ISSN: 2690- 912X

Research Article

Journal of Genetic Engineering and Biotechnology Research

Decision-Making Procedure on Rational Allocation of Resources of the Agro-Industrial Complex

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Submitted: 2025, Mar 18; **Accepted:** 2025, Apr 01; **Published:** 2025, Apr 10

Citation: Ziyadellaev, D. Sh., Mukhamedieva, D.T., Mamarajabov, M. E., Pattaxonovich, A. Z., Ziyodullaeva, G. E. (2025). *J Gene Engg Bio Res, 7*(1), 01-06.

Abstract

Research into the principles of preparation and assessment of the consequences of decisions made in the agro-industrial complex showed that in the procedure for making decisions on the rational allocation of resources, it is necessary to substantiate the system of macroeconomic indicators. For this, it is necessary to formulate the functional tasks included in the decision-making process. The procedure for making decisions on the rational distribution of resources in the agro-industrial complex is considered in the article; the implementation of this procedure is aimed at ensuring that, based on solving the problems of allocating and using resources, the results of production grow faster than the costs of it, so that the selected areas of resource substitution correspond to the task of saving resources. The aim of the study is multicriteria optimization that takes into account finding a compromise solution in cases of Pareto unsolvability of the original problem. When implementing optimization systems into work, as a rule, the question arises of the possibility of the result satisfying several criteria at once. Therefore, a system based precisely on the methods of multicriteria optimization will have a high practical significance. The processes conducted at the enterprises of the agro-industrial complex are considered in time; therefore, the principles of dynamic programming are used. To find a compromise solution in cases of Pareto unsolvability of the original problem, a fuzzy approach to the fulfillment of goals and constraints was chosen. Dynamic programming methods and fuzzy set theory are solution methods.

Keywords: Mathematical Model, Numerical Study, Filtration, The Groundwater, Aquifer, Monitoring, Forecasting

1. Introduction

Development of a forecasting system for macroeconomic indicators such as the need for agricultural products, the volume and structure of production, as well as the sale of products for the automated management of agricultural facilities and services to the population in conditions of uncertainty of initial information is associated with the acquisition, storage, classification, updating, processing and delivery in a convenient for the user form of very large volumes of various analytical and summary information [1].

One of the promising areas in which artificial intelligence technologies are used is the analysis and processing of data based on computer vision. At present, the attempts are made to apply them in the field of agricultural industry. They consist in the development of mathematical computer algorithms based on the formation of specific mathematical models, called artificial neural networks (a mathematical model and its computer implementation, the interaction of the elements is similar to the activity of biological neural networks of living organisms) [2]. This technology successfully copes with a number of tasks, which include early diagnosis of diseases of animals and plants, makes it possible to successfully and timely combat them, as well as prevent their occurrence at all. The material for the analysis of such events can be photographs taken both at the micro- and macro-levels (animal population, cultivated areas). In these cases, progressive pathologies can be detected and the necessary operational measures can be taken to eliminate them.

In addition to photography, it also includes the collection of statistical information based on the electronic computer sensors installed in agricultural facilities, which monitor changes in the required indicators in dynamics and inform the manager about deviations from the established standards in order to intervene and transfer the situation on the right track. IntelinAir, which is represented on the market as an organization for the implementation of precision agriculture, is currently engaged in such events. This is precisely what we mean by doing business (in our case, in agricultural sector) and optimizing it on the basis of regularly recorded indicators. IntelinAir is currently focused on supporting corn and soybean farmers in Illinois, Iowa, Ohio and Indiana. Another organization in the field of data analysis and processing based on computer vision is the Canadian Research Center for Plant Phenotyping and Imaging at the University of Saskatchewan. Statistical libraries of data parameters on various agricultural crops are being formed, which, with the development of digital technologies, can be successfully used and applied in various kinds of agro-industrial projects, as well as in research projects, aimed at solving current agricultural problems and improving technologies in this area. With the development of the capabilities of electronic computers in everyday human activities, robotics is increasingly involved; it gradually begins to appear and spread in the agricultural sector [3]. This technology allows us to automate business processes, freeing up precious time for research.

