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MATHEMATICAL ANALYSIS OF ECONOMIC MODELS

Forecasting the dynamics of the spread of anemia in the regions of Russia based on an agent-based model

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Annotation. The article deals with the development of an agent-based model of the dynamics of the spread of anemia in Russia. A structure is presented that includes residents' agents, food producers and sales agents. For each acting subject in the model, algorithms have been developed that determine their interactions with each other. For food producers, their purchases, sales, production process and dynamics of investments in fixed assets are modeled. For sales agents - the formation of the range and prices of products, taking into account transport and trade margins, and for

households - food based on their income, composition and habits. Depending on the quality of the food received and the current stage of anemia, the expected dynamics of the disease is modeled . The article deals with the issues of software implementation and information content of the model, the user interface is presented. Four scenarios of the dynamics of the socio-economic environment of the model are formalized, taking into account epidemiological and external economic risks, including the “trade war” scenario, which takes into account increased inflationary risks in relation to food products. A series of calculations was carried out to predict the dynamics of the spread of anemia under the conditions of the developed scenarios. A program of subsidizing low-income families was proposed and its influence on the availability of a balanced diet and the incidence of anemia among Russian residents was studied. Calculations show that, in the absence of special support measures, a balanced diet becomes available to a smaller number of residents (65% compared to 78% in 2019) under the most likely “trade war” scenario at the moment. At the same time, the total amount of subsidies required to provide low-income families with quality food varies from 300 billion to 1 trillion rubles. per year, depending on the size of the allocated benefits.

Key words: agent-based modeling, anemia, nutrition, recommended intake.

JEL classification: I15.

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INTRODUCTION

According to the World Health Organization (World Health Organization…, 2019), anemia is a common disease worldwide that affects both developed and developing countries. The causes of anemia vary depending on the geographical location of the state, the sex and age of its inhabitants. However, diet-related iron deficiency anemia remains the leading global cause of anemia (Thejpal, 2015). Experimental and epidemiological evidence suggests that impairments can be reversible through well-chosen measures taken by the health care system . These measures should include supplementing the diet with foods rich in micro- and macronutrients and vitamins, and fortifying staple foods with micronutrients and supplements (DeMaeyer et al., 2019).

The task of implementing a balanced food policy becomes especially urgent in the context of rising food prices and declining incomes of the population during the COVID-19 pandemic, and the directions of such a policy can be state regulation of prices, various types of subsidies to the population, investment support and tax incentives for domestic manufacturers, as well as updating healthy nutrition standards and informing the population about them. The analysis of the whole variety of policy parameters and its possible consequences is a complex task, which requires the use of modern tools, in particular information systems for predicting the consequences of political decisions (Tracy, Cerdá, Keyes, 2018).

The aim of our study, implemented by an international team of specialists from Russia , India, and the Republic of South Africa, is to create tools for predicting the prevalence of anemia in the BRICS countries, based on agent-based modeling methods . Based on the interaction of various micro-level risk indicators, this method will help develop appropriate intervention strategies to reduce anemia among a vulnerable population. The objectives of the study include the development of the structure and algorithms of the agent -based model, its software implementation and information content, as well as scenario calculations that take into account epidemiological and external economic risks.

LITERATURE REVIEW

Over the past 40 years, agent-based modeling (ABM) has become an increasingly popular approach to the study of social systems. While the use of AOM in health care is in its infancy, models have already been developed in fields as diverse as epidemiology, drug trafficking and physical activity. In public health, agent-based modeling has historically been used almost exclusively to model the transmission and control of infectious diseases (Epstein, 2009). ABMs are a natural approach for modeling the transmission of infectious diseases because interactions between individuals and environmental influences often lead to population patterns of disease.

In terms of policy issues, models that examine the dissemination of information and the effectiveness of preventive measures (Barbrook-Johnson, Badham, Gilbert, 2016) or food systems (Li, Zhang, Pagán, 2016) can be noted. (Barbrook-Johnson et al., 2016) describes ABM, in which agents (people) reacted to communication messages in accordance with their own attitude and other relevant parameters. Communication between agents is carried out in the form of a set of "messages". Each message consists of predefined choices over a period of time (for example, every 10 days), audience targeting (media channel and population), and content. Agents respond to received messages in accordance with the content of the message, which can take on the following values: description of benefits; providing information on the epidemic status, emphasizing the norms. Thus, the message influences decision making and choice of behavior by changing decision factors. Analyzing consumer behavior and competition for his attention, you can also use AOM. In the case of nutrition, behavior can be a choice between healthy and unhealthy foods, as well as a preference for products from a particular manufacturer . Thus, in (Lamjed, Drogoul, Bouron, 2001) an agent-based behavior model is presented

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consumers in a competitive market. The model includes a virtual population that makes purchasing decisions by choosing between several brands.

In (Li et al., 2016), the authors investigate whether a hypothetical media and nutrition education campaign could lead to an increase in fruit and vegetable consumption in New York City. Previous research has shown that factors such as social status, wealth, local dietary habits, and social factors (e.g., social norms) are directly related to fruit and vegetable consumption (Glanz et al., 2005; Rose and Richards, 2004) . Traditional statistical models have a limited ability to predict eating behavior because they do not fully capture complex interactions between people and only cover the effects caused by these interactions. To solve complex problems in research, an agent-based model is used that takes into account individual factors (for example, age, gender, education, food environment) and their proximity to other agents, their interaction to predict food preferences in a closed area.

