the optimization of cross-cutting technological processes in agriculture and food industry to improve food security in the Northern territories of Russia. There is a need to consider cross-cutting processes of procurement and transportation of agricultural raw materials and production of functional food products from them, including their enrichment, as objects for analysis and synthesis of new solutions, and on this basis to form a model and structure of initial data for its further use as a tool to justify the optimal location of enterprises for the production of functional food products and their optimal quantity for Russia's conditions. Information search and analysis showed that in recent years researchers from many countries have been paying more attention to the study of health status and improvement of nutrition processes of different population groups living in difficult climatic conditions of the Northern territories and the Arctic (Agbalyan *et al.* 2009; Polikarpov *et al*. 2010; Pushmina 2011; Chashchin *et al.* 2014; Khasnulin *et al*.

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2015; Nikonov *et al.* 2018; Ananskikh *et al.* 2019). This is due to the geopolitical situation and the location on these territories of huge and demanded resources of oil and gas, reserves of gold, platinum, diamonds, chromium, nickel, lead, tin, manganese, as well as biological resources, including freshwater, populations of animals and commercial fish. Due to the specifics of the particular geographical, geopolitical situation in the Arctic, the interests of many states and global business intersect. At the same time, researchers note that the shortest sea and air transport routes passing through the Arctic are very important for the economic and industrial liaising between America, Asia and Europe. On the website of the Ministry of Agriculture of the Russian Federation in the section "State Support of the Food and Processing Industry," it is noted: "An important area of development is the technology for creating complex functional ingredients and essential nutrients for the production of a wide range of general and specialized products." At the same time, the analysis showed that the changes that have been made in the Development Strategy of Food and Processing Industry of the Russian Federation for the period until 2020, approved by Decree of the Government of the Russian Federation from June 30, 2016 no. 1378-r, as well as in the Project of Development Strategy of Food and Processing Industry of the Russian Federation for the period up to 2030 do not include sections devoted to solving problems of food security of the Northern territories of Russia, as well as the development of industries, providing the population with functional food products. The results of research on the influence of natural and industrial peculiarities and the related influence of nutritional factors on the health and performance of the population permanently and temporarily living in the North of Russia are presented in the works of numerous Russian researchers (Buganov *et al.* 2003; Golubchikov *et al.* 2003; Khasnulin 2004; Klimova *et al.* 2015; Semenova 2015). Researchers note that at present the population of the territories of the North and the Arctic is characterized by a pronounced lack of protein products that are a source of essential proteins, amino acids and pronounced low protein absorption, which is below 80 %. As a result of the transformation of northerners' diets, there is a shortage of vitamins, minerals, and dietary fibers. Frozen, preserved, and dried foods with a long shelf life are actively included in the diet of northerners (Ermosh *et al*. 2018). In this regard, theoretical and applied research on food security issues in the North and the Arctic is at the forefront for many countries, including Russia, the United States, Northern Canada, Greenland, Norway, and Finland (Poleshkina 2018). Thus, the search for effective ways to solve the problems of food security in the Northern regions and the Arctic is of strategic importance for the development of these territories. The solution of these urgent problems will contribute to the development of the economy, industry, ecology, and protection of the interests of concerned countries (current and potential) involved in solving these problems. That is why, in the future, there will inevitably be a significant increase in the number of people living and working in these territories, including children, teenagers, and women. These factors determine the need to create conditions for ensuring food security for various groups of the population of the territories of the North and the Arctic. When solving this problem, it is necessary to take into account that living and working in these territories takes place under uncomfortable natural and climatic conditions, and at times even extreme conditions. One of the ways to take this situation into account is to use health-saving technologies, among which the most important place is occupied by technologies that provide high-quality scientific-based nutrition using high-quality food products that meet the conditions of the North and the Arctic. In these conditions, for the object under study, there is a need to consider logistics as a cross-cutting technological process that reflects the interaction of technological operations for the production of raw materials, the formation of stocks, their transportation, processing of raw materials and production of final products from them. The authors' research has shown that such cross-cutting technological processes are typical for a number of industries and play a particular role for the Russian economy, in view of effective development of which it is necessary to provide it with scientifically-based logistics territorial interregional and global world connections. As shown by the authors, of particular importance is the optimization of cross-cutting technological processes in agriculture and food industry to improve food security in the northern territories of Russia. In this regard, this work considers the solution of logistics problems on the example of the production of agricultural food products, their transportation, processing and production of functional food products. The research takes into account that the regions of Russia are located in completely different natural and climatic zones of the country (Auzan *et al.* 2012; Bobylev *et al.* 2012). Therefore, when choosing research areas for various aspects of economic security, including food security, it is necessary to fully consider the specifics of these regions, taking into account that the northern parts of Russia (in recent years, including the Arctic) begin to

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play an increasing role in the development of the economy by expanding development of unique natural resources (mineral, forestry, fishing, etc.) in these areas.