It should be noted that this technology is closely related to the previous direction and can be used to optimize the internal processes of robotic systems, as well as act as a platform for collecting the necessary data from agricultural and agro-industrial facilities. An example of robotic technology that imitates human functions in agriculture is the Prospero robot [2,3]. It has the following capabilities: individual planting of seedlings up to digging a hole for a seedling and its placement in it, follow-up and harvesting. The computer system contains algorithms for landscape recognition, on the basis of which the ideal conditions for growing the necessary crops are selected. Scientists and researchers at the University of Aarhus in Denmark have developed the "Hortibot" robot, capable of recognizing agricultural crops and, accordingly, eliminating weeds by mechanical action or using chemical reagents [4,5]. This development is considered a significant breakthrough in the scientific world since previously, it was not possible to qualitatively distinguish useful agricultural crops from weeds autonomously. In addition to such unique one-off projects in the agricultural market in the field of robotics and the introduction of systems that support artificial intelligence technologies, there are currently the following aspects:

- The introduction into agricultural practice of automated remote small flying vehicles (drones) [7], which can locally deliver the resources necessary for plants and animals, carry hazardous chemicals without threatening human life, and also take photos; the data obtained from them can be successfully used in computer systems vision;
- Automated agricultural complexes, which are more high-tech and sophisticated equipment in the manner of tractors, combines, excavators, capable of performing several different functions: planting and harvesting, control over the development of plant and animal crops, elimination of pests and the consequences of natural and climatic phenomena [2-5].
- From an informational point of view, the implementation of a system of models makes specific requirements for the development of a unified data bank and the corresponding software system. At the same time, the software allows the implementation of both individual models and the system as a whole, taking into account the possibility of expert intervention [6].

At various levels of management, for the purpose of state regulation of the development in the agricultural sector and the implementation of various projects in the sectoral sub-complexes of the agro-industrial complex and the sphere of public services, forecast and analytical data on the formation of the structure of production are used along with regulatory and reference and reporting and statistical data. Justification of forecast and analytical data is most effectively conducted on the basis of the construction and use of macroeconomic models for forecasting the choice of the structure of production [7].

The scientific novelty of the work is the development of an optimization model for the rational allocation of resources, taking into account finding a compromise solution in cases of Pareto unsolvability of the original problem. Since the processes occurring at the enterprises of the agro-industrial complex are considered over time under conditions of uncertainty, the principles of dynamic programming and the theory of fuzzy sets are used.

2. Materials and Methods

The aim of the work is to study the principles of preparation and evaluation of the consequences of decisions made in the agro-industrial complex. When making decisions on the rational allocation of resources, it is necessary to substantiate the system of macroeconomic indicators [9].

The objectives of the study are:

Formulation of functional tasks included in the decision-making process. Unlike conventional problem solving, this process involves experts who can provide the necessary information to enter into the model.

- Formulation of a decision-making procedure for the rational allocation of resources.
- Developing a set of decision-making models for the rational allocation of resources.
- Using mathematical models and methods of their implementation, an information base was developed and a dialogue system was created, which serve as a reliable tool for developing theoretical prerequisites for decision-making in the agricultural sector of the economy of the Republic [10].

In the conditions of agro-industrial integration, the increase in the efficiency of the branches of the agro-industrial complex largely depends on the optimal allocation of resources.

The problem of rational resource allocation is reduced to the problem of dividing a fuzzy set into subsets [11-15].

For a given set R={r_1, …, r_n} of resources $r_j \in R$, j=1,…,n, having dimensions P(r_j) ≥ 0 it is required to find a partition into m disjoint subsets R_1, …, R_m, minimizing $\sum_{i=1}^{m} f(q_i)$, where f-continuous, non-negative and convex downward on (0;q_{rp}]; q_i - subset size R_i, equal to $\sum_{r\in R_i} P(r)$ under the following restrictions on the size of subsets: $q_i < q_{rp}$, i = 1,…,m.

To solve this problem, a parametric set of algorithms is proposed, where α = 1, 2,… . According to the algorithm [12], resources are allocated in two stages. On the first stage, distribution performed according to the exhaustive search algorithm, the resources of the set R(α), formed from min{n, αm} of the maximum resources of the set R. For this, a "discrete-continuous" problem is formed from the original discrete problem, the set of resources of which is R(α) $\cup\, r^H$, where r^H -"contiguous" resource with a size P(r^H)= $\sum P(r)$, r ∈ R\ R(α). Unlike discrete resources r ∈ R, continuous resource can be split into any number of parts, which are distributed into different subsets. Resource allocation set R(α) of original problem is assumed to be equal to the resource distribution of the set R(α) in the optimal solution of the above-mentioned "discrete-continuous" problem. At the second stage, to the obtained distribution of the resources of the set R() using the algorithm [11], all remaining unallocated "discrete" resources are added, from which the "continuous" resource was formed r^H.