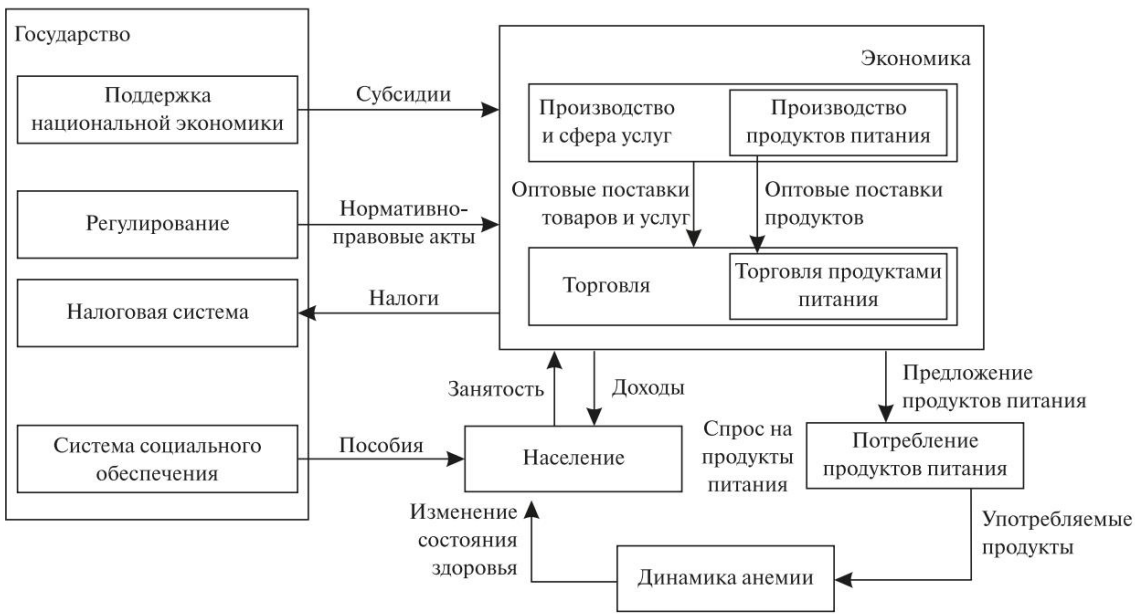
The difference between the developed model and known analogues is, firstly, its specialization in assessing the spread of a chronic disease (anemia); secondly, taking into account in this assessment various aspects of food production, trade and consumption and the influence of eating habits on the development of anemia; thirdly, the integration of agents into the developed socioeconomic environment of the model, including employment, income, and the budget system, which makes it possible to take into account a large number of factors when making a forecast and to model the consequences of various political decisions regarding food policy.

RESEARCH METHODS

Model Structure

The agent-based model of the dynamics of the spread of anemia is based on an artificial society that reflects the age and sex composition and health status of the population in the regions of Russia . The model reflects the main demographic processes: growing up, birth and death of agents, as well as marriages and divorces that affect the composition of households (Novikova et al., 2019).

The economic environment of the model includes organizations in various sectors of the economy, employment in which provides income for the population (Fig. 1). Organizations of the agriculture , fish farming and food industries are part of the economic environment



Rice. 1. The structure of an agent-based model of the dynamics of the spread of anemia

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and at the same time, acting subjects of the model, directly involved in providing the population with food. Similarly, among the organizations of the trade sector, organizations that trade in food products stand out.

Resident agents shape the demand for food depending on their income and eating habits. The chosen diet affects the health of the population, in particular the incidence of anemia.

The state in the model is an active participant in socio-economic processes, acting through the channels of the investment and tax systems, the social security system , as well as regulating the activities of economic entities by regulatory legal acts. Alternative options for political decisions form sets of control actions that are fed into the model of the dynamics of the spread of anemia. Their impact on the health of the population is assessed taking into account the initial state of the objects, as well as potential scenarios of the external environment that may take into account epidemiological risks, international trade and exchange rates.

Next, the algorithms of basic processes in the agent-based model will be considered.

signs of the spread of anemia.

Food production

Food producers in model A are characterized by five parameters:

$$AP = \langle P, Z, S, I, M \rangle, \quad (1)$$

where P is production; Z - purchases; S - sales; I - investments; M - marketing.

Production P is given through the volume of output V, the range of output PA_j and the production delay PT_j for each type of product j:

$$P = \langle V, PA, PT \rangle, \quad PA = \{PA_j\}_{j=\overline{1,m}}, \quad PT = \{PT_j\}_{j=\overline{1,m}}. \quad (2)$$

The output mix and production delay are determined by the industry to which the manufacturing organization belongs. Food production in Russia, according to the current classification of types of economic activity, is carried out within the framework of three industries: “01. Crop and animal husbandry, hunting and the provision of related services in these areas”; “03. Fishing and fish farming”; "ten. Food production”. The largest production delay will be in crop production (especially in open field cultivation), the smallest in food production.

Purchases Z include the range of purchases ZA and the share of imports in purchases for each type of raw material i:

$$Z = \langle ZA, ZT \rangle, \quad ZA = \{ZA_i\}_{i=\overline{1,n}}, \quad ZT = \{ZT_i\}_{i=\overline{1,n}}. \quad (3)$$

The range of purchases is determined by the degree of processing of products in the industry: in the industrial production of food products, all raw materials are purchased, in agriculture and fish farming - only auxiliary substances (fertilizers and feed).

Sales S are characterized by the wholesale price SP_j and the export share SE_j for each type of product j:

$$S = \langle SP, SE \rangle, \quad SP = \{SP_j\}_{j=\overline{1,m}}, \quad SE = \{SE_j\}_{j=\overline{1,m}}. \quad (4)$$

Investment I is determined by PR profit , own investment OI and government SI subsidies :

$$I = \langle PR, OI, SI \rangle. \quad (5)$$

Marketing M includes target groups of buyers B and tags T that define positioning product on the market:

$$M = \langle B, T \rangle. \quad (6)$$

The main categories of buyers are foreign organizations, domestic manufacturing organizations and sales agents acting as intermediaries in the sale of final products to households.