The study took into account the fact that the biological factors have a continuous and varied impact on human health in the Arctic, and the climate and weather conditions determine the mental and physical health of the Arctic population, as well as influence the course of somatic and epidemiological diseases. A study of the current diets of the incoming population in the Far North has shown that it is unbalanced in terms of the content of nutrients, vitamins, and minerals (Buganov *et al.* 2003; Lebedeva *et al.* 2014). In the context of this issue, research on women's health is of great importance for families living in the natural and climatic conditions of the North and the Arctic – research on the well-organized Nutrition of women, including pregnant and lactating women. In one of these studies (Gmoshinskaya *et al.* 2019), it is recommended to include products traditionally used by the indigenous population living in these territories in the planning of rational diets for pregnant and lactating women. Many researchers pay special attention to the organization of high-quality Nutrition for children and adolescents living in the Northern and Arctic territories (Vlasova *et al.* 2016).

This is because, for example, with an increase in the time spent living in the Arctic zone of Russia, children become more exposed to risk factors and non-infectious diseases (Tokarev 2008). The incidence rates of children and adolescents in the Arctic zone of Russia exceed the national indicators by 1.4 and 1.3 times, respectively. Adding enriched foods in diets will allow for better adaptation to the harsh climate conditions of the Arctic (Novikova *et al.* 2019). Research and development in the field of solving the problem of creating specialized food products for the population of the Northern territories of Russia were carried out by many researchers who studied the quality of natural resources harvested and processed in the North (meat, fish, and vegetable). Stepanov *et al.* (2014) examined the prospects for the use and quality of products from the meat of domestic and commercial animals of the North, as well as natural resources available in the Northern territories. Stepanov *et al.* (2016) also showed the prospects for the production and consumption of food products by the population, including raw materials of natural origin. These conclusions are confirmed by studies of the characteristics of fruit and berry food resources growing in the Far North (Tyupkina *et al.* 2010).

Enrichment of raw materials and food products, diets of northerners, with vitamins, macro-and microelements is important for the implementation of tasks in the field of food security and healthcare of the country as a whole, and especially for the territories of the North and the Arctic. The current stage of food enrichment with macro-and microelements is characterized by the fact that not all food products can meet the daily and human physiological need for macro - and microelements, and even more so in the conditions of the North and the Arctic. The authors believe that this fact is evidence of the need for research aimed at developing new intellectual property objects – good variants of functional food products. It is important that the implementation of this research is aimed not just at providing the population of the north of Russia with specific physical amounts of food, but at the need to meet their needs in high-quality and natural food, while simultaneously ensuring import substitution and increasing the food security of the Russian North.

In addition, ongoing and planned projects of the Russian Federation for the development of the Northern territories and the Arctic identify these territories as the potential for the movement of civilians and military personnel to these territories, which also confirms the significance of the chosen research direction. The analysis showed that to improve food security and ensure a balanced diet for various groups of the population living in the North and the Arctic territories of Russia, people working in these conditions permanently or on shifts, people sent to the North and the Arctic on a business trip, and their family members, it is necessary to substantiate, develop and bring to market fundamentally new intellectual property objects – specialized functional food products.

Among such products, of particular importance are products which formulations provide for the use of various food resources of these territories, among which the plants of Northern latitudes are emphasized in this work. Given the above, for residents living in the Northern latitudes and the Arctic, it is worthwhile to develop formulations for functional food products that include plants of Northern latitudes. So, there is a need to consider cross-cutting processes of procurement and transportation of agricultural raw materials and production of functional food products from them, including their enrichment, as objects for analysis and synthesis of new solutions, and on this basis to form a model and structure of initial data for its further use as a tool to justify the optimal location of enterprises for the production of functional food products and their optimal quantity for Russia's conditions.

MATERIALS AND METHODS

n the course of this study, as the objects for analysis and synthesis of new solutions were considered cross-cutting processes of procurement and transportation of agricultural raw materials and production of functional food products from them, including enrichment.

The purpose of forming the model and structure of the initial data is to obtain a tool to justify the optimal location of enterprises for the production of functional food products and their optimal quantity for Russia's conditions. According to the methodology of work, when building a mathematical model, the minimum cost of the entire route from the field to the consumer is taken as a criterion for optimizing the cross-cutting processes of procurement-transportation of agricultural raw materials and production of functional food products from them, including enrichment. As a result of solving this task, optimal routes should be built that will provide the transportation of the volumes of products needed by the population, which are determined by the number and need of the region's population for functional Nutrition. The factors that should be involved in the mathematical model under consideration are examined below. It is reasonable to introduce the concept of a certain conventional unit of goods transported in the considered mathematical model, for example, a traditional product of cereal (hereinafter "CCP"). Besides, the model will also consider the transportation of enriched products (hereinafter CCPe) aimed to fill the deficit of certain trace elements. Here CCP is defined as the total volume of grain production in a given region. It is impractical to take into account a specific specialization or multi-specialty of grain production due to a fairly wide range of grains grown in the main agricultural regions (wheat, rye, barley, oats, legumes) and narrow specialization in several certain crops (buckwheat).

