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THE ECONOMIC-MATHEMATICAL MODELLING OF PROCESSES OF OPTIMIZATION OF SUGAR RAW MATERIALS' LOGISTICS AT SUGAR FACTORIES

Abstract. The mathematical model of proceeding in the supplies of agricultural on a factory-producer under force-majeure circumstances of their deficit products is suggested. It enables bringing in to the supply of feedstock not only own sources but also alternative ones. Small and middle farmers became such suppliers. This helps to reduce the risk of failures in raw materials' supply to sugar factories, as well as to integrate the interests of large associations of sugar producers with the interests of small and medium producers. This also helps to solve the tasks of socio-economic development of rural areas as it provides sales to small and medium agroproducers.

The mathematical formulation of the problem is complicated by the presence of probabilistic parameters. Therefore, in the case of mathematical modeling, a stochastic network model was used.

The complexity of the task of organizing the supply of raw materials by small and middle producers is due to the fact that the set of sugar beet suppliers is an open heterogeneous system, and the consumer is a link of a centralized association with a hierarchical structure.

The factor of heterogeneity of the suppliers' set is due to the fact that each of them acts autonomously and even has no information about the actions of other suppliers.

The mathematical model allows to predict the time of implementation of the project and to solve the task concerning delivery of raw materials of the quantity required, for a given period of time, from a substantial number of autonomous suppliers. The developed mathematical model has allowed to take into account the influence of probabilistic factors on the decisive factor - the timely organization and restoration of the necessary resource for the smooth operation of sugar production.

Independent substructures, by definition, do not have access to the centralized network schedule of the producer. In order to resolve this contradiction, the following decision is taken. For each of the autonomous primary producers, their own network schedule is created.

The developed mathematical model can be used for other cases of emergent stocks replenishment, urgent formation of commodity batches of agricultural products.

Keywords: mathematical model, stochastic parameter, optimum forecasting, vector variables.

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ЕКОНОМІКО-МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ПРОЦЕСІВ ОПТИМІЗАЦІЇ ЛОГІСТИКИ ЦУКРОВОЇ СИРОВИНИ НА ЦУКРОВИХ ЗАВОДАХ

Анотація. Запропоновано математичну модель відновлення запасів сільськогосподарської продукції на заводі-виробнику за форс-мажорних обставин їх дефіциту. Це дає можливість залучення до постачання сировини не тільки з власних, а й з альтернативних джерел. Такими постачальниками стають малі та середні виробники. Це дозволяє зменшити ризики зривів постачання сировини на цукрові заводи а також інтегрувати інтереси великих асоціацій виробників цукру з інтересами малого та середнього виробника. Це також допомагає ви-рішити задачі соціально-економічного розвитку села бо забезпечує збут для малих та серед-ніх виробників агропродукції.

Математична постановка задачі ускладнена наявністю імовірнісних параметрів. Тому при математичному моделюванні використана стохастична мережева модель.

Складність задачі організації постачання сировини від малих та середніх виробників обумовлена тим, що сукупність постачальників цукрового буряку є відкритою гетерогенною системою, а споживач є ланкою централізованої асоціації з ієрархічною структурою.

Фактор гетерогенності сукупності постачальників обумовлений тим, що кожен з постачальників сировини діє автономно і навіть не має інформації про дії інших постачальників.

Математична модель дозволяє прогнозувати час виконання проекту і вирішити здачу постачання сировини в потрібній кількості у заданий термін від значної кількості автономних постачальників. Розроблена математична модель, дозволила забезпечити врахування впливу імовірнісних факторів на вирішальний чинник – своєчасну організацію та відновлен-ня необхідного ресурсу для безперебійної роботи цукрового виробництва

Автономні субструтури, за визначенням, не мають доступу до централізованого мережевого графіку виробника. Задля вирішення цього протиріччя приймається наступне рішен-ня. Для кожного з автономних постачальників формується власний мережевий графік.

Розроблена математична модель може бути використана для інших випадків екстреного поповнення запасів, термінового формування товарних партій сільськогосподарської продукції.

Ключові слова: математична модель, стохастичний параметр, оптимальне прогнозування, векторні змінні.