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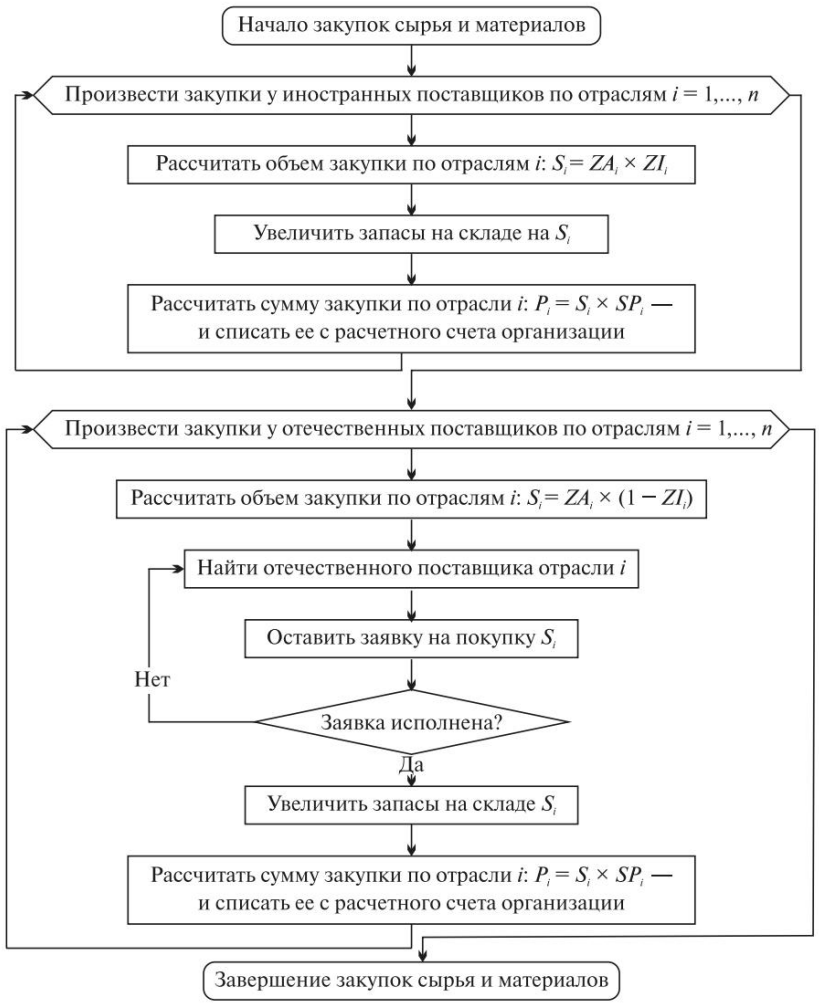

Rice. 2. Scheme of procurement of raw materials and materials

The marketing policy of the organization in the model is set using the attributes associated with it : "healthy food", "best price", "fast food", "natural product", "elite product". Attributes are related to target household consumption patterns, determining the positioning of the product in the market. Thus, the attributes “ healthy food” and “natural product” are associated with a balanced template, and “best price” with a minimum level of consumption.

The components of the manufacturer model are implemented within the framework of the organization's production and financial cycle , which is an iterative repetition of the purchase of raw materials and materials , the production and sale of finished products, as well as investment in the expansion of production capacities. Let's take a closer look at each step.

The purchase of raw materials and supplies (Fig. 2) is carried out first from foreign suppliers in accordance with the shares of imports *ZAi* in each type of raw material i. This is the order of operations in the algorithm is associated with the assumption that we consider the stocks of raw materials from foreign suppliers to be unlimited. For domestic suppliers, the required volume of purchases of each type of raw material i is calculated and an application is formed, which the supplier considers and fulfills if he has enough products in stock. Otherwise, the next supplier is selected and the process is repeated . When making a purchase, the stock of raw materials in the warehouse increases and the amount of delivery is debited from the organization's settlement account.

Production of products includes the write-off of raw materials from the warehouse, simulation of the production *holdings PTj* and an increase in stocks of products in the warehouse after an appropriate period of time.

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Rice. 3. Product sales scheme

The sale of products (Fig. 3) is also carried out first to foreign buyers in accordance with the shares of *SE* exports in each type of manufactured product. This is necessary in order to fulfill obligations under warehouse for sale within the country. Next, applications for the purchase of products of each type by domestic manufacturing organizations and sales agents are processed in the order in which they are received . As long as there are products of a certain type in the warehouse, they are sold at the wholesale price *SPj* (the stock of products in the warehouse is reduced and payment is credited to the settlement account). When the stock in the warehouse runs out, all remaining unfulfilled orders are entered in the list of unsatisfied orders for analysis of demand dynamics in the next step.

The investment process of the manufacturing organization begins with the calculation of profit:

$$PR \; S \; SP \; ETA \quad , \tag{7}$$

where Sj — the sum of sales of the organization by type of product j; *SPj* is the organization's wholesale price for products *E* - expenses of the organization (including the purchase of raw materials and wages of employees); *A* - depreciation of fixed assets of the organization; T—taxes paid by the organization; PR—received net profi

Next, the ratio of unsatisfied orders for various types of products to total organization's general sales (U):

$$U \quad SN \; SP \; jj \quad / \quad SSP \quad , \tag{eight}$$

where S - the amount of sales of the organization by type of product j; *SPj* is the wholesale price of the organization for the induction of the form j; *SN* is the volume of unsatisfied orders by type of product j. If U>0 - the demand for the organization's products exceeds its output and it needs to invest part of the profit in expanding production capacity to increase output; *U* ÿ 0 — investment is limited by the amount of depreciation for the renewal of decommissioned equipment.

The calculation of the total investment I takes into account the receipt of the state subsidy *SI,* the calculated share of net profit *PR* and the depreciation A of the manufacturing organization. After investing, the output of the organization increases proportionally:

$$V^{*} = V \left(1 + \frac{I}{OS}\right), \tag{9}$$

where v^{*} - increased output of the organization; *V* is the organization's current output; *I*- the total volume of investments made; *OS* is the current value of the organization's fixed assets.

