MODELING OF A MULTI-LEVEL LOGISTICS SYSTEM FUNCTIONING

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Abstract. *Purpose*. The logistics of the agrarian sector covers the study of the management processes of material, informational and their consequential financial flows that have formed on the market of agricultural products and are distributed from its producer to consumers. The logistics chain is built starting from the planning processes of the production cycle of agricultural products and ending with the sale to the final consumer. Building an effective logistics system includes cost control, effective management of materials and finished products storage, provision of information support, development of delivery traffic diagram, service provision, formation of a freight network, etc. The purpose of the work is the development of mathematical methods and models for the systematic analysis of the functioning of the regional logistics system of providing agricultural material and technical resources. *Methodology*. To solve it in the proposed monograph, based on the study of the functioning of the modern logistic system of material and technical support, the methods of system analysis, the theory of mass service and the theory of stock management are applied. This allows to study in detail all aspects of external and internal connections, create a model of the system functioning, adequately assess its implementation, determine the optimal working conditions and, at the same time, forecast the financial characteristics of the activity. To solve this problem, a number of tasks are set in the paper. They take into account a large number of random factors, complex interactions of task parameters, non-linear dependencies, the influence of time delays on the overall functioning of the system, the formation of sales volumes

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and supplies of material resources. The models and methods of problem solving are original both from the point of view of research methodology and from the point of view of predicting the implementation of such systems. *Practical implications.* The greatest effect of logistics is achieved in integrated supply chains, which are implemented on the basis of large enterprises through the integration of raw material bases and industrial processing enterprises. When studying logistics support, in addition to the issue of transportation, considerable attention should be paid to the infrastructure for product storage. When organizing technical service and specific problems related to this, it is possible to solve such tasks as creating a competitive environment, certain changes in management; elimination of the shortage of material and technical resources due to the increase in production volumes, the introduction of new progressive technologies; creating a market for services and used equipment. *Value/originality*. The system of material and technical support is an organizational and management mechanism of interconnected actions of economic formations adapted to market conditions, aimed at timely and rhythmic provision of commodity producers with agricultural machinery, spare parts, fuel and lubricants. Under market conditions, their activity is based on a contractual basis and is more influenced by various external factors. Therefore, the problem arises of choosing such a mechanism of operation of logistics systems that form a regional system of material and technical support, in which their activity will be profitable and profitable.

1. Introduction

One of the reasons for the crisis state of agricultural production is the imperfection of the material and technical supply system, its market conditions and modern production requirements noncompliance against the background of the progressive aging of the means of production. Non-payment is one of the reasons for the crisis state of material and technical support and, as a result, the reduction in the volume of realization by enterprises of material and technical support. Their main functions are: 1) supply, 2) repair and 3) maintenance of all types of material and technical resources. At the same time, there is a need to create such organizational forms of technical service provision and maintenance that will quickly respond to changes in the market situation, provide producers with the necessary resources in a timely manner, and as a result of their activities, will receive profits for the reproduction of their own production and will be profitable. The main problems of such service logistics systems are:

1) creation of a competitive environment, certain changes in management, creation of agricultural services based on state or private ownership;

2) elimination of the shortage of material and technical resources due to the increase in production volumes, introduction of new progressive technologies;

3) creation of a market for services, a market for used equipment, which requires a certain structural reorganization of the service.

In view of the relevance of the above-mentioned problems, and taking into account that they are solved mainly at the level of the region, the object of the study is the regional system of material and technical support. The system of material and technical support is an organizational and management mechanism of interconnected actions of economic formations adapted to market conditions, aimed at timely and rhythmic provision of goods producers with agricultural machinery, spare parts, fuel and lubricants. Their activities are based on a contractual basis and are more influenced by various external factors. Therefore, the problem arises of choosing such a mechanism of operation of the system of regional agrotechnical service enterprises, which form a regional system of material and technical support, in which their activity will be profitable and economically rational.

To solve it, the methods of system analysis, the theory of mass service and the theory of stock management are applied in the proposed monograph based on the study of the functioning of the modern logistics system. This brings us to study in detail all aspects of external and internal connections, create a model of the system's functioning, adequately assess its behavior, determine the optimal working environment and, at the same time, forecast the financial characteristics of the activity. To solve this problem, a number of tasks are set in the paper. They take into account a large number of random factors, complex interactions of task parameters, non-linear dependencies, the influence of time delays on the overall functioning of the system, the formation of sales volumes and supplies of material resources. The models and methods of problem solving are original both from the point of view of research methodology and from the point of view of predicting the behavior of such systems.