In applied terms, the distribution of *n* resources among *m* similar enterprises of the agro-industrial complex, subcomplex is of certain interest. Such a problem is a probabilistic analog of a deterministic problem. In the problem, a system consisting of *m* similar enterprises receives *n* resources of independent claims. The flow rate j is λ_j, j = 1,…,n.

3. Results

Let m be an integer; q and q_{rp} - are the positive numbers, q < q_{rp}; f- is the function defined on (0; q) is f-continuous in the domain of definition and positive, as well as convex on (0;q_{rp}). Problem under study Π (m, q, q_{rp}, f) of resource allocation is formulated as follows.

A set of $Д_П$ individual tasks I ∈ $Д_П$. The initial data of the individual task I are the set of R types of resources $r_j \in R$, j=1,…,n and the set P of resource sizes P_j = P(r_j) ∈ Q. It is known that for I formula (1):

$$\frac{1}{m}\sum_{r\in R} P(r) \le q < q_{rp} . \qquad (1)$$

By an admissible solution X to Problem I we mean a partition of the set R into *m* disjoint subsets R_1,R_2,…, R_m, which are the size of the subset q_i(X, I), equal to the sum of the sizes of its constituent resources, does not exceed q_{rp}, i.e.

$$q_i(X, I) = \sum_{r\in R_i} P(r) < q_{rp} ,\ i=1,\dots,m . \qquad (2)$$

Under the optimal solution to the problem I ∈ $Д_П$ such X^* ∈ $S_П(I)$ feasible solution is understood, where $S_П(I)$- is the set of feasible solutions to the problem I ∈ $Д_П$, such that $F_П$(X^*, I)≤ $F_П$ (X, I) for any X $S_П(I)$, where

$$F_П(X, I) = \sum_{i=1}^{m} f(q_i(X,I)) . \qquad (3)$$

It is required for a given task I ∈ $Д_П$ to find the optimal solution $X^* \in S_П(I)$ for $S_П(I) = \varnothing$.

Algorithm for solving the problem I ∈ $Д_П$ includes the following sequence of actions.

- From the set R, form the set $R_{Z(\alpha)} \cup r_H$, where $R_{Z(\alpha)}$- are the sets from min{n, αm} maximum size of the resources of the set R,r_H -"contiguous" resource with a size P_H = P(r_H) =$\sum P(r)$, r ∈ R\ $R_{Z(\alpha)}$
- Determine the distribution Z(α) of resources of set $R_{Z(\alpha)}$ over *m* subsets such that, first,

$$\max(q_i(Z(\alpha),I)+c_i(P_H, \bar{q}(Z(\alpha),I)) < q_{rp} , \quad (4)$$

second, for any X(α) ∈ $S_П(I)$, where $S_П(I)$ - different partitions set X(α) of the set $R_{Z(\alpha)}$ Rinto *m* subsets

$$\sum_{i=1}^{m} f(q_i(Z(\alpha),I) + c_i(P_H, \bar{q}(Z(\alpha),I)) \le \sum_{i=1}^{m} f(q_i(X(\alpha),I) + c_i(P_H, \bar{q}(X(\alpha),I)), \qquad (5)$$

if αm >n and the function *f* is not strictly convex, then, third,

$$\min \bar{q}(Z(\alpha),I) \ge \alpha \max_{r\in R\setminus R_{Z9\alpha)}} \{P(r)\} \qquad (6)$$

If does not exist Z(α) ∈ $S_П(\alpha)$, satisfying condition (1), then the resource allocation is terminated and the "false" response is generated according to the algorithm.