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Food trade

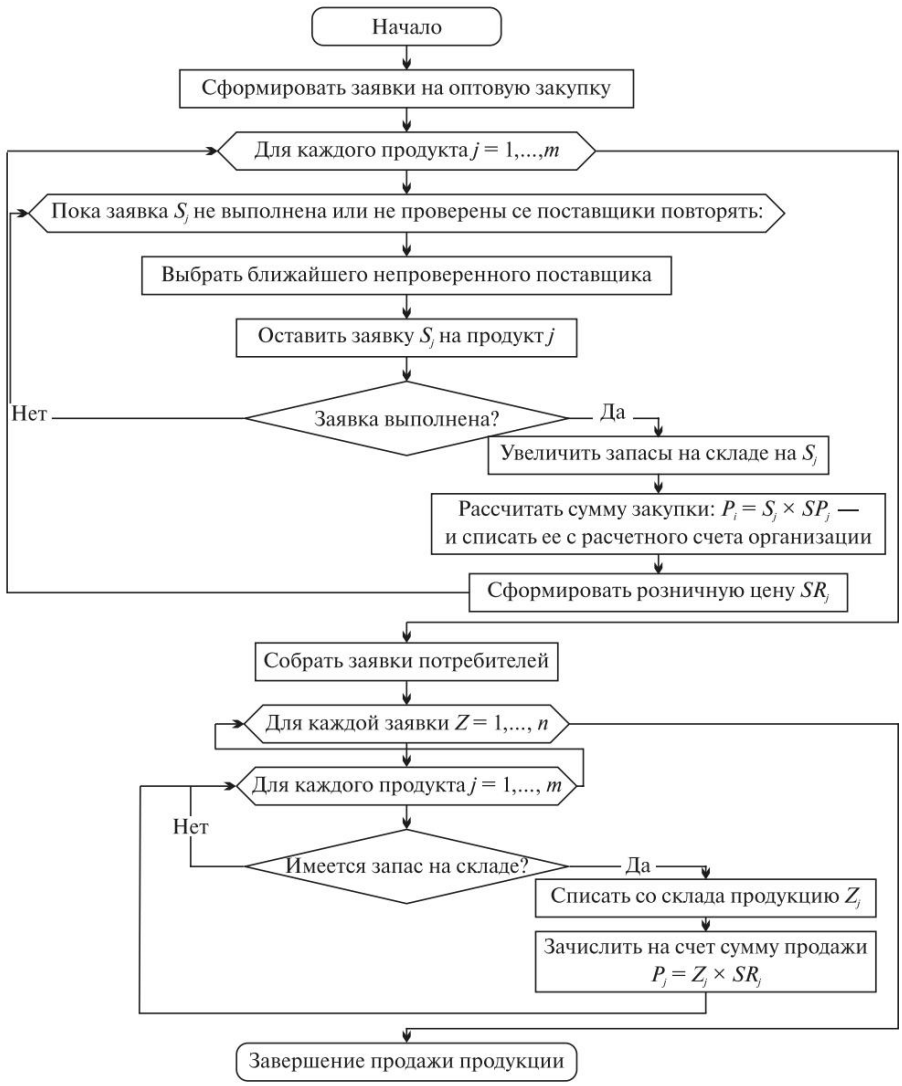
In each region of the model, two aggregated agents are created - resellers: one in urban, the other in rural areas. For each sales agent, a basic assortment is formed based on data from monitoring outlets in all regions of the Russian Federation, carried out as part of the project.

The reseller model receives requests from buyers-households formed within the framework of the consumer model. Based on the received requests from buyers, the sales agent generates requests for bulk purchases from manufacturers. The selection of a supplier begins with organizations in your region, then in neighboring ones, and so on, until the required assortment is formed or all suppliers are considered (Fig. 4). When the order is fulfilled, the stock of products in the warehouse of the sales agent is increased and payment for the delivery is made from his current account.

The formation of the retail price for the product is made taking into account the wholesale price and trade transport charges:

$$RP_j = SP_j + TE_j ME_j, \quad (10)$$

where RP_j is the retail price of product j; SP_j is the wholesale price of product j; TE_j - transport margin; ME_j - trade margin.



Rice. 4. Scheme of work of a sales agent

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The transport margin *TE* consists of three components:

$$TE\ TBE\ LE\ T\ CE, \quad (11)$$

where *TBE* is the base transport margin when purchasing from a supplier in your region; *LE* - additional transport margin for delivery from other regions, proportional to the distance to them; *TCE* - additional transport margin for delivery to the countryside.

Trade margin *ME* —

$$ME\ MBE\ MCE, \quad (12)$$

where *MBE* is the base trade margin; *MCE* is an additional trade margin when selling in rural areas.

Thus, food in rural outlets is on average more expensive due to additional transport costs associated with delivery to remote villages from urban warehouses, and additional trade margins due to lower turnover in rural stores. The amount of each markup is determined on the basis of a comparison of the results of monitoring outlets in different regions of the Russian Federation. Further, in the model, the processing of customer requests and the sale (if available) of the products included in them are carried out.

Demand for food

A household's demand for food depends on its income, the composition of the household, and its eating habits, which determine the choice of food to eat. The family's food budget (S) is calculated on the basis of data on the incomes of all its members and the consumption patterns of households of various incomes and compositions:

$$S\ D = F, \quad (13)$$

where *D* is the total family income; *F* - the share of income that is allocated to the purchase of products food items.