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ЭКОНОМИКО-МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ОПТИМИЗАЦИИ ЛОГИСТИКИ САХАРНОГО СЫРЬЯ НА САХАРНЫХ ЗАВОДАХ

Аннотация. Предложена экономико-математическая модель восстановления запасов сельскохозяйственной продукции на заводе-изготовителе при форс-мажорных обстоятельствах их дефицита. Это дает возможность привлечения к поставкам сырья не только из собственных источников, но и из альтернативных. Такими поставщиками становятся малые и средние производители. Это позволяет уменьшить риски срывов поставок сырья на сахарные заводы, а также интегрировать интересы крупных ассоциаций производителей сахара с интересами малого и среднего производителя.

Математическая постановка задачи осложнена наличием вероятностных параметров. Поэтому при экономико-математическом моделировании использована стохастическая сетевая модель.

Разработанная экономико-математическая модель может быть использована для других случаев экстренного пополнения запасов, срочного формирования товарных партий сельскохозяйственной продукции.

Ключевые слова: математическая модель, стохастический параметр, оптимальное прогнозирования, векторные переменные.

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Introduction. The situation with the cultivation of sugar beet in Ukraine, has undergone significant changes since 1990. Sugar producers have effectively created vertically integrated structures that deal with all steps: from planting to the shipment of finished products. The number of sugar factories in Ukraine during this time decreased from 192 to 46 [1]. The country lost its position on the world sugar market; the gross values of production reduced significantly and, consequently, the need for raw materials as well.

The dissolution of collective farms created a significant number of small and medium-sized farms - producers of products of the agrarian sector. They were the first who were struck by the reduction in purchases of sugar beet. This led to a decrease in the total area of sugar beet sowing and, accordingly, in the volume of its harvesting by small agricultural enterprises. The decline in the production of sugar beet led to the loss of material and technical means needed for its cultivation and harvesting [1; 2]. Available technical means are outdated and extremely worn out. The equipment which is intended for the harvesting of sugar beets is the most worn out of all means. The wear level is 70-80% [2]. These are factors which do not favor the production of sugar beet by farms characterized by small sown areas. But there are other factors which favor growing raw materials sugar products by small and medium-sized farms. In particular, a significant part of the areas in the Kharkiv region, where sugar beet was grown, is represented by relatively small ones. According to the literature, the average area of sugar beet sowing, belonging to one farm of the Kharkiv region, amounted to approximately 166 hectares [3]. Such a distribution of areas of sugar beet sowing, the circumstances of dissolution of collective farms and other factors determine the nature of the use of agrarian resources in certain regions and require taking into account the need for the formation of, in certain circumstances, decentralized supply of raw materials by sugar producers [3].

Obviously, the use of small-sized sowing areas by large, vertically integrated structures, is so scattered, and thus is extremely limited under the current business model. The use of industrial, intensive technologies on those areas was not feasible. This has led small farms to crop rotation (sugar beet is extremely useful as a precursor culture), sugar factories lost their areas used for raw materials cultivation and were stopped. The organization of chains of growing and supplying raw materials should create preconditions for the restoration of their work.

Analysis of research and problem statement. At first glance, it is impossible to combine the interests of vertically integrated sugar producers and small and medium-sized producers. The existing forms of management within beet sugar industry in Ukraine, sugar production structures, do not respond to the challenges of time.

According to the researchers, this is due to the fact that such a form of procurement is outside the control for compliance with regulatory prices for the supply of agricultural products by the relevant authorities [7]. Alongside with the overproduction of sugar beet this can lead to negative consequences – collapse of market prices for sugar beet [3].

Demand for tolling raw materials, according to [3], does not always depend on its quality. in particular, the factor of purchasing prices for sugar beet can serve as an indicator for this. The highest quality index is sugar content: in the Dergachi district of Kharkiv region it is the largest for many years [3]. But, according to the association "Kharkivtsucor", which is confirmed by information from the Main Department of Statistics of the Kharkiv Region, the price for this raw material is higher in other regions [3]. Some sugar producers, using their pricing policies, are, thus, trying to create their own raw material zones, to test new supply chains, aiming at securing themselves against a certain part of the risks associated with the lack of their own raw materials' base.