- If, during distribution, the current maximum size of the subset is at least q_{rp}, then the allocation of resources stops and the algorithm generates the answer "false". Wherein $\alpha(m, q, q_{rp}) = (mq - q_{rp})/m(q_{rp} - q)$,

$$L_j(\alpha,m,k,y)=\frac{[m/k](f(yg_1(\alpha,k)+(k-1)f(yg_2(\alpha,k)))+(m-k[m/k])f(y)}{mf(y)}-1, \quad (7)$$

where

$$g_1(\alpha,k) = (\alpha+2)/(\alpha+1) - 1/k(\alpha+1),\ k=1,2,\ldots,m; \quad (8)$$

$$g_2(\alpha,k) = 1 - 1/k(\alpha+1),\ k=1,2,\ldots,m; \quad (9)$$

$$H_i(\alpha,m,q) = \sup_{0<y<q}\max_{2\le k\le m} L_j(\alpha,m,k,y). \quad (10)$$

Let us give the calculation of Bellman's recurrence relations for solving this dynamic programming problem.

200 units of resources need to be spent on 4 enterprises in the agricultural complex. Each enterprise receives a different amount of income depending on the amount of resources allocated to it.

$$x_0 = x_0(0;40;80;120;160;200);$$
$$u_{01} = u_{01}(0;15;28;60;75;90);$$
$$u_{02} = u_{02}(0;14;30;55;73;85);$$
$$u_{03} = u_{03}(0;17;33;58;73;92);$$
$$u_{04} = u_{04}(0;13;35;57;76;66);$$
$$x_1 = x_1(0;40;80;120;160;200);$$
$$f_1 = f_1(0;15;28;60;75;90);$$
$$x_2 = x_2(0;0;80;0;0;0);$$
$$f_2 = f_2(0;15;30;60;75;90);$$
$$x_3 = x_3(0;40;80;0;40;80);$$
$$f_3 = f_3(0;17;33;60;77;93);$$
$$x_4 = x_4(0;0;80;0;0;80);$$
$$f_4 = f_4(0;17;35;60;77;95).$$

Here:
x_0 - is the amount of resources that can be provided in different situations;
u_{0i} - i - is the income received from the allocation of a certain amount of resources x_0 - to the enterprise;
f_i-i is the income received in the case of the allocation of resources x_i - per one enterprise?

From this table, we find the optimal resource allocation plan. As a result of the allocation of 200 units of resources to 4 enterprises, the agricultural complex will earn 95 units. In this case, 80 units of resources will be given to the fourth enterprise, and the remaining 120 units of resources will be allocated to 3 enterprises. This merger will give 60 units. In this case, the resource is not provided to the third enterprise. This means that 120 units of resources will be allocated to the first and second enterprises. However, the resource will not be given to the second enterprise either. Thus, the remaining 120 units of the resource will be given to the first enterprise. From this, the agro-complex earns 60 units. Thus, we have found the optimal resource allocation plan:

$$x_{opt} = x_{opt}(120;0;0;80). \quad (10)$$

The total income corresponding to this plan is 95 units. The fourth enterprise receives an income of 35 units, and the first enterprise receives an income of 60 units.

4. Discussion

Issues of multicriteria optimization, dynamic programming, and fuzzy logic were studied by many specialists. Among the scientists who worked on the problem of multicriteria optimization, the main results on dynamic programming belong to R. I. Bellman, and significant developments in the field of fuzzy logic belong to L.A. Zadeh [13-16]. Recently, a scientific direction appeared that combined fuzzy logic and dynamic programming – fuzzy dynamic programming. However, despite the wide development of many theoretical and methodological aspects of this problem, in most studies, little attention is paid to the creation of recurrence relations for solving the problem of multicriteria fuzzy dynamic programming, which consists in the so-called "curse of dimensionality".

The proposed work is based on multicriteria optimization, which takes into account finding a compromise solution in cases of Pareto unsolvability of the original problem. When implementing optimization systems into work, as a rule, the question arises of the possibility of the result satisfying several criteria at once. Therefore, a system based precisely on the methods of multicriteria optimization will have a high practical significance. Since it is important to consider the processes taking place in the enterprises in time, to analyze by time intervals, therefore, it is necessary to use the principles of dynamic programming. An approach is needed that is relevant for use in a dynamically changing market situation, and its essence lies in the fact that the solution at each next step depends on the previous ones. To find a compromise solution in cases of Pareto unsolvability of the original problem, a fuzzy approach to the fulfillment of goals and constraints was chosen. Practice shows the high efficiency of combining fuzzy logic and optimization problems, the so-called "physification" of goals and constraints.