The total family income consists of wages, business profits and benefits from the state, which are received by all family members. The structure and size of agents' incomes are determined in the process of model operation and are directly related to the economy (employment and wages) and government control actions (introduction of new types of benefits, their indexation or cancellation). The share of income allocated to food purchases depends on the size of income (the lower the family income, the greater part of it goes to purchase food) and the composition of the household (single people, couples, children). This indicator is calculated on the basis of data on the structure of consumption of the population published by the Federal State Statistics Service1

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The amount allocated for the purchase of food is distributed among food categories according to the eating habits of the household. To formalize this process, the model introduces the concept of a “diet template”, which determines the share in spending on each category of products:

$$W_r = \{w_i^r\}, \quad \sum_{i=1}^{n} w_i^r = 1, \quad (14)$$

where W_r is a template for diet r; w_i^r is the share of category *i* in diet r.

The choice of template is influenced by household goals and available consumption levels. The level of consumption available depends on the level of food prices and can vary greatly from region to region. The model identifies three types of diet compliance with the principles of a balanced diet: I) allows you to get at least 90% of the nutrients (vitamins and minerals) that prevent the development of anemia; ii) get at least 75% of key nutrients; III) get less than 75% of key nutrients.

The composition of the food basket, developed in collaboration with specialist nutritionist Dr. Natisha Dukhi, includes cereals, dairy, meat and fish products, fruits and vegetables available in all regions of Russia (for more details on the composition of the developed basket, see (Mashkova et al . ., 2021)). Prices for products in various regions were estimated using specially organized monitoring in 77 subjects, as a result of which

¨ See the materials of the website of the Federal State Statistics Service (http://www.gks.ru).

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prices for 31,354 products. Information on the regions not covered by the monitoring was taken from the Unified Interdepartmental Information and Statistical System (EMISS).

Even if a family has enough money to purchase all the necessary products, this does not mean that it will adhere to the principles of proper nutrition. The model introduces the concept of a “target food pattern”, which reflects how the household diet meets modern standards. Balanced, mixed, and unbalanced target templates are identified, and their prevalence among the Russian population is assessed based on VTsIOM2 monitoring .

To reflect all aspects of the formation of demand for food by households, a special five-step algorithm has been developed in the model.

Step 1. The household budget and the amount allocated for food consumption are calculated nutrition.

Step 2. The target consumption pattern is taken into account, which determines the preferences of the household . If a household has sufficient funds, the quality of the diet will be determined by its target food pattern, otherwise the cost of food will play a key role. So, taking into account the possibilities and preferences, the appropriate consumption pattern W_r .

Step 3. The budget is distributed by product categories according to the structure of the template W_r .

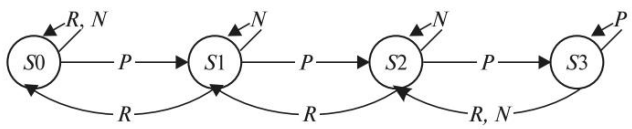
Step 4. For each category, a basic part is formed from the products most frequently used by the majority of the population and a random component that adds variety to the diet of a particular household. Selected products are purchased from a sales organization.

Step 5. The nutritional value of the purchased set of products is assessed, and the share of consumption by each member of the household of nutrients that affect the dynamics of anemia is calculated from the recommended intake of these nutrients.

The dynamics of the spread of anemia

The quality of the diet consumed affects the dynamics of the development of anemia in residents, depending on their current stage of anemia, gender and age. On fig. Figure 5 shows a model of the dynamics of the transition through various stages of anemia, depending on the nutrition received. The states S denote the stages of anemia: 0 — a healthy person; 1 - anemia of the first degree (mild severity); 2 - anemia of moderate severity; 3 - severe anemia. The transitions correspond to the quality of the food received in accordance with the recommended intake norms (RDA) of key nutrients: R - rich in vitamins and minerals, consumption of more than 90% RDA (diet
I type); N - normal, consumption of at least 75% RNP (diet type II); P - poor, consumption of 50–70% RDA (diet type III).

Transitions in the model are probabilistic, the probability of transitions is determined by calibrating the model on historical data. Based on the automaton model, for each agent , after determining its diet and the proportion of nutrients received from the recommended intake, its current stage of the disease is calculated, while also taking into account the time delay required to complete the transition.



Rice. 5. Automatic model of anemia dynamics depending on the quality of the food received

State regulation

In the model, the state can directly or indirectly influence the processes of production and consumption. fusion of food products by carrying out such various control actions as:

[2] Analytical reviews of VTsIOM "Healthy lifestyle: monitoring" (https://wciom.ru/analytical-reviews/analiticheskii obzor/zdorovyj-obraz-zhizni-monitoring) and "Nutrition: proper and safe" (https://wciom.ru /analytical-reviews/ analiticheskii-obzor/pitanie-pravilnoe-i-bezopasnoe).

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– introduction of changes in the legislative regulation of production and trade in products, food norms and standards;

– implementation of investment programs and the introduction of tax incentives for domestic food manufacturers;

– introduction of restrictions on the export and import of products;

– payment of targeted subsidies for the purchase of food products to low-income families;

– organization and improvement of free food programs in kindergartens and schools.

Alternative options for control actions are fed into the model of the dynamics of the spread of anemia, thus, the analysis of the simulation results allows a comparative assessment of political decisions in terms of their impact on the dynamics of morbidity among the population.

This paper analyzes the impact of subsidies on food purchases for low-income families. Control options are formed as a share of the cost of the food basket, which is covered by a subsidy for those families whose income does not allow all their members to purchase products that are part of the optimal basket. Thus , the amount of the allowance varies for different regions and years (since the cost of the food basket is calculated taking into account expected inflation). Also, the size of the subsidy for a particular family is affected by its income and size:

$$s_i \quad \min \quad p^r S\, npbpn^r \quad {}_{ii} \quad I, \quad {}_i \qquad \text{(fifteen)}$$

where *si* is the subsidy for family i; *pr* is the cost of the food basket in region r; *S* is the share of the cost of the food basket covered by the subsidy; *bi* is the total budget of family i; *bi* is the share of the budget allocated by family i for the purchase of food; *ni* is the size of family i.