In the scientific paper [3], a detailed analysis of the application of tolling conditions to the supply of raw materials to sugar factories is conducted. It is accompanied by economic calculations and is based on practical experience. The result of the analysis was a substantiated claim that the use of sugar raw materials under tolling not only will not lead to a crisis in the industry, but will be also a real way out of the situation [3].

The analysis, carried out for different types of raw materials used in the production of bioethanol, showed that in regions with climatic conditions similar to Ukrainian one, in particular in the European Union countries, the share of sugar beet is significant and has a tendency to increase [9; 10]. Obviously, small producers of bioethanol in Ukraine come to the conclusion about the expediency of using sugar beet. However, the production of bioethanol and the cultivation of raw materials are not yet rigidly determined; production links are not strictly defined. In addition, each bioethanol producer can quickly reorient to other raw materials in the case of a shortage in sugar beet supply.

The flexible nature of the relationship between sugar and bioethanol production stabilizes the market for sugar beet and protects small and medium-sized farms that grow sugar beet against a certain part of the risks of overproduction.

On the other hand, large producers face certain risks, force majeure circumstances, which account for an increase in the cost of production. An example of such force majeure circumstances is the situation, which caused significant losses of the association "Ukrsugar" in the sugar beet marketing year 2016/2017 [11]. Ukrzaliznytsya at that time was not able to provide transportation of raw materials and finished products of sugar producers. Manufacturers were compelled to take an emergency procedure of the transportation by vehicles [11]. Overhead transportation costs are higher than in case of the railways, and these losses were further increased compared to the standard ones due to emergency situation. Manufacturers will experience the impact of this force majeure for many years, as insurance against a new type of risk will increase the cost of production [11].

To solve similar problems of large sugar manufacturers, of vertically integrated holdings, the adding of the sugar beets supply from small and medium-sized farms to their own sources of raw materials could be used. This type of supply can serve as an additional source of raw materials or as an insurance factor under force majeure circumstances [12-15]. The under supply of sugar beet from own sources at certain moments could be relied on tolling raw materials to ensure the continuity of sugar production, but it forces the switch to a different technological level, in particular that is related to information facilities of regional markets for agricultural products [15].

The main factor for the organization of tolling raw materials' delivery is the digitization of the task at its every stage.

In Ukraine, the forecast of sugar beet yields and supply volumes for certain raw material areas is not refined. At the beginning of sugar beet harvesting, the technologists of associations of sugar producers make a selective analysis [6]. Small and medium-sized farms are not aware of these forecast data throughout the period of sugar beet harvesting. This does not allow such farms to use even tactic planning activities. Therefore, the digitization of the production of sugar raw materials must be strengthened in this direction. The efficient farming is not possible without a well-grounded planning of its activities. It is not possible to effectively use even classical methods of economic and mathematic planning. The classic methods of optimization tasks for beet sugar production, in particular, for the harvesting of root crops, were developed by Yu.P. Chernova and I.D. Stepanenko [3]. Modeling of sowing area in different farms on the example of the raw material zone of one of the Vinnytsya factories was suggested in the study of M.Yu. Codenska and M.I. Kinakh [3]. The criterion of optimality for the developed model was selected minimal costs for the processes of supply and processing of sugar raw materials. In the papers of other scientists, extended sets of variable parameters were used for modeling purposes. In particular in [16; 17], except of the areas of raw materials' sowing by individual farms, changes in indicators of their quality depending on the terms of storage, the material and technical base involved, etc., are taken into account. The modeling of sugar beet production, both throughout its whole chain, and at each its element, was developed in such a way as to ensure the supply of the necessary quantities of raw materials for the uninterrupted operation of factories and getting a commodity product – sugar [16; 17]. But these models can not be used to simulate the emergent situation of raw materials' replenishment.

Different approaches are used to form the mathematical models of sugar beet production. One of them is a factor approach. One experimentally identifies a group of factors that affect the result. The degree of their influence on the result and the type of functional dependence on the identified factors of influence is studied. The mathematical model is checked for historical data and uses it to generate forecasts for current and next periods [18].

There are a lot of questions about such methods, their accuracy and feasibility. In particular, the form of dependence, the magnitude of influence, the set of factors of influence on the result are taken as independent of one agricultural season to another. Checking the form of dependence, the magnitude of each factor impact, the matching of a set of factors for each season is a very costly task that requires effort and time. These methods are not suitable for the situations of abrupt, mobilization nature.