In the considered mathematical model, the transportation network of delivery, processing, distribution of raw materials and CCP is represented as a graph consisting of vertices and edges. The vertices of a graph correspond to the administrative regions of the Russian Federation, while at various stages of decision, the vertices can correspond to either Federal Districts, or territories, regions, and republics – a regional graph. Any region can be a supplier of raw materials, a processor, and a consumer of final products. At the same time, the lack of raw materials in a particular region is represented by a zero-value yield. In connection with the above, regions should be divided into surplus and deficit ones: by various types of food raw materials, by processing capacity, and by consumption. The boundaries of this division are determined individually by the types of raw materials and CCP. The graph associated with the previous one is the graph of points for processing food raw materials, in which they are represented by the vertices of the transport network – the processing graph. The processing point may be associated with an administrative division, in which case it will completely coincide with the regional graph. At the same time, it is more efficient to use a derived graph based on administrative one, but taking into account the location of processing points, for example, in accordance with the deficiency of a particular type of raw material, or, conversely, its surplus, i.e. in regions with a surplus – the point of production, storage and recycling of raw materials. A specific location of an existing processing point is determined by its actual address – the capital of the region – is chosen based on the deficiency of raw materials or CCP in the region, economic and social considerations, and food security of the region.

The model is to look for a solution in a stepwise manner: initially, recommendations are given for the location of raw material processing points, taking into account the cost of distributing raw materials to all nodes of the graph (zero values are allowed) and then the charge of distributing CCP to all nodes of the graph (not less that the region's (node) needs in the CCP must be delivered. The edges of the considered graphs represent various transport routes (road, railway, and water). To obtain a preliminary decision, the type of transport is not specified, but the flow of grain products and CCP are taken into account. Numerical characteristics of the edges can be the length of routes, tariffs for transportation of raw materials and CCP, and the route capacity.

RESULTS AND DISCUSSION

In recent years, there is a pattern in the Russian Federation, which consists in the following: the increase per ton in transportation volumes of grain from regions with a surplus to the regions of the Russian Federation, in which there is a deficit of grain crops of their own production, leads to an increasing volume of grain transportation between areas of the country for two and a half tons. Based on the above, intermediate transportation of wood requires detailed optimization, since as a result of intermediate movements of grain crops, the load on the transportation network is greater than required for transporting grain between regions of the Russian Federation.

For the mathematical model, there is introduced a set of indices:

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i – region;

Set of parameters are introduced (initial data in a tabular form):

S_i – the number of raw materials (CRP) produced in region i, ton;

P_i – need of region i for CCP;

U_i – need of region i for CCPe;

$T_{n,\ m}$ – the cost of transportation of 1 ton of CCP and CCPe from region n in region m, ruble*ton, where n – number of the first region in the pair;

m – number of the second region in the pair;

A set of variables is introduced:

W_i – the amount of raw materials (CRP) transported in region i (amount of raw materials processed in a region), as well as the amount of CCP produced in a region, $W_i = V_i$;

G_i – the surplus of raw materials in a region left after meeting the need of other regions, ton ($G_i \geq 0$);

Q_i – the amount of CCP transported in a region, ton, $Q_i> = P_i$;

Y_i – the amount of CCPe transported in a region, ton, $Y_{i>} =U_i$;

The following dependencies and restrictions are introduced:

$Z = \sum Q_i \times T_{n,\ m} + \sum Yi \times T_{n,\ m}$

Table 1. Example of documenting input data by time of product transportation, hour.

Region	1	2	3
1	0	50	75
2	50	0	18
3	75	18	0

Values on the diagonal line can also be considered as internal transportation in the region.

Table 2. Example of documenting input data by the cost of transportation of 1 ton of products by rail (according to the data of 2018).

Region	1	2	3	4	5	6
1	0	518,006	1054,721	412,7678	1223,102	741,345
2	489,3088	0	753,0381	618,567	893,3558	270,1115
3	996,2901	753,0381	0	521,514	168,3812	525,0219
4	…	…	…	…	…	…
5						
6						

Table 3. Example of documenting input data by volumes of transportation of grain raw materials and CCP between the regions, ton.

Region	1	2	3
1	0	800	0
2	800	0	500
3	200	400	0

The volume of transportation is assigned based on the regional processing capacity. At the same time, there may be no reverse movement of goods. Diagonal elements show the volume of transportation within the region. The cost of delivering raw materials can be determined by the distance and volume of grain transportation, on the other hand, it is possible to obtain data in an integral form – the cost of transportation from point 1 to point 2. From the perspective of applying the mechanism for solving transport problems, the second representation of the transportation cost is more appropriate.