Consider the problem of controlling a dynamic system. Let X be a finite set of possible states of this system and U be a finite set of possible values of the control parameter. Functioning of the system, i.e. its transitions from state to state is described by the system of equations of state [13-15].

$$x_{t+1} = f(x_t, u_t), t = 0,1,\ldots,N-1, \quad (11)$$

f - unambiguous mapping $X * U \to X$, i.e. the state of the system at time t + 1 is uniquely determined by its state and the value of control at time t, i.e. we are dealing with a deterministic system.

Consider the problem of controlling such a system under fuzzy initial conditions. We will assume that at any time point t the value of the control u_t must obey a given fuzzy constraint C_t, described by a fuzzy subset of the set U with a membership function $\mu_t(u_t)$.

Control of this system at the time interval from 0 to N-1 is considered. Let a fuzzy control goal be given in the form of a fuzzy subset G_N of the set X, representing a fuzzy constraint on the state of the system x_N at the last point in time N. The task, therefore, is to choose a sequence of controls u_0, u_1,..., u_{N-1}, which satisfies the fuzzy constraints and ensures the achievement of the fuzzy goal G_N. Initial state of the system x_0 we assume given.

Note that the fuzzy target G_N can be considered a fuzzy subset of the set $\underbrace{U \times U \times ... \times U}_{N}$, since the state x_N can be expressed as by solving the system of equations of state (11) for t = 0,1, .., N-1. After that, in accordance with the Bellman - Zadeh approach, the fuzzy solution to the problem can be represented as

$$\mu_D(u_0,...,u_{N-1}) = \min\{\mu_0(u_0),...,\mu_{N-1}(u_{N-1}),\mu_{G_N}(x_N)\}, \tag{12}$$

i.e., as a fuzzy subset of the set $\underbrace{U \times U \times ... \times U}_{N}$.
We will seek a maximizing solution to the problem, i.e. control sequence $\bar{u}_0,...,\bar{u}_{N-1}$, having the maximum degree of membership in the fuzzy solution D, i.e.

$$\mu_D(\bar{u}_0,...,\bar{u}_{N-1}) = \max_{u_0,...,u_{N-1}} \min\{\mu_0(u_0),...,\mu_{N-1}(u_{N-1}),\mu_{G_N}(x_N)\}. \tag{13}$$

We will use the usual dynamic programming procedure for this. We write (13) in the following form:

$$\mu_D(\bar{u}_0,...,\bar{u}_{N-1}) = \max_{u_0,...,u_{N-2}} \max_{u_{N-1}} \min\{\mu_0(u_0),..., \mu_{N-1}(u_{N-1}),\mu_{G_N}(f(x_{N-1}),u_{N-1}))\}. \tag{14}$$

The following equality holds. Let γ - be the quantity independent of u_{N-1}, and - g(u_{N-1}) arbitrary function u_{N-1}. Then

$$\max_{u_{N-1}} \min\{\gamma, g(u_{N-1})\} = \min(\gamma, \max_{u_{N-1}} g(u_{N-1})\}. \tag{15}$$

Using this equality, we write (4) in the following form:

$$\mu_D(\bar{u}_0,...,\bar{u}_{N-1}) = \max_{u_0,...,u_{N-2}} \min\{\mu_0(u_0),...,\mu_{N-2}(u_{N-2}), \max_{u_{N-1}} \min\{\mu_{N-1}(u_{N-1}),\mu_{G_N}(f(x_{N-1},u_{N-1}))\}\} \tag{16}$$

and introduce the notation

$$\mu_{G_{N-1}}(x_{N-1}) = \max_{u_{N-1}} \min\{\mu_{N-1}(u_{N-1}),\mu_{G_N}(f(x_{N-1},u_{N-1}))\}.$$

Functionis $\mu_{G_{N-1}}(x_{N-1})$ a membership function of a fuzzy goal for a control problem at a time interval from 0 to N-2, corresponding to a given goal G_N control over the interval from 0 to N-1. The meaning of this function can be explained as follows. Let us assume that as a result of the choice of some controls u_0,..., u_{N-2} system will go out of state x_0 to the state x_{N-1}, defined by the system of equations (4). Then, as it is easy to understand, the choice of control u_{N-1} we can achieve the maximum degree of achievement of a given goal, equal to $\mu_{G_{N-1}}(x_{N-1})$ In this way, $\mu_{G_{N-1}}(x_{N-1})$ there is a maximum degree of goal achievement G_N in the case when at step N-2 the system turned out to be in the state x_{N-1}.