There is an approach related to identification of trends in the dynamic time series of the investigated factor for past agricultural seasons and extrapolation of the revealed trend for future periods. In addition to the trend characteristics, the influence of seasonal factors (for this we need to have information about the factors that tend to repeat over a short period – even a certain day of the week), cyclical factors and even stochastic factors are taken into account. This is a weighty argument for applying this approach in the mathematical model of supplying the required volumes of sugar raw materials.

The advantage of this approach is the absence of the need to study the influence of each factor separately and the set of factors as a whole. The disadvantage of trends' use in a dynamic time series is a significant discrepancy of the results from the real situation. Inaccuracy of the forecast within this approach is primarily attributed to the changes in the conditions from season to season [19, 20].

Let's consider the application of the given approach to the situations of an emergency in more detail.

Some scholars used ARIMA modeling (abbreviation for autoregressive integrated moving average) and its modification – SARIMA simulation to model sugar production. Sometimes ARIMA and SARIMA simulations are defined as Box-Jenkins (BJ) methodology [20]. The purpose of this modeling is out-of-sample prediction. This coincides with the task of forming a forecast or scenario of a crisis situation in the supply of sugar raw materials set out in this article.

Let's analyze the feasibility of ARIMA, SARIMA, BJ simulation use for the formation of a mathematical model for our problem.

To form the forecast based on the Box-Jenkins methodology a fairly wide range of models is used. These are one-dimensional or multidimensional factor models, models that use the principle of inertia, auto-regression process (AR), etc.

The application of these methods is successful when the time series has a linear deterministic character, even in the case of ruptures or, for example, certain seasonal trend changes. Thus, in order to apply ARIMA, SARIMA, BJ simulation to the solution of emergent, mobilization tasks that clearly do not have a trend, a lot of work is needed to adapt them. In this case, the technical issues must be resolved. For example, those related to the choice of the criterion of stationarity AR (p), the difficulties caused by the presence of a large number of parameters, and the cost of obtaining information about these parameters. Therefore, the use of ARIMA, SARIMA, BJ simulation to solve the problem is not appropriate.

Let's consider the existing approaches to forecasting the effectiveness of the logistic component of the task of organizing the sugar raw materials' supply.

In recent years, many scholars have been working to improve various aspects of logistics mechanisms [21-26, 29-30]. While forming mathematical models, most researchers focused on issues of transport logistics, warehouse and production logistics. But there are almost no studies devoted to the mathematical modeling of autonomous microeconomic systems.

To assess the efficiency of the logistics scheme, in particular, one uses the so-called aggregate indicator. This indicator is a function of the profit on the sale of finished products and the total costs associated with the organization and operation of the logistics scheme. Total cost of logistics is also used to assess performance. This indicator is an additive function of the flow of resources, the costs associated with the storage of these resources, loss of profit due to the inefficient organization of supply and the use of material stocks. The next indicator is storage costs. This indicator depends on the average size of production stocks and unit, per hryvnia of stock, storage costs.

Obviously, the use of all these indicators for a mathematical model for the solution of the emergent supply of sugar beets is possible only as an estimate.

The purpose of the article is to develop an alternative scheme for supplying small consignments of agricultural raw materials from a significant number of small and medium-sized producers to restore the resources of the sugar producer under the conditions of their shortage. A mathematical model must be developed that can not only determine the minimum required supply, but also predict the time of this operation.

Research results. Let's consider the problem of supplying raw materials under conditions of emergency.

To solve the task of mobilizing the supply of tolling raw materials it is necessary to have its mathematical model, which will become the core of the information provision of the task solution.

The main purpose of the mathematical model is an optimal prediction of the minimum amount of additional sugar beet supply in a clearly defined time interval to ensure the stable operation of one or a group of sugar factories.

Let’s indicate the volume of the resource of the i-th supplier of tolling raw materials as Bi, then the required minimum amount of raw materials for a sugar plant can be calculated by the formula

$$B = \sum_{1}^{n} B_i \rightarrow min \qquad (1)$$

where n - the number of suppliers of tolling raw materials that provide the required minimum amount of reserves.

For the information management system, a signal to start the logistics operation of the supply of tolling raw materials will be the lack of supply of resource A for the stable operation of sugar production.