The purpose of the paper is the development of mathematical methods and models for the systematic analysis of the functioning of the regional logistics system of providing agricultural material and technical resources.

The object of the study is the regional system of material and technical support of the Vinnytsia region.

The subject of the research is mathematical methods and models for analyzing and forecasting the activity of regional systems of providing material and technical resources.

Research methods are based on the principles of general systems theory and system analysis. The work uses methods of mathematical statistics, probability theory, mass service theory, and inventory management theory.

2. Modeling a logistics systems functioning

Over the last period, the world economy has been characterized by the rapid development of globalization, transformation and restructuring processes, which have a particularly critical effect on the characteristics of the economic growth of states. The issue of development strategies elaboration both in the coordinate system of the global economic territory and in view of changes in intrastructural trends is intensifying. Scientists pay attention to the study of the dynamism of economic processes, as a result of which forecasts of socio-economic development trends of both enterprises and industries, as well as states and global interactions at the world level, are formed [1].

In this regard, modern scientific research and the development of economic theories should be based on a number of scientific hypotheses obtained through quantitative measurements and proof-of-concept experiments on the basis of analysis conducted by methods of economic-mathematical modeling.

Modeling of the dynamic development of economic systems is studied in the scientific works of V.M. Geits, S.P. Kurdiumov, V. Leontev, I. Prigozhin, H. Haberler, and others. The final result of these works were the theoretical foundations of the functioning of economic systems from the standpoint of sustainability, sustainable development, cyclicality, synergy, etc. A number of issues, including applied aspects of modeling economic dynamics, development of new models of dynamics, its assessment from the standpoint of systemic changes and information uncertainty are in the field of view of researchers [2].

In the new era the world economy is developing in conditions of local and global crises associated with unpredictability and information uncertainty. The cyclical nature of such processes cannot only produce isolated negative consequences, but also lead to global crises, causing a synergistic effect by combining them into cause-and-effect chains. Modeling includes all components of scientific knowledge of the essence of economic processes and allows forming images of system thinking when searching for ways to solve problematic tasks.

It should be noted that the etymological origin of the concepts "modeling" and "model" has a philosophical meaning, the essence of which is determined by the degree of proximity to the simulated reality. A model can be understood as an artificially created image that reflects reality in specific properties. Such properties can be specified physically in the form of layouts, or with the help of an informational description – in the form of algorithms, formulas, etc. At the same time, modeling acts as a process, the result of which is the creation and study of a model within the limits of the established tasks [3]. In the process of modeling, a real object is studied based on the model from the standpoint of learning about its behavior and new properties. In addition, when it is impossible to use a real object when the circumstances of its functioning change, the model acts as the main source for conducting an experiment. The feasibility of an experiment based on a model is determined by many factors, first of all, it is obtaining. The theory of construction of experiments is one of the powerful tools of data processing. In general, conducting an experiment is considered to be the organization of research that will allow collecting the necessary data, using mathematical and statistical methods for their processing, and obtaining correct and objective conclusions [3; 4]. Thus, as a result of modeling, the main thing is not only the development of a theoretically grounded model, but also the construction of a plan for its analysis and evaluation.

It should be noted that the evaluation of the model and its comparative analysis with reality takes place with the help of the human factor. A person, in one way or another, simulates real events, at the same time acquires new knowledge and builds a behavior sequence, that is, forms a management decision. In his works, Stafford Beer emphasizes the key role of a person in the decision-making process and the ability to conduct simulations, which is due to such features of living organisms as: the speed of response, the accumulation of information, the ability to build sufficiently strong conclusions based on too little information.