Table 4. Example of documenting input data by the cost of transportation of product unit, ruble/ton.

Region	1	2	3
1	0	100	110
2	100	0	50
3	110	50	0

Diagonal elements may also represent the cost of internal transportation. When solving a transportation problem in the classical formulation, the optimization criteria, in addition to price, can also be the distance or time to carry out the transportation of grain raw materials or CCP (Tables 1-4).
The following characteristics will serve as limitations of the considered mathematical model:
- minimum cost price (of the final product);
- the minimum volume of raw material transportation, no more than 4 thousand tons in a single delivery;
- yield, no more than 100 hectare\ton;
- minimum processing capacity (40000+10000n), $n = 0,1, \ldots$;
- demand – no less than 100000 tons and no more than 1200000 tons of products must be delivered to region j;
- capacity of the intermediate terminals. The capacity of the intermediate terminals is in the range from 60 to 100 thousand tons, while the capacity of processing plants is in the range of 50 to 65 thousand tons, respectively, in the solution of the problem focus should be on the projected capacity of the terminal – 80 thousand tons, and processing production – 57 thousand tons.
- the upper limit of processing capacity is 1250 thousand tons.
The volume of deliveries to the region, taking into account the population and enrichment of raw materials in the model, is presented in Table 5.

Table 5. Example of documenting input data by the volumes of transportation of grain raw materials and CCP in the region, thousand tons.

Region	1	2	3
1	0	80	0
2	80	0	50
3	20	40	0

As initial data for the considered mathematical model, the following characteristics should be considered:
- raw material productivity;
- tariffs for transportation of raw materials and CCP;
- distances for transporting raw materials and CCP;
- the population of the Russian Federation region;
- the region's need for CCP;
- price of grain raw materials and CCP;
- the table on the deficit for each region for the selected micronutrients;
- the cost of CCP in the place of cultivation, presented in the form of a table.

At the model's first stage of solution, the raw material is transformed into an enlarged cereal product and enriched enlarged cereal product.

Stage 1: Transforming the raw materials into CCP and CCPe.
The 1st stage provides for the formation of a table with the initial data for the 2nd stage for the existing CCP and CCPe in the region (Table 6).

Table 6. Example of documenting input data by the production, needs and processing of grain raw materials, CCP and CCPe.

Regions	CCP	CCPe	Cost of raw materials	Cost of CCP	Cost of CCPe	Yield, center/hectare	Population, million	Need for CCPe, ton
Region 1	100	14	6500	7345	8814	120	5	8000
Region 2	200	14	6200	7006	8407	140	4	6000
Region 3	500	30	6700	7571	9085	110	2	4000
…								
…								
…								

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Drawing from the data on transportation companies, data set is formed on the average tariffs for shipping with large-capacity transport (more than 20 tons) between the regions (Table 7).

Stage 2: Distribution of CCP and CCPe

The second stage involves addressing the task of regional distribution for filling the deficiency on specified micronutrients (Table 8).

Table 7. Example of documenting input data by the tariffs for transportation of grain raw materials and CCP, ruble ton^{-1}.

Tariffs	Region 1	Region 2	…
Region 1	0	500	…
Region 2	500	0	…
…	…	…	…

Table 8. Example of documenting input data by required volumes of CCP for each region.

Region	CCP volumes, thousand tons
Region 1	200
Region 2	450
Region 3	500

The objective function of this model is to determine the volume of the CCP and CCPe for each region, minimizing the total logistics costs:

- the volume of CCP produced, V_j for each region;
- the volume of CCPe produced, V_{je} for each region.

Optimization criterion:

- minimum total logistics costs concerning the above restrictions;
- meeting the demand for enriched CCPe products.

Further, the structure of the mathematical model is discussed.

In the considered mathematical model, the transportation network for delivery, processing, and distribution of raw materials and cereals (hereinafter referred to as the CCP) is represented as a graph consisting of vertices and edges. The transition to the CCP formation is associated with the appearance of a clear movement of raw materials because there are a huge number of types of raw materials available in the growing areas.

The vertices of the graph correspond to the administrative regions of the Russian Federation. In view of the above, regions should be divided into surplus and deficit ones: by different types of food raw materials, by processing capacity, and by consumption. The processing point may be associated with an administrative division, so it will completely coincide with the regional graph. At the same time, it is more efficient to use a derived graph that relies on administrative one, but takes into account the location of processing points, for example, in accordance with the deficiency of a particular type of raw material or its surplus. The specific location of an existing processing point is determined by its actual address – the capital –, the projected one is chosen based on the deficiency of raw materials or CCP in the region, economic and social considerations, and the food security of the region.