The condition for finding the value of the reserve resource A is the formula

$$A > A_{min} \qquad (2)$$

where A_{min} is the minimum production reserve. That is, it is a reserve that provides a certain amount of stable production time.

The minimum production reserve is determined by the formula

$$A_{min} = \sum_{1}^{k} A_j \qquad (3)$$

where A_j is the volume of the resource which serves the j-th day of production, k is the time of continuous operation of the sugar manufacturer, which is measured by twenty-four-hours.

Obviously, time k is also the minimum time to organize the supply of the required amount of raw materials to ensure the work of sugar production. When the source is tolling raw material, then the mathematical model must be adapted exactly to the organization of supply from this source.

The required amount of tolling raw materials can be determined by the formula

$$\overrightarrow{D_{min}} := \sum_{1}^{n} \overrightarrow{D_n} \qquad (4)$$

where $\overrightarrow{D_{min}}$ — vector of the minimum supply, $\overrightarrow{D_n}$ — supply vector of the supplier n.

The need for the transition from scalar quantities to vector in a mathematical model is due to the fact that the minimum supply will be determined not only by the amount of sugar beet, but also by its quality, delivery price, the cost of delivery of raw materials, and the delivery time z-days. That is, the minimum supply $\overrightarrow{D_{min}}$ and the amount of supply from each supplier $\overrightarrow{D_n}$ can not be measured by one number, but merely by a matrix of numbers. This matrix is not necessarily linear.

The time of delivery of raw materials should be less than the time of the continuous operation of the sugar manufacturer based on its reserves

$$z \leq k \qquad (5)$$

Determining the time of delivery of raw material z has some difficulties, which are related to the realities of organization of supply.

The difficulty of the task of organizing the supply of tolling raw materials, firstly, is associated with the fact that the set of suppliers of sugar beet is an open heterogeneous system, and the consumer- sugar producer, is a certain chain of centralized associations of producers characterized by hierarchical structure.

The factor of heterogeneity of the set of suppliers is attributed to the fact that each of the suppliers of raw materials acts autonomously and, in certain circumstances, does not even have information about the actions of other suppliers.

But, in our opinion, the supplier of raw materials can be considered as a derivative substructure with respect to the producer of sugar.

As the analysis of sources [27, 28] shows, a mathematical model used to solve similar problems is a network model.

In this case, there is a contradiction. Independent substructures, by definition, do not have access to a centralized network graphic of the producer. In order to resolve this contradiction, the following decision is taken. For each of the autonomous suppliers, their own network graphic is created. The above solution meets all the requirements and real circumstances of such a model for the organization of delivery of tolling raw materials.

The peculiarity of the suggested mathematical model, which is completely superimposed on the real circumstances, is that the parameters of the vector $\overrightarrow{D_n}$ for each of n suppliers are different and may change randomly. This affects the timing of deliveries of raw materials in a crucial way, since failure to execute the supply schedule over a period of time affects the outcome of one of the suppliers, whether the task of forming the required reserve is fulfilled or not. Mathematically this is represented as the effect on the vector of minimal supply.

Thus, the problem takes a stochastic character. Let's determine whether the decisive parameter in the organization of force majeure supply of raw materials – delivery time z is also a random variable.

The stochastic nature of the "delivery time z" parameter is the second factor, which extremely complicates the task of optimal prediction.

Let's analyze in these circumstances the mathematical formulation of the problem. When the delivery time z is a random variable, its change is subject to the statistical distribution. In this case, a stochastic network model can be used to construct a mathematical model.

For the construction of the algorithm it is possible to use, for example, the Scheme of the Program Evaluation and Review Technique (PERT) [27], but with certain changes and detailing the algorithm for forecasting the time of execution of the project - in our case, the supply of raw materials in the required quantity at the given time.

For the formation of a stochastic network model, one must know the distribution law and the type of distribution of the z value of each supplier. In real circumstances, the supply of raw materials from small farms is simplified by the fact that the z parameter for each sugar beet producer in a heterogeneous system of autonomous supply of raw materials is subordinated to one distribution law. This also leads to the fact that the type of distribution is the same for each of n suppliers.

The distribution parameters are also influenced by the actions of the structure that has permission to make managerial decisions. For the mathematical model we are considering, one of these parameters will be predicted when the event occurs. Previously, it was indicated that the predicted time can be determined by the formula (3).