In economics, the modeling method is focused on the solution of complex problems, built under conditions of limitation, lack of information, uncertainty and risk. In this regard, modeling is inextricably linked with systematicity, analysis and synthesis. The theoretical justification of this approach can be recognized as a general theory of management, the main provisions of which include: system analysis of the object taking into account interrelated relationships; formalization of the management function; feedback principle; information uncertainty; study of the internal structure according to the "black box" principle [5; 6]. The object of economic analysis is a recorded or observed economic process, the set of which defines the system. The study of systems takes place on the basis of formalization, providing processes with defined characteristics to assess their quality. Variables that describe the economic system are the volumes of various goods and services that are produced and consumed, added or subtracted from existing stocks, sold and bought at set prices. Production processes can be described as the transformation of one variable into another, and the quantitative relationship between them is identified with all possible technological options. As stated in [1], economic systems have quasi-mechanistic properties and develop with the appropriate speed and acceleration. In view of this, modeling based on dynamic factors allows to explain the main theories of modern economic science, including the theory of business cycles, the theory of games and economic behavior, the theory of evolution and synergy.

The main principles of research into models of dynamic economic systems are [2]:

1. The principle of systematicity. It consists in the fact that the system model is evaluated as a set of components (subsystems and elements), the interaction of which initiates the ability to form relations (connections and influence), which as a result forms the properties of the system as a whole.

2. The principle of complexity examines the system as a heterogeneous, interconnected and interacting set of components, united into a single entity based on defined priorities, functions and a global purpose.

3. The principle of purposefulness consists in the study of a system behavior arrangement in order to achieve the final result.

4. The principle of integrity. The ability of system components to form an internal structure, the functioning of which results in the appearance of new qualities that are not characteristic of each component separately.

5. The principle of information transparency. The system should be open for controlling, measuring and recording data at specified points of operation.

6. The principle of conceptuality assumes that the model of the economic system involves the inclusion of components based on theoretical justification.

7. The principle of complexity reduction (maximum simplification) consists in maximally simplified models in relation to the complexity of tasks.

8. The principle of compliance. The model and the real process assume similarity in terms of criteria and properties.

9. The principle of optimality. It involves the study of the best characteristics of the system under specified conditions.

10. The principle of development (evolution). The model of the economic system shall meet the requirements of development according to the life cycle phases from the moment of birth to the moment of death or transition to another more developed form.

11. The principle of hierarchy. In the process of functioning of systems, components with a dominant function appear, subjugating the functions of others.

12. The principle of invariant character allows to create a model, regardless of the change in its numerical content and configure it for multiple use.

13. The principle of coherence is that a necessary and sufficient change in one of the components of the system causes a response of changes in other components as well as in the system as a whole.

14. The principle of extraspectiveness, in which the problem of the system's behavior goes beyond its boundaries and covers the external environment and super-high levels.

15. The principle of intraspectiveness. The study of system behavior is focused on the structure of the system and the interaction of its components.

16. The principle of controllability and feedback. Changes in the state of the components in the system should occur in such a way that when the external environment changes, the system itself does not significantly

deviate from the trajectory of its movement in the direction of achieving the optimal goal.

The general concept of the study of dynamic economic systems is the dynamic theory of general equilibrium and the theory of stability. From an economic point of view, equilibrium is determined by opposing factors at the micro- and macroeconomic levels. At the microeconomic level, it is possible to determine the ratio of benefits (profits) and losses (costs) by such a rule of balance. At the macroeconomic level, it is possible to evaluate the ratio of production and consumption as an equilibrium. In general, there is a significant number of theoretical works dedicated to the mathematical justification of equilibrium states, including the utility theory of John von Neumann and Oskar Mongerstern and the equilibrium theory of John Nash. Bringing the system out of equilibrium is possible due to disturbance factors, the influence of which can cause an impulse to change characteristics. At the same time, such changes may be insignificant and the economy will acquire initial signs, on the contrary, the changes may be significant and it will be impossible to return the characteristics of the economy to the initial level. In the second case, the economic process will either exist according to the new rules, or there is a possibility of its return to the original course due to artificial regulations. Thus, the system loses its balance and becomes unstable in relation to external influences.

The stability of the economy is a multifaceted characteristic. In our opinion, the vulnerability of the economy can be assessed by its ability to be sustainable. An unstable system acquires significant risks, loses its equilibrium state, and carries out fluctuations of various shapes and sizes around it. From the standpoint of mathematical theory, stability measurement is based on the analytical solution of systems of differential equations and the assessment of their initial state. Structurally stable dynamic systems are those systems that, showing instability at some parameter values, can be transferred to a stable state due to a change in parameters. The degree of remoteness of the system from the limit of stability is called the margin of stability [1].