Software implementation of the model

The agent-based model of the dynamics of the spread of anemia is a complex software system that includes interfaces, databases, and modules that implement the dynamic modeling functions described above. The software implementation of the model is made in C# in the MicrosoftVisualStudio environment, the database is supported using the PostgreSQL DBMS. The use of these software tools makes it possible to provide high computing performance required for a multi-agent system with a large number of active agents.

The information content of the model is based on data from the Federal State Statistics Service (FSGS)3 , RLMS monitoring4 , power information system6 SPARK-Interfax5 and open Internet portals dedicated to . The initial simulation data is loaded into the model in the form of tables. The basic tables of initial data are: the population of the regions by sex and age and their distribution by households; the number of patients with anemia in the regions of the country; industry classification of food products and raw materials for their production; volumes of food production in the regional context; income of the population; prices for products in the regions; nutritional value of food; food intake norms for different population groups. The issues of obtaining and converting the initial data to the format required for loading into the model are considered in more detail in (Mashkova, 2021).

In total, about 1.5 million resident agents are created in the model, which corresponds to a scaling of 1:100, i.e. each agent in the model represents 100 Russian residents of the same gender and age group. Also, 6,500 aggregated organizations representing industries in various regions are being created, of which 1,777 are organizations of industries that produce food products. The created objects and the relationships between them are stored in the model database.

[3] Website of the Federal State Statistics Service (http://www.gks.ru).

[4] Russian monitoring of the economic situation and health of the population of the National Research University Higher School of Economics (https://www.hse.ru/rlms/).

[5] SPARK-Interfax (official site: https://spark-interfax.ru/).

[6] Portal about healthy eating Health-diet: https://www.health-diet.ru/

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Modeling the dynamics of the spread of anemia is carried out taking into account the initial state of objects that are transferred from the database. In the process of dynamic modeling , the composition and characteristics of these objects change (growing up, changes in health status and the birth of new agents, changes in the output of organizations and household incomes), the corresponding changes are stored in the model database.

To run the model, it is necessary to choose a scenario that determines the parameters of the economic environment and a set of control actions, which are government support measures for food producers and/or low income families. As the results of modeling, the availability of a balanced diet to the population, the number of patients with anemia among children and adults can be displayed on the screen; also this information can be presented on the map for certain regions of Russia. Obtaining more detailed simulation data and uploading them for comparing the results of different series of experiments is carried out using a direct access to the model database.

RESULTS AND DISCUSSION

The uncertainty of the further dynamics of the epidemiological situation in Russia and its impact on the economy and the social sphere determine the use of the scenario approach when carrying out predictive calculations on the developed model. Modeling of the dynamics of the spread of anemia was carried out for the medium term until 2025 under three scenarios that take into account epidemiological risks and related changes in economic processes:

- Scenario 1 (pessimistic) - waves of coronavirus infection are regularly repeated here. Under this scenario, restrictive measures continue and global demand continues to decline ;

– scenario 2 (conservative) – assumes that the spread of the coronavirus will end in 2023. In this case, economic growth (both Russian and global) can be expected in two years;

– Scenario 3 (optimistic) – assumes the pandemic will subside by the end of 2022 and innovation by this date in all spheres of the economy;

- Scenario 4 (trade war) - in the light of recent events, it seems necessary to also consider a scenario that takes into account the political risks that have arisen under the conditions of a conservative epidemiological scenario.

Within the framework of the developed scenarios, the model includes series of forecasts of the following values factors for the Russian economy.

1. *The exchange rate of the ruble against the US dollar.* Starting from a course of 75 rubles. for 1 dollar at the time of the start of modeling (January 2022), in the optimistic scenario, its gradual decrease to 65 rubles is considered, in the conservative one it remains at the level of 70–75 rubles, in the pessimistic growth up to 80–85 rubles. for 1 dollar. In the “trade war” scenario, an increase in the dollar exchange rate to 120 rubles is considered.

2. *Market price of a barrel of oil.* In the optimistic scenario, an increase to $100 per barrel is expected; in the conservative scenario, the price will remain at the level of $75–85; in the pessimistic scenario, it will fall to $40–50 per barrel. The “trade war” scenario assumes an increase in world energy prices, in particular, the price of a barrel of oil to $140 per barrel.

3. *The volume of exports of products from* the agricultural, mining and manufacturing sectors, which, to varying degrees, are under pressure from the imposed restrictions. Thus, the volume of exports of food products and energy carriers grows in all scenarios, the demand for other types of minerals and manufacturing products falls in the pessimistic scenario as a result of a slowdown in the global economy, which is experiencing less need for raw materials, components and equipment. In numerical terms, annual export growth of 5–10% is expected in various sectors; in the conservative scenario - maintaining the volume of exports of the manufacturing industry; a 2–5% increase in agricultural production and minerals; on the pessimistic side, there is a 2–5% drop in exports of extractive and manufacturing industries, while maintaining high volumes of exports of agricultural products. The “trade war” scenario provides for a decrease in exports

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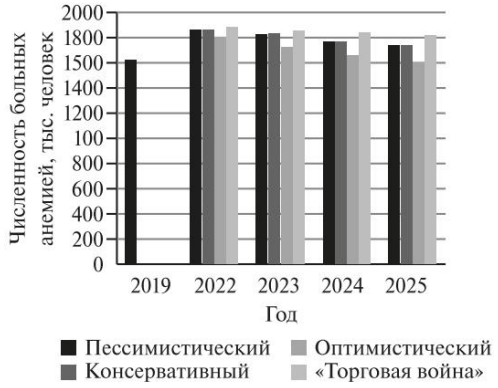
agricultural products due to state regulation up to its complete halt in 2022.