Further, since $x_{N-1} = f(x_{N-2},u_{N-2})$ it is clear that the quantity $\mu_{G_{N-1}}(f(x_{N-2},u_{N-2}))$ there is a maximum degree of goal achievement G_N in the case when the system turned out to be (after N-2 control steps) in a state x_{N-2} and on N-1 step control was chosen u_{N-2}. It is easy to see that the choice u_{N-2} at the N-1 step, it is necessary to ensure (taking into account the fuzzy constraint on u_{N-2}) as large a value as possible

$$\min\{\mu_{N-2}(u_{N-2}),\mu_{G_{N-1}}(f(x_{N-2},u_{N-2}))\}.$$

Let us introduce the corresponding notation

$$\mu_{G_{N-2}}(x_{N-2}) = \max_{u_{N-2}} \min\{\mu_{N-2}(u_{N-2}),\mu_{G_{N-1}}(f(x_{N-2},u_{N-2}))\}.$$

Value of $\mu_{G_{N-2}}$- is the maximum degree of achievement of a given goal G_N in the case when at the N-2 step the system is in the state x_{N-2}.

Consider the problem of control to such a system under fuzzy initial conditions, i.e.:

$$\mu(x_0) = (\exp(-x^2/100);\exp(-(x-40)^2/100);\exp(-(x-80)^2/100);$$
$$\exp(-(x-100)^2/100);\exp(-(x-160)^2/120);\exp(-(x-200)^2/225))$$
$$\mu(u_{01}) = (\exp(-x^2/25);\exp(-(x-15)^2/40);\exp(-(x-28)^2/40);$$
$$\exp(-(x-60)^2/100);\exp(-(x-75)^2/100);\exp(-(x-90)^2/100));$$
$$\mu(u_{02}) = (\exp(-x^2/25);\exp(-(x-14)^2/40);\exp(-(x-30)^2/40);$$
$$\exp(-(x-55)^2/100);\exp(-(x-73)^2/100);\exp(-(x-85)^2/100));$$
$$\mu(u_{03}) = (\exp(-x^2/25);\exp(-(x-17)^2/40);\exp(-(x-33)^2/4$$
$$\exp(-(x-58)^2/100);\exp(-(x-73)^2/100);\exp(-(x-92)^2/10$$
$$\mu(u_{04}) = (\exp(-x^2/25);\exp(-(x-13)^2/40);\exp(-(x-35)^2/4$$
$$\exp(-(x-57)^2/100);\exp(-(x-76)^2/100);\exp(-(x-66)^2/10$$

Here
x_0 - is the corresponding function of the amount of resource that can be allocated in different situations;

u_{0i} - i - is the corresponding function of the income received in case of resources allocation x_0 - to the enterprise.
Thus, we have determined the corresponding function of the optimal resource allocation plan:

$$\mu(x_{opt}) = (\exp(-(x-120)^2/80);\exp(-x^2/40);$$
$$\exp(-x^2/40);\exp(-(x-80)^2/100));$$

Thus, the direct application of the fuzzy dynamic programming method to form optimal solutions is hampered by the following circumstances:

- "Curse of dimensionality" - the requirement for a large amount of addressable storage space (depending on the number of nodes and the dimension of the state vector, the number of nodes and the dimension of the control vector, and the required number of steps); to solve this problem, iterative methods must be applied;
- The required trajectory of the state vector and the control vector does not match the provided nodes of the state vector and the control vector; to solve this problem, it is necessary to apply approximation methods between nodes;
- To fulfill the initial conditions imposed on the state vector, it is necessary that the state vectors satisfy the dynamic transition relations with the required initial state vector.

5. Conclusion

Implementation of the model is aimed at ensuring that, based on solving the problems of allocating and using resources, the results of production grow faster than the costs of it, so that the selected areas of resource substitution correspond to the task of saving resources.

To implement the proposed algorithm, a software package was developed. It includes a program for updating the database, implementing an algorithm for optimal resource allocation and outputting calculated results.

The proposed algorithm contributes to ensuring the interchange-ability of resources and their proportional distribution in the agro-industrial complex.

In general, it should be noted that as a result of applying the method of dynamic decision support programming, it was possible to simulate the optimal production plan, the plan for the receipt of raw materials, and to bypass Pareto insolvability with fairly small deviations from the original plans due to the introduction of elements of fuzzy logic into the multicriteria optimization of the dynamic system.

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