In the process of bifurcation, a search for new equilibrium states is carried out, while among the options of possible structures, the system (as a self-organized totality) will necessarily take the form that will most satisfy its need to resist external disturbances. During the search of all possible options for existence, the system is in a transition process and carries out an evolutionary movement, which may have inertia (returning back), in order to find the most perfect form of management according to the specified criteria. The transitional process is associated with chaos and uncertainty. It is because of chaos and disorganization, according to many economists, that the economy is cyclically reproduced and acquires new perfect forms, reproducing a synergistic effect. The emergence of a synergistic effect is associated with the results of the influence of the external environment, resulting in the formation of non-equilibrium states, which results in self-organization and an increase in the level of orderliness.

The study of economic systems is based on the basic principles of dynamics modeling, which allow a comprehensive assessment of the entire evolution of the system's behavior and its internal structure. Conceptual approaches in the assessment of dynamic economic systems should be recognized as analysis from the standpoint of maintaining equilibrium and stability, chaos and synergistic development, which have a wide range for further research.

3. Principles of the system approach in managing logistics processes

Changes in the competitive environment in the agricultural sector are due to a number of objective reasons, one of which is the influence of the logistics component in the management of enterprises and the formation of supply chains of agricultural products. Logistics of the agrarian sector (agrilogistics) includes the study of the processes of managing material, informational and accompanying financial flows that have formed on the market of agricultural products and are distributed from its producer to consumers. It covers the entire activity of the enterprise, starting from the planning processes of the production cycle of agricultural products and ending with its sale to end consumers. The construction of effective agrilogistics includes cost control, effective storage management of materials and finished products, provision of information support, development of a transport scheme for deliveries, provision of service, formation of a freight network, etc.

Modern agrilogistics is built on integrated system connections, where participants provide a coordinated mechanism of collective activity with the maximum effect of utility. The integration of agrilogistics ensures not only the appropriate level of competitiveness of agricultural products, but also acts as one of the mechanisms for obtaining cost minimization and formation of product supply at lower prices. This is achieved not at the expense of reducing product quality, but at the expense of avoiding a number of supply risks with the coordinated interaction of all participants in the agrilogistics chain [7]. Ukraine's significant export potential makes it necessary to improve and develop agrilogistics, the functioning of which should be aimed at ensuring time-independent supplies of agricultural products with a minimum level of costs.

The issues of logistics management are relevant both for small agricultural formations and for large integrated agricultural holdings and cannot be solved without an appropriate level of financial support. In this regard, under the conditions of the EU's contributory influence on the sale of agricultural products on European markets, the systematicity of decisions in agrilogistics will ensure the formation of effective promotion of product flows with the maximum expected level of sales income.

Ukraine has the potential ability to obtain stable growing rates of agricultural production supply, which is due to a number of favorable geographical, climatic, and resource conditions. At the same time, the key factor is not only the success in the cultivation of agricultural products, but also the effectiveness of the implementation of actions to preserve and deliver the harvest of previous and current marketing years to the final consumer. In this regard, the issue of introducing systemic solutions in agrilogistics, which today are related both to the theoretical and methodological principles of agricultural and industrial complex management, and to the possibilities of their practical implementation, is intensifying.

The modern agrilogistic concept corresponds to the methodology of the system approach. The conceptual provisions of agrilogistics range it as the main component in obtaining the maximum effect from the realization of the expected opportunities in the agricultural sector in the conditions of integration and globalization of trade relations.

Today, the agricultural sector in Ukraine includes a large number of manufacturing enterprises, each of which has its own legal foundations and is characterized by a different degree of management integration. According to the State Statistics Service of Ukraine, as of November 1, 2019, the number of producers of agricultural products in Ukraine was

48,504 enterprises, of which the largest share was occupied by farms – 66.9% [8]. As of November 1, 2019, the Ministry of Agrarian Policy of Ukraine allocated UAH 666,645.0 thou, of which UAH 2,580,409.1 thou were allocated under the main programs of support for the development of the agricultural sector. In particular, UAH 104,085.3 thou were allocated for financial support of activities in the agri-industrial complex by reducing the price of loans; UAH 103,249.3 thou were allocated to the regions and used; UAH 153,222.0 thou were allocated for the farm development financial support [9].