Fig. 4. *Dynamics of domestic demand* by groups of industries that have become the object of the most stringent regulation in the context of persistent epidemiological risks: entertainment, sports, catering, and, to a lesser extent, trade, since online sales of goods are activated when stores are closed. The optimistic scenario assumes the return of organizations in the affected industries to pre-crisis levels in 2022 and then their moderate growth of 2–4% annually. Under the conservative scenario, a return to pre-crisis indicators is expected in 2023; in the pessimistic scenario, growth in the affected sectors will continue to decline compared to the pre-crisis level of indicators until 2025.



Rice. 6. Number of patients with anemia in Russia, based on the results of scenario calculations

5. *Inflation* in the optimistic scenario returns to the target value of 4%; in the conservative, it decreases to 6%; in the pessimistic one, it remains at the current level of 8% (according to the Federal State Statistics Service, 2021). The “trade war” scenario assumes an increase in inflation rates to 15% in 2022, followed by a decrease to 10–12% per year.

The parameters of the developed scenarios were included in the developed agent-based model of the dynamics of the spread of anemia. The results of the performed calculations are shown in Figs. 6. Compared to 2019 figures, anemia is projected to rise to 1.8 million in all scenarios in 2022, driven by falling incomes and rising food basket costs. In subsequent years, along with the stabilization of the economic situation , a decrease in the number of people suffering from anemia is expected, but only in an optimistic scenario is it possible to reduce the number of cases to the values of 2019.

The observed differences in the scenarios are primarily due to the scenario indicator of food basket inflation, which exceeds the income growth rate in both the conservative and pessimistic scenarios. This situation can be corrected either by state regulation of food prices or by subsidies to low-income families. To conduct a series of calculations to assess the effectiveness of control actions, the second option was chosen, while varying the amount of the state benefit. The amount of payments is related to the cost of an optimal food basket that provides at least 75% of the necessary vitamins and minerals while meeting the caloric requirements of the diet (2500 kcal for an adult male). The cost of the basket is determined by the composition of its food products and the price of these products in different regions of the country. Prices for foodstuffs in different regions were estimated based on the results of monitoring in the regions (see paragraph “Demand for food”) and information from the EMISS.

As a possible control action in a series of calculations, the option of paying targeted benefits to families whose income does not allow for the purchase of products included in the type II diet is considered. For calculations, the following options for compensation by subsidies were chosen:

1) basic — there are no subsidies of this type;

2) 20% of the cost of a type II ration is covered;

3) 50% of the cost of a type II ration is covered;

4) the full cost of the type II ration is covered.

The analysis of the effectiveness of control actions was carried out under the conditions of a conservative scenario and a “trade war” scenario.

The calculations show that in 2019, a balanced diet of type II was available to almost 80% of the population of Russia, with the implementation of a conservative scenario, a decrease is predicted.

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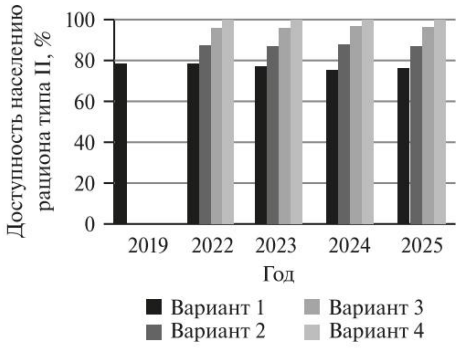
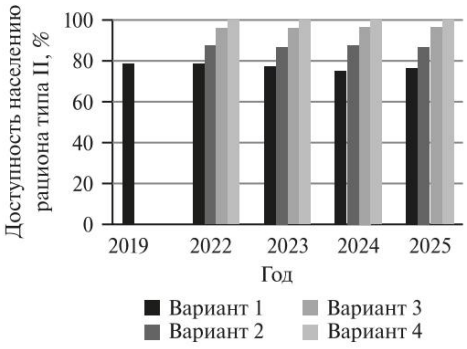


Rice. Fig. 7. Forecast of access to the population of the level II diet under various options for the program of subsidizing low -income families (conservative scenario)



Rice. Fig. 8. Forecast of availability of type II diet to the population under various options for subsidizing low-income families (trade war scenario)

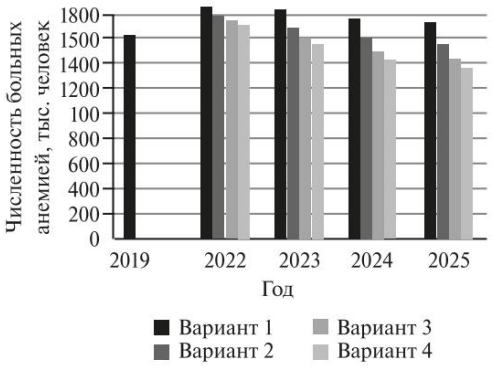
this indicator to 78%. The graph presented in fig. 7 shows how much the availability of Type II diet has increased with the implementation of the presented subsidy program for low-income families. With the implementation of the second and third options for subsidizing, the diet is available to 83-88% of the population, with the implementation of the fourth option - for all residents of Russia.

Under the conditions of the “trade war” scenario, the availability of a balanced diet for the inhabitants of Russia decreases even more dramatically - to 65% of the population (Fig. 8), which makes the subsidy program for low-income families necessary for an increasing number of residents.