The general principle of solving the mathematical model is as follows. The problem will be presented as a graph consisting of three fractions. The first fraction consists of vertices corresponding to the points containing the product. The second fraction relates to processing points, the third – to destination points to which the finished product that is the product from the processing point is to be delivered. For the vertices of the first fraction, the initial content of the product is known, and for the third fraction – the need for products. For each pair of vertices of the first and second fractions, as well as the second and third, the cost of transporting a ton of products is known. It is necessary to transport all products through T vertices of the second fraction (that is, choose no more than T points of enrichment) so that all vertices of the third fraction have no less than required, and the total cost of transportation would be minimal.

The model should give recommendations on the location of raw material processing points, taking into account the cost of raw material distribution at all nodes of the graph (zero values are allowed) and the subsequent cost of CCP distributions at all nodes of the graph.

Model input data:

- raw material productivity;

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- tariffs for product transportation;
- transport distances;
- the population of the region;
- the needs of the area;
- cost of raw materials and CCP.

Output data:

- minimum total costs;
- production profitability;
- deficiency and surplus.

Mathematical methods:

- linear programming methods;
- dynamic programming methods;
- flows in graphs;
- binary search;
- combinatoric elements;
- floating-point algorithm.

Then, the mathematical formulation of the considered problem is considered:

- for each set of regions, the cost of transporting one ton of enlarged product is known;
- there are *N* regions, each with *xi* tons of universal enlarged product available;
- for each region, it is known how much-enriched product should be imported based on the needs of the population.

The following restrictions are brought:

- the product is universal (the model considers an enlarged product);
- the entire product must be processed;
- the number of processing points is not more than 80.

With a large number of enrichment points (> 9), enlarged products from several close regions are delivered to a single processing point, which in some sense is the closest.

Further, the theoretical foundations of the formation of a system for managing the transport and information flows of raw materials and functional products are considered.

Further, the problem is presented as a graph consisting of three fractions:

- the first fraction consists of vertices corresponding to the points containing the product;
- the second fraction represents processing points;
- the third fraction is the destination points where enriched products, i.e. the products from the processing point, are to be brought;
- the initial content of the enlarged products is known for the vertices of the first fraction, and the need for enlarged products – for the third fraction.

For each pair of vertices of the first and second fractions, as well as the second and third, the cost of transporting 1 ton of the enlarged product is known.

It is necessary to transport the entire enlarged product through *T* vertices of the second fraction (that is, choose no more than *T* processing points) so that all vertices of the third fraction have no less than required, and the total transportation costs would be minimal (Figure 1).

Formally, let b_k of the second fraction vertex, the transfer points, $k = id1,..., IDT$, a_i of the vertex of the first fraction, b_j of the vertex of the third fraction, receiver points, A_{ik} the cost of transporting one ton from point *i* to point *k*, A_{kj} cost of transporting one ton from point *k* to point *j*.

The needs of the population are denoted as *Mj*, stocks N_i. Let x_{ik} and x_{kj} be the transportations of enlarged products. It is necessary to find such *x*, so that:

$$\sum x_{ik}A_{ik} + \sum x_{ki}A_{ki} \to min$$

and the following limitations would be respected:

$$\sum x_{kj} \leq M_j$$

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$$\sum x_{jk} \leq MN_j$$

Further, a general description of the algorithm is presented. Adding two fictitious vertices, which will be further called the source and the drain. From the source, we draw the edges of throughput capacity *Ni* and zero cost to the vertices of the first fraction.

We connect the vertices of the first and second fractions by edges of the throughput capacity equal to infinity, and with the cost of *Aik*. We will do the same for the vertices of the second and third fractions. The maximum flow of the minimum cost will give the answer to the problem.

It should be noted that the vertices that will be selected as processing points can be processed using the combination generation algorithm when their number is less than 8. Otherwise, the method of vertices clustering based on the cost of transportation will be applied, and the vertices of the second fraction will be determined based on the clustering parameter for the maximum cost within a single cluster.

This parameter will be processed sequentially since the different values are no more than a square of the number of regions.