The agricultural and industrial complex is characterized by growing rates in 2019 as well. Thus, according to the Ministry of Agrarian Policy and Food of Ukraine, the index of agricultural products in 2020 was 88.5%. The basis of external supplies are grain and oil crops, vegetable oils and oil seed coarse meal, which in general make up more than 80% of volumes. There is an increase in such product groups as: meat – by 17%, dairy products – by 6%, fruits and berries – by 11%, processed vegetable and fruit products – by 22% [10].

One of the main problems of the agricultural sector remains logistics, which is primarily associated with the preservation of the collected tonnage of products, its transportation and sale to the final consumer [11]. The functioning of agrilogistics is reflected in the export potential of Ukraine, and with it, the replenishment of the budget. In the foreign trade turnover of food and agricultural products for January-December 2020, the share of the export of food and agricultural products in the total export of the country was 45.1%. The specific weight in the export of food products and agricultural products in 2020 by individual product groups was the following: grain crops – 42.4%; vegetable oil – 25.6%; oilseeds – 8.1%; cakes, solid waste from the extraction of vegetable fats and oils – 6.3%.

There are real needs for terminals, both sea and river. With the need for more than 60 million tons of simultaneous grain storage, the existing facilities in Ukraine are designed for a capacity of 34 million tons. The lack of storage and warehouses forces producers to sell the products collected from the fields, without taking into account the prices, at the same time receiving a lower level of profit in comparison with the expected one. At the same time, storage in case of non-compliance with the relevant conditions reduces the quality of products, which is reflected in the final sales revenue.

Thus, agrilogistics requires a systematic approach both in solving issues of financing logistics projects and in ensuring an uninterrupted cycle of circulation of material flows with the final sale of agricultural products.

Logistics historically has deep roots and has been mentioned since the time of the Roman Empire as a military discipline [12–13]. The modern interpretation of logistics comes from the sources of the theory of flow management in operational management, where the main element of management is the operations carried out at the enterprise, connected in a chain, defined by a given sequence and functional purpose. At the same time, logistics acts as an integrator of relations between sections of the operations chain and serves as an ideology of coherent and optimal management from the point where the flow originates to the point where it ends. Logistics is a science that studies the theory and practice of managing material and related information flows [14–17]. The object of logistics is the material flow, which is the basis of material production and acts as a source of obtaining the consumed value. The uncertainty and value of the material flow is identified with the movement of information and financial flows, which are accompanying ones and are studied in relation to the movement of this flow. E.V. Krykavskyi emphasizes the perception of logistics as effective management of the material flow, including points of origin and delivery to the final consumer [13].

Agrilogistics is considered as a branch functional subsystem in the general management system of a specific enterprise, region and state. In her paper [18] T.V. Kosareva defines agricultural and industrial complex logistics as the science and practice of managing economic flows in the field of production, distribution, exchange and consumption of agricultural products. O.P. Velychko emphasizes the peculiarities of the biological nature of logistics flows. [19]. You can agree with all the statements but there are many controversial issues. In modern studies of agrilogistics, the primary source is considered the formation of a material flow, which is presented in the form of raw materials, finished products, semi-finished products, biological assets, services, etc., generated in the course of agricultural operations. That is, it is represented both in the form of items and materials (fertilizers, seeds, plant protection products, feed, equipment, etc.), and in the form of "living goods" (plants, animals, and other biological assets). The specificity of relations formed in agrilogistics is determined by many factors, among which one should highlight [7]:

1. Priority of the land resource. The main resource in economic management is land, which accordingly affects both the technical and economic components of logistics operations and the property relations formed within agrilogistics systems. The volume of cultivated areas plays a significant role in forecasting the volume of the gross harvest of crops. In 2019, the area of agricultural land in Ukraine was 41,310.9 thou hectares, of which 32,757.3 thou hectares were arable land, 2,283.9 thou hectares were grasslands, 5,250.3 thou hectares were pastures, and 852.7 thou hectares were perennial plantations.

2. Presence of structural changes in farms. Agroholdings exert a significant influence on the development of agriculture, mainly manifested in export activity (increased export of products), reduction of costs, growth of capitalization and attraction of investors. This effect is achieved through the integration of production and supply chains.