The function of the distribution of time estimates in these circumstances has certain characteristics.

These are: unimodality, absence of breaks in the function of distribution of time estimates on the interval of its definition, the integral values of the start and end of the change interval of the delivery time z.

All of these features are inherent in beta distribution.

The use of beta distribution in the proposed mathematical model is also due to the real circumstances of the supply of sugar beet. Supply of raw materials from a large number of small autonomous farms depends on a large number of factors. The indicated factors often have a stochastic character, and each of them individually may have a small effect on the timely replenishment of raw materials. But, in this case, the presence of an open heterogeneous system of suppliers of sugar raw materials, there is a certain, limited number of probabilistic factors whose influence is significant.

The influence of these factors determines the asymmetric nature of the probability distribution.

That is why the choice of beta distribution, as the main under consideration, is predetermined by these circumstances [27, 28].

It is known that beta distribution with free parameters of density α, β has a characteristic pattern of probability distribution [28].

The free density parameters have the appropriate interval limits:

$$\alpha, \beta > 0, \quad x \in [0,1] \tag{6}$$

Under these conditions, the distribution function of probability is based on the formula:

$$f_x(x) = \{\Gamma(\alpha - \beta)x^{\alpha-1}(1-x)^{\beta-1} / \Gamma(\alpha)\Gamma(\beta)\} \tag{7}$$

where $\Gamma(\alpha)$, are gamma functions that are known to be calculated as follows:

$$\begin{aligned} \Gamma(\alpha) &= \int_0^\infty x^{\alpha-1}\exp\{-x\}\,dx \\ \Gamma(\beta) &= \int_0^\infty x^{\beta-1}\exp\{-x\}\,dx \end{aligned} \tag{8}$$

Next, we must use the general method for generating random variables α, β with the distribution $x \sim$ C (α, β) for any values greater than zero of the free parameters of density α and β.

It is known that when two independent random variables (in this case, α and β) can be described by a gamma-function:

$$\begin{aligned} Y_1 &\sim \Gamma(\alpha, 1) \\ Y_2 &\sim \Gamma(\beta, 1) \end{aligned} \tag{9}$$

then the ratio (10) has beta distribution.

$$Y_1 / \textstyle\sum_i Y_i \sim C(\alpha, \beta) \tag{10}$$

This again proves the validity of the use of beta distribution in this mathematical model.

The beta distribution density is considered in the planned interval of time from its value for a pessimistic event variant to its value for an optimistic variant and is calculated by the formula

$$\varphi(z) = \frac{C^\alpha (z-t)^{\alpha-1} \exp\{-C(z-t)\}}{\Gamma(\alpha)} \tag{11}$$

where C and α are constants, t is the delay in the supply of raw materials.

Since C and α are constants, time delay remains the only one parameter under control.

The time delay is the main factor that determine the time of raw materials' delivery for the organization to restore minimum reserves of resources and to ensure the stable operation of sugar production.

Conclusions. The use of tolling materials as a reserve solves several problems for the sugar manufacturer.

Firstly, this makes it possible to reduce the amount of raw material reserves of factories. The reduction in the areas of heap of producer, respectively, leads to a decrease in sugar loss and other parameters of the quality of raw materials, at the same time reducing the size of heap allows you saving money needed for their creation.

Secondly, this reduces the risk of force majeure disruptions in the supply of raw materials to sugar factories.

Third, it allows the integration of the interests of large associations of sugar producers with small and medium producers.

Fourth, it solves the tasks of socio-economic development of the village.

To optimize deliveries, a mathematical model for organizing the supply of raw materials from a large number of small autonomous producers has been developed. Such a form of supply of agricultural products depends on a large number of factors. These factors often have a stochastic nature. The developed mathematical model, has allowed taking into account the influence of such factors on the decisive parameter- the timely organization and restoration of the necessary resources for the smooth operation of sugar production.

The suggested mathematical model is able not only to determine the minimum required supply, the predicted time of the operation, but also allows you allocating the use of the available amount of resource *A* in the best way.

The developed algorithm for organizing the supply of agricultural products from a significant number of small and medium-sized producers can be used for other tasks of managing agrarian projects.

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