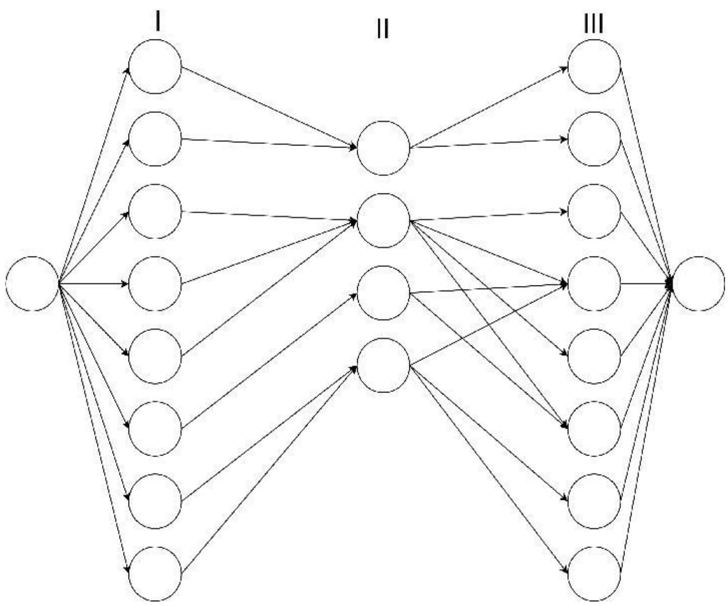

Fig. 1. Graph from the third fraction, corresponding to the specified model.

To solve this task, it is necessary to perform the sequence of the following steps:

1. Construct a graph *G* of three fractions, as described above.
2. Fix the number of processing points *K*.
3. Find the highest cost of *x*, which is no more than *K* processing points (vertices of the second fraction of the constructed graph) led by an edge from some vertices of the first fraction. To do this, the binary search algorithm is to be used.
4. Find the maximum flow in the graph *G*, in which only those edges which cost is not more than *x* are to be left.

Algorithm for finding the maximum flow of the minimum cost

Flow transport problems that are considered in transportation networks are highly relevant since they are able to model a large range of applied mathematical problems, including problems for finding the maximum amount of flow of the minimum cost of transportation.

In practice, such mathematical models should include such parameters of transport networks as its throughput capacity, which in turn depends on road clogging, repairs, road surface quality, etc. These parameters are highly likely to change over time. Such problems are "stationary-dynamic." This area of research is less studied.

Further, the mathematical model of finding the flow of minimum cost in fuzzy dynamic transport network is considered (Bozhenyuk, Gerasimenko, Rozenberg, 2012):

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$$\sum_{t}\sum x_{kj}A_{kj}(t) \rightarrow min$$

$$\sum_{t=0}^{p}\sum A_{sj}(t) - A_{js}\big(t - f(t)_{js}\big) - v(p) = 0$$

$$\sum_{t=0}^{p} A_{ij}(t) - A_{ji}\big(t - f(t)_{ji}\big) = 0$$

$$\sum_{t=0}^{p}\sum A_{tj}(t) - A_{jt}\big(t - f(t)_{js}\big) + v(p) = 0$$

Below are explanations of above expressions.
The first expression means the following: to find the minimum route of transportation of the maximum amounts of transported products in the transportation network for the specified amount of time (Bozhenyuk *et al.* 2012).
The second expression means that the maximum amount of flow $v(p)$ for the specified number of p time periods is equal to the flow leaving the source for the number of time periods $A_{sj}(t)$.
The third expression means that for each node x_i and each moment of time t, the number of flow $A_{ji}\big(t - f(t)_{ji}\big)$ that entered x_i at time $t\text{-}f(t)_{ji}$ is equal to the number of units of flow $A_{tj}(t)$, that leaves x_i at time t.
The fourth expression means that the maximum amount of flow for the number of periods equal to p is equal to the flow entering the drain for p time periods $\sum A_{tj}(t) - A_{jt}\big(t - f(t)_{js}\big)$.
In other words, it is necessary to transport $v(p)$ flow units at minimal logistics costs, and it is necessary that the extreme flow unit at the time enters the drain no later than p.
The algorithm for solving this problem is further described. The first step is to move from the given fuzzy dynamic graph to a fuzzy already static graph stretched over time by p intervals by generating a separate copy of each vertex x_i in each considered time period t.

Table 9. Time parameters for passing along the arcs of the flow of grain raw materials and CCP.

Time moment, T	Time of passing along the graph arcs, t_{ij}					
	(x_1, x_2)	*(x_1, x_3)*	*(x_2, x_4)*	*(x_2, x_5)*	*(x_3, x_4)*	*(x_4, x_5)*
0	1	4	4	2	5	1
1	1	3	1	4	4	4
2	3	1	3	1	3	1
3	2	1	3	2	3	1

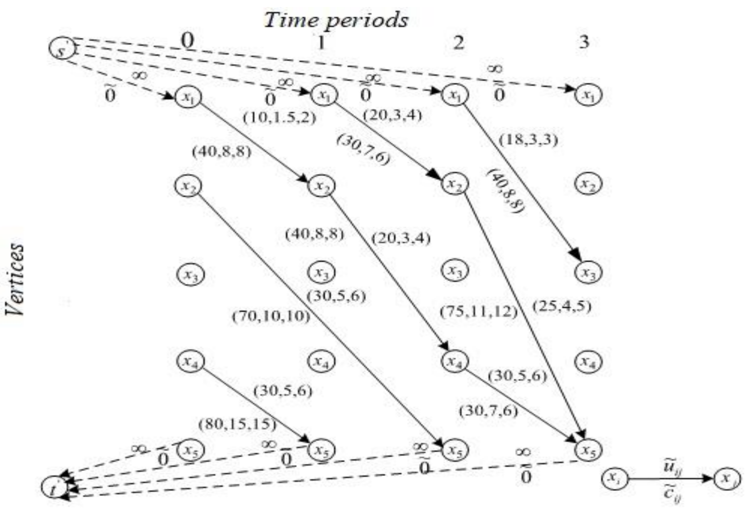

Fig. 2. Example of a graph stretched over time, which represents a transportation network for grain raw materials and CCP.