3. Environmental and natural risk impact. The dependence of agricultural works on weather conditions makes it necessary to have a clear administration in the implementation of the operational schedule according to the technological charts of growing and harvesting. The high profitability of certain agricultural crops (sunflower, rapeseed, corn, etc.) attracts producers with significant profits, which is achieved without looking back on the observance of ecological balance and the quality of land resources.

4. Availability of seasonal supply and demand fluctuations in the market of agricultural products. The seasonality of agricultural production determines compliance with the optimal time schedule for the consistency of operations within the marketing year. Significant volumes of simultaneously received products require an efficient storage and distribution system, both at our own and at leasehold warehouse facilities.

5. Price disparity between the cost of the final product and the means of production. Significant disparities in the value of the final products of agriculture and industry require clear coordination of financial flows, taking into account budget planning and cost coverage, constant monitoring and forecasting of prices for seeds, energy resources, plant protection products, fodder and service services.

6. Significant dependence on transport infrastructure. The organization of methods of delivery of agricultural products requires in many cases an intermodal method of transportation over long distances. At the same

time, fluctuations in the prices of lubricants during the sowing period force agricultural producers to take credit at the expense of the future harvest.

7. Significant influence of state regulation. In many areas of agrarian business, the influence of the "invisible hand of the state" is available, which is manifested in the promotion of lending to individual enterprises, the introduction of quotas, permits, the provision of state support in the form of subsidies, etc.

Agrilogistics is aimed at solving the main tasks:

– compliance with international quality standards in food safety;

– transition to innovative management models in supply chains;

– introduction of the latest technologies of collection, processing, transportation, storage and distribution of agricultural products;

– increasing the level of competitiveness of agricultural products on the domestic and foreign markets;

– increasing the level of investment attractiveness of the agricultural sector;

– increase in profits of agricultural producers.

The material flow advances within the limits of the agrilogistic system determined at specific levels of the economy: macro-level (within the enterprise), meso-level (within the region), macro-level (within the state), mega-level (in the global world space). The agrilogistics system should represent an economic system defined by a set of elements and processes of material flow management in agriculture with established structured connections and a logistical purpose.

The agrilogistics system functions in accordance with the principles of the system approach and system analysis. The use of a system approach in agrilogistics involves the identification of the main characteristics, the management of which will allow the system to be adapted to changes in the external environment and maintained in a stable established mode of operation. The main properties of agrilogistics systems are:

1. Complexity, which is characterized by the number of elements, subsystems, methods of interaction.

2. Hierarchy, which reflects the rule of ordering elements of a lower level in relation to elements of a higher level of logistics management.

3. Emergence, the ability of the system as a whole composition to perform the given function of the goal, which cannot be achieved by its individual parts.

4. Structuredness implies the presence of an internal organizational structure.

5. Dynamism of development implies a change in system characteristics over time.

6. Information uncertainty, which is reflected in the risks of behavior under the influence of the external environment.

7. Adaptability, the ability to change the structure and carry out a multivariate choice of behavior under the influence of the external environment.

8. Self-organization, the ability to form new forms with a higher level of organization.

9. Synergism, the ability to obtain a significant level of effect as a result of the processes of self-organization and self-reproduction.

The main principles of the system approach in the management of agrilogistics systems are:

– The principle of systematicity, the processes and elements by which the system is determined, have unique cause-and-effect relationships that are manifested in the properties of the whole. That is, the system has such properties that in the event of its destruction, none of its chains will be able to implement them.

– Principle of decomposition. It consists in the fact that the structure of agrilogistics and agrilogistics chains involves the synthesis of its components from a higher to a lower level.

– The modeling principle characterizes that each agrilogistics system must have a final level of formalization, that is, its model shall be described by a certain number of parameters, blocks and restrictions.

– The principle of uncertainty lies in the probabilistic nature of the properties of the agrilogistics system.

– The principle of effectiveness is that in order to change the behavior of the agrilogistics system, it is necessary to cause an external influence that exceeds the critical value.

– The principle of consistency, according to which changes in the characteristics of each level of the agrilogistics system shall be coordinated among themselves.

– The principle of complementarity and sufficiency consists in the defined completeness of decisions made at different levels of the hierarchy.

– The principle of purposefulness characterizes the functional capabilities of the agrilogistics system in terms of following the established goal.

– The principle of alternative (multivariance) of choice, associated with the ability to choose behavior in accordance with the response to external influence and purposefulness.