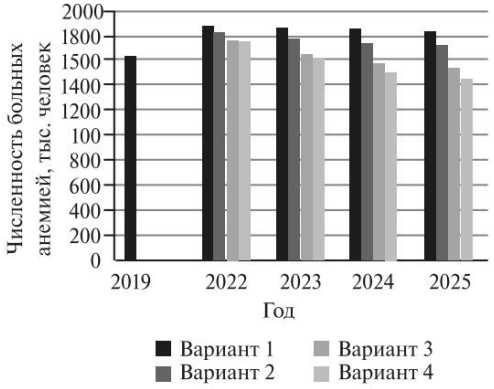
The required amount of subsidies is calculated in the program as the sum of benefits of this type paid to families in all regions of Russia. Taking into account the expected inflation, assumed at the level of 6% in the conservative scenario, the annual amount of subsidies lies in the range of 250–350 billion rubles. for option 2, 430–550 billion rubles. for option 3, 490–625 billion rubles. for option 4 (see table). In the trade war scenario, the amount of subsidies required is much higher, primarily due to higher food inflation rates (10–15% annually).

The number of patients with anemia is inversely proportional to the availability of a balanced diet to residents and, with the implementation of the subsidy program, decreases to 1.4–1.55 million people in the conservative scenario and 1.4–1.7 million people in the “trade war” scenario (Fig. 9). , ten).

An analysis of the simulation results allows us to conclude that the implementation of even the smallest version of the subsidy program leads to a significant reduction in the number



Rice. 9. Forecast of the dynamics of the spread of anemia in Russia under various options for the program of subsidizing families with low incomes (conservative scenario)



Rice. Fig. 10. Forecast of the dynamics of the spread of anemia in Russia under various options for a program to subsidize low -income families (trade war scenario)

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Table. Required amount of subsidies under the family support program low income

Year	Amount of subsidies per year, billion rubles					
	conservative scenario			Trade war scenario		
	Option 2	Option 3	Option 4	Option 2	Option 3	Option 4
2022	255.1	430.3	488	341.1	577.2	645.4
2023	284.8	473.9	536.6	454	764.5	850.5
2024	313.4	512.5	580.6	550.6	934.2	1037.7
2025	344.4	556.9	624.6	624.1	1071.4	1187

patients with anemia by 2024 under the conservative scenario, however, if the currently most probable “trade war” scenario is implemented, in order to achieve such results , it is necessary to implement intermediate option 3, and its cost will be about 3 billion rubles. for four years.

CONCLUSION

This paper presents a toolkit developed by an international team for predicting the dynamics of the spread of anemia in the BRICS countries. As a research method, agent-based modeling was chosen, which, in the context of the task, provided the opportunity to take into account the influence of the quality of the food received on the occurrence and course of anemia in various categories of the population. The structure of the model includes resident agents, food producers, and sales agents. The algorithms of the model reproduce the processes of food production from agricultural raw materials to ready- to-eat products, as well as the import and export of food products.

The model is distinguished by a sufficiently high degree of detail of the processes under study. For example, when modeling the work of resellers, the difference in the assortment of food products in urban and rural areas, as well as pricing aspects in different regions due to differences in climate and infrastructure, are taken into account. When modeling aspects of food consumption, the quality of the food ration available to households is assessed in terms of the presence of recommended intakes of key vitamins and microelements, the deficiency of which leads to the development of anemia, while consumption rates take into account the sex and age of the resident agent.

The developed model is based on a number of assumptions.

1. The development of iron deficiency anemia under the influence of the quality of the diet received is considered and the use of special supplements prescribed by doctors for the treatment of severe stages of anemia is not taken into account.

2. The diet of only private households is studied, while the diet of collective households (boarding schools, prisons, barracks) is considered to be in line with current state nutrition standards.

3. The budget of private households in the model is assumed to be shared, as is the quality of food received by members of one household.

The elimination of assumption 1 is the task of further research by our team. Assumptions 2 and 3 are due to the insufficiency of initial data for more complete detailing of these processes.

On the basis of the developed model, a series of calculations was carried out aimed at predicting the dynamics of the spread of anemia in the regions of Russia under various scenarios, the parameters of which reflect epidemiological and external economic risks. Calculations show an increase in the number of patients with anemia by 10–12% in 2022 compared to the values of 2019, which is taken as the base year. In the optimistic scenario, the incidence returns to the base year level by 2025; in the conservative and pessimistic scenarios, it remains 5–7% higher than it. Under the conditions of a conservative scenario, the consequences of the program of state subsidies for low-income families are modeled. According to the results

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the full implementation of such a program will provide access to a balanced diet for all residents of Russia and will lead to a decrease in the number of patients with anemia by 25% compared to the forecast in the absence of such a subsidy.

The presented structure and algorithms of the model are universal for all BRICS countries, the necessary differences can be reflected in the sets of initial data, in particular , the regional structure, size and age and sex structure of the population, incomes, food prices and traditional diets in different countries.

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Forecast of anemia prevalence in the regions of Russia using the agent-based model

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abstract. In the article development of the agent-based model of anemia prevalence in Russia is discussed. The structure of the model is presented, which includes agents-residents, food producers and sales agents. For each actor in the model, algorithms have been developed that determine their interactions. For food producers, their purchases, sales, production process and dynamics of investments in equipment are simulated. Simulation of sales agents includes the assortment formation and product prices, taking into account transport and trade margins. Households form their diet based on their income, composition, traditions and habits. The expected dynamics of anaemia is modeled depending on the quality of the food received and the current stage of the disease. The article also discusses program realization and information support of the model; the user interface is presented. Four scenarios of the dynamics of the socio-economic environment of the model are formalized, taking into account epidemiological and external economic risks. A series of calculations was carried out to predict the dynamics of anemia prevalence under conditions of the developed scenarios. A program of subsidizing low-income families was proposed and its influence on availability of a balanced diet and anemia prevalence among Russian residents was studied. The calculations show that in the absence of special support measures, a balanced diet becomes available to a smaller number of residents (65% compared to 78% in 2019) in the conditions of the most likely “trade war” scenario. At the same time, the total amount of subsidies required to provide low-income families with quality food varies from 300 billion to 1 trillion rubles per year, depending on the amount of benefits allocated.

Keywords: agent-based modeling, anemia, nutrition, recommended daily allowance.

JEL Classification: I15.

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