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At the second stage, a fuzzy residual network is constructed for the time-stretched graph created at the first stage, depending on the values that follow the arcs of the flow graph (Table 9). The residual network is generated as follows: over a time-stretched network, depending on the values of flows moving in such a way that each arc in the residual fuzzy network that connects the *i* vertex-time pair with the *j* vertex-time pair, over which the flow has fuzzy residual throughput capacity (Fig. 2).
At the third stage, the path of the minimum cost using the Ford-Bellman minimum cost algorithm is found (Ford *et al.* 1966; Bozhenyuk *et al*. 2006) from an artificial source to an artificial drain in the generated fuzzy residual network, making calculations from zero values of flows. The fourth stage of the algorithm is to run the maximum number of flow units along the found path, depending on the edge in the residual transport network with the minimum residual throughput (Fig. 3).
The fifth stage consists in updating the flow values in the graph for arcs that connect the vertex-time pair with the changed cost, including generation of the flow along the corresponding arcs passing from *i* to *j*.
Sixth stage. If the maximum flow of the minimum cost is found, then the transition to the original dynamic graph is made in the following way: we drop the artificial vertices and arcs that connect them to other vertices of the graph.

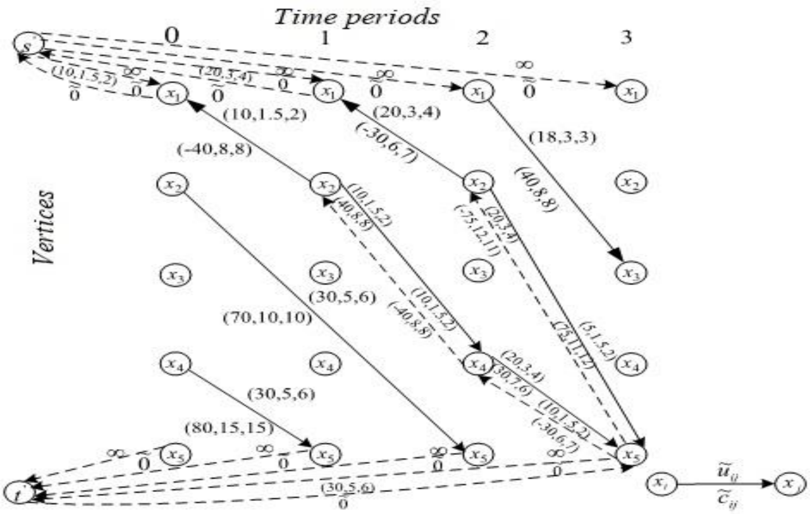

Fig. 3. The residual network after finding the optimal flow on a graph, which represents a transportation network for grain raw materials and CCP.

As a consequence of the above, it should be noted that the maximum flow *v(p)* in the initial dynamic graph is obtained, which has a minimum cost and which is equivalent to the flow from sources to drains after removing the fictitious vertices. It should be mentioned that the source is the initial vertex of the initial graph, stretched over *p* intervals. A drain is a finite vertex of the initial graph that is also stretched over *p* intervals.
Thus, we considered an algorithm for finding the maximum flow of the minimum cost in a fuzzy dynamic transportation network. Flow transport problems that are considered on transport networks are highly relevant since they are able to model a large range of applied mathematical problems, including problems for finding the maximum amount of flow of the minimum cost of transportation.
A regressional dependence is constructed for the study on arbitrary data:

$$T_{ave} = \sqrt{-8959.39 + 34.16\sqrt{\frac{P_{yr}}{N_{crf}}}}, \text{ rubles.}$$

The coefficient of determination of the constructed model is 98.63 %.
Thus, the model and structure of the source data for finding the optimal location of grain processing capacity is formed.

CONCLUSION

1. Cross-cutting technological processes that reflect the relationship of technological operations of raw material production, stock formation, their transportation, processing of raw materials and production of final products

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from them are characteristic of a number of industries. They play a special role for the Russian economy, in view of effective development of which it is necessary to provide it with scientifically based logistics territorial interregional and global world connections. Of particular importance is the optimization of cross-cutting technological processes in agriculture and food industry to improve food security in the Northern territories of Russia. In the future, there will be a significant increase in the number of people living and working in these territories, including children, adolescents and women. Enrichment of raw materials and food products, diets of northerners with vitamins, macro-and microelements is important for the implementation of tasks in the field of food security and health of the country as a whole, and especially for the territories of the North and the Arctic. The current stage of food enrichment with macro-and microelements is characterized by the fact that not all food products can meet the daily and human physiological need for macro-and microelements, and even more so in the conditions of the North and the Arctic.