The integration properties of agrilogistics systems make it possible to achieve the main purpose of logistics: to deliver products of the required quality in the specified quantity at the specified time to the specified location with minimum costs. At the same time, the construction of an agrilogistics system goes through all the stages of process management according to the scheme: purpose → strategy → technology → business → processes → logistics functions → operations. Agrilogistics systems are oriented both to the size of the enterprise and to the target purpose. In this regard, maintaining balanced processes in the system and ensuring its stable functioning relies on ensuring a certain level of administration. The conceptual difference of the management system of the agrilogistics system in this case is the inclusion of a central element of administration, which performs a number of informational and analytical functions. The tasks of the logistics administrator are: optimal management of conflicts in the agricultural environment; construction and monitoring of virtual supply chains of agricultural raw materials and agricultural products; development of request priority charts and lines of information processing results; optimization of internal delays in the movement of information flows; electronic monitoring of logistics operations; controlling the full costs of the logistics circuit, etc. The efficiency criteria of logistics administration can be defined as: minimization of total logistics costs; maximizing profits in the supply chain; maximization of the present worth cost of income in the logistics system.

From the standpoint of optimal dynamic management, the administration functions in the mode of performing established tasks and serving information requests to the logistics administrator. The administrator receives information about events and the status of processes in the logistics system in the request mode. Hierarchical administration takes place in real time in accordance with the flow of incoming orders and synchronization of the processing of management influences. The source of information is the logistics system itself, which acts as a generator of information flows.

Their main characteristics are: number and volume of requests (messages), directional selectivity, traveling time, intensity, cost of service, degree of certainty. The contour of logistics administration will be understood as a diagram of connections of key unites of logistical influence on the movement of flows in the logistics system. The contour of logistics administration should be integrated into the organizational structure built according to possible models: hierarchical, network and virtual.

The formation of Ukraine's export potential is inextricably linked to the development and introduction of modern models of material flow management, which relies on agrilogistics in order to minimize total costs. The greatest effect of agrilogistics is achieved in integrated supply chains, which are implemented on the basis of large agricultural holdings through the integration of raw material bases and industrial processing enterprises.

4. Peculiarities of the logistics of Ukraine's agricultural sector

The development of Ukraine's agricultural sector is one of the primary tasks of the state leaders. Recently, more and more attention has been paid to the organization of agricultural production on the basis of branched production structures such as agribusiness holding companies, corporations, concerns, etc., which can concentrate all stages of operational cycles from the cultivation of raw materials (agricultural products) to the final product of processing (food products). At the same time, most of the expenses for the arrangement and production are carried out at the stages of growing the raw product, which is due to the specifics of agriculture. In this way, the study of the methodology of the logistics of agrarian enterprises, the identification of its system characteristics, and the construction of criteria for the effectiveness of the logistics systems of the agrarian sector become relevant.

One of the priority trends of the recovery of Ukraine's economics was and remains the development of the agricultural sector, which is primarily related to ensuring the food security of the state. According to the official website of the State Statistics Committee of Ukraine [20], the amount of investments in the fixed capital of agriculture in 2019 amounted to UAH 59,130 million, which is 89.14% of the level of 2018. However, despite the decrease in investments over the last year, the agricultural sector remains attractive for investors.

In the conditions of globalization of economic transformations, the main subjects of the agricultural market have become large organizational formations of the type of integrated production structures – agricultural combines, agricultural holdings, concerns, corporations, whose activities focus on increasing the scale of agricultural production and centralizing the main production facilities [21]. In Ukraine, about 40 production associations own more than 50,000 hectares of land, 150 companies have a land fund of 20,000-50,000 hectares and have potential opportunities for land expansion and transformation into agricultural holdings. The amount of land used in agricultural production in Ukraine is 32-33 million hectares, of which 40% are cultivated by small and medium-sized farms. The number of employees at such enterprises is determined by a territorial feature, that is, the workers live in these territories and are mostly elderly people, which is the main component of the increase in the labor shortage. Financial management of small and medium-sized businesses in the countryside faces a significant problem of repaying loans, while agricultural holdings associated with foreign capital have the opportunity to receive cheap loan funds from international banks. The well-founded inability to withstand growing risks and financial problems increasingly lead to the restructuring of the agricultural market, which is manifested in the displacement of small enterprises and the emergence of strong players such as agricultural holdings, corporations, etc. The management of such structures requires new approaches based on a systematic understanding of key problems and their solving from the lower level of the hierarchy (subsidiary companies) to the higher level (parent company).