2. These factors determine the need to create conditions for ensuring food security of various groups of the population of the territories of the North and the Arctic. When solving this problem, it is necessary to consider that living and to work in these territories is accompanied by uncomfortable natural and climatic conditions and sometimes extreme conditions. One of the ways to take this situation into account is the use of health-saving technologies, among which the most important place is occupied by technologies that provide high-quality scientifically-based Nutrition using high-quality food products that meet the conditions of the North and the Arctic.

3. This study resulted in the formation of an original mathematical model and the structure of the initial data for obtaining a tool for justifying the optimal location of enterprises for the production of functional food products and their optimal number for Russia's conditions.

4. The developed mathematical model of the logistic system of providing the population with functional food is a justification of economic efficiency through technology procurement, transportation and production of functional foods. At the same time, the conditions for implementing the mathematical model are defined: the number of enterprises, the average and maximum annual productivity, and the step of variation in productivity.

5. During the study, there were selected optimization criteria of cross-cutting processes of procurement and transportation of agricultural raw materials and production of functional food products with regard to their enrichment – the minimum cost of delivery of raw materials and a universal product and method of finding the optimal solution for a mathematical model for the location of product processing industries.

6. During the study, there was established the change in the cost of final products with an increase in the number of processing enterprises. It was found that the rational number of processing points is in the range of 7-12, while the optimal number is 7-9. For the next period, according to expert evaluation, the operation of four following enterprises can be recommended: the first – the reference enterprise on the territory of the Northwestern Federal District – the Trading house "Yarmarka", the second – on the territory of the Republic of Komi or Kirov region, providing functional products of the territories of North of the Urals, the third – in Yakutia and the fourth in the territory of one of Far East regions. The feasibility of creating small enterprises-producers of Federal Target Program in other regions of the country is shown in section 2.

7. When planning the creation of new enterprises, it is recommended to use the results of research on the project, especially in relation to plants that grow in Northern latitudes. At the newly established enterprises, it is recommended to focus on the creation of functional food products that ensure in the diet a combination of fixed European food traditions with specific national traditions of the peoples of the North, so that the traditional Northern food rich in protein and fat will complement the diet of all residents of the North with saturated carbohydrates and vegetable fats. In addition, it is recommended to use marine resources, in particular kelp, as well as formulations developed by the Far Eastern Federal University with a sufficient content of iron, selenium, potassium, phosphorus, magnesium, vitamins B, E, PP, β-carotene, sufficient fiber content, enriched with zinc, iodine, vitamins C, A, E, D, pectin substances (patents of the Russian Federation No. 2562218, No. 2562222, etc.).

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مدل ریاضی برای توصیف فرایندهای تولید غذاهای فراسودمند (عملکردی) با غنی سازی آن‌ها

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چکیده

فرآیندهای فناورانه که منعکس کننده‌ی رابطه‌ی بین فناوری تولید مواد خام، تولید کالا، حمل و نقل آن‌ها، فراوری مواد خام و تولید محصولات نهایی هستند، در بسیاری صنایع متداول هستند. نکته‌ی مهم، بهینه سازی فرایندهای فناورانه در صنعت کشاورزی و صنایع غذایی برای بهبود امنیت غذایی در سرزمین‌های شمالی روسیه است. در این راستا، در این مطالعه، اقدام به مدل‌سازی و ساختار دهی داده‌های اولیه برای به دست آوردن ابزاری برای توجیه و توضیح موقعیت بهینه‌ی شرکت‌ها برای تولید محصولات غذایی فراسودمند و تعداد بهینه‌ی آن‌ها برای روسیه شده است. در مطالعه حاضر رویکرد اولیه برای تشکیل مدل ریاضی به‌منظور توصیف لجستیک تولید فناوری ارائه شده است که شامل بهینه سازی هزینه‌های حمل و نقل محصولات غذایی عملکردی از حیث غنی سازی است که به توجیه بازدهی و راندمان اقتصادی فناوری تدارکات، حمل و نقل و تولید غذاهای فراسودمند کمک می‌کند. محققان، تغییرات در هزینه‌ی محصولات نهایی را با افزایش تعداد کارخانجات فرآوری، تعریف کرده‌اند. همچنین نتایج نشان داد که تعداد مراکز فرآوری (شرکت‌های تولید محصولات غذایی فراسودمند) ۷-۱۲ است در حالی که تعداد بهینه ۷-۹ است.

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