Agricultural business, compared to other types of activity, is characterized by a sufficiently large risk, primarily related to the availability and quality of raw materials, which makes the implementation of logistics technologies relevant both at individual enterprises and at the regional and state levels. In this regard, the logistics of enterprises of the agrarian complex requires a systematic approach [22; 23], in consequence of the implementation of which an established management mechanism is formed based on the key performance characteristics of the flow of orders, products (raw materials, materials), finances, as well as their organization and maintenance. In this case, the management of flows is carried out, the movement of which generates processes and operational cycles as a whole. In accordance with the formation of processes, the structure of logistics of agricultural sector enterprises is determined by their organizational features for the following: small and medium-sized enterprises, large and integrated production structures. For small and medium-sized enterprises, logistics management can be concentrated both in a separate unit with clearly defined functions, and coordinated at a specifically defined level within the organizational and structural unit. At large enterprises and industrial associations, the logistics management system is extensive and mostly depends on the mechanism of interaction of structural units. Thus, logistics systems of joint productions can meet different purposes and have different system characteristics:

1. Agribusinesses formed by successive merger or by obtaining control levers over small enterprises united by a common type of activity (horizontal integration). The purpose of such groups is to obtain new ones and maintain stability in the existing segments of the product sales market. Organizationally, the logistics systems of such associations can be a set of logistics management subsystems of equivalent enterprises – branches or subsidiaries, which have a centralized mechanism for coordinating actions at the level of a higher management body.

2. Businesses that are enterprise associations of a single technological cycle through vertical integration (from raw materials to the production of finished products). The purpose of such associations is to minimize the total costs of production due to their scale, obtaining minor fluctuations in sales prices, which in turn ensures stability and balance in the competitive environment of other enterprises. In this way, the logistics management system is a series of interconnected subsystems that are controlled at the points of the technological cycle chain from enterprises engaged in the production of raw materials with the consistent formation and transfer of management influence on the level of processing and manufacturing of the final product. In recent years, the agricultural sector has been characterized by a low level of efficiency (Table 1).

Over the period from 2017 to 2019, the financial result before taxation increased by UAH 22,229.8 million. Despite the obtained result, the share of enterprises that received a loss from the results of their activities increased by 3.3%. It should be noted that the production of plant products remains the most profitable. At the same time, systemic connections are due in no small part to the formation of costs, since the costs of agricultural

Table 1

Agricultural Output Effectiveness Indices

Indices	2018	2019	2020	Departure of 2020 from 2018	Departure of 2020 from 2019
Financial result before tax, UAH mln	70,770.2	93,553.6	81,596.7	10,826.5	-11,956.9
Businesses that earned pre-tax profit as a percentage of the total	86.8	83.5	83.2	-3.6	-0.3
Financial result, UAH mln	93,549.5	115,852.7	108,100.9	14,551.4	-7,751.8
Businesses that earned pre-tax loss as a percentage of the total	13.2	16.5	16.8	3.6	0.3
Financial result, UAH mln	22,779.3	22,299.1	26,504.2	3,724.9	4,205.1
Net profit (loss), UAH mln	70,461.8	92,892.9	81,032.6	10,570.8	-11,860.3
Enterprises that received net profit as a percentage of the total	86.7	83.5	83.1	-3.6	-0.4
Financial result, UAH mln	93,249	115,197.6	107,547	14,298	-7,650.6
Enterprises that received net loss as a percentage of the total	13.3	16.5	16.9	3.6	0.4
Financial result, UAH mln	22,787.2	22,304.7	26,514.4	37,27.2	4,209.7
The level of profitability of all activities, %	14.2	16.6	13.9	-0.3	-2.7
The level of profitability of operational activity, %	18.9	19.8	19	0.1	-0.8
Number of employees, persons thou	479.8	472.1	443.7	-36.1	-28.4

Source: Office Statistics Service of Ukraine, 2020 [20]

enterprises specialized in the production of plant products are dependent on industrial enterprises (chemical, energy, food industry) and have significant export-import potential, for example, in the following types of products such as oil and grain crops. Livestock production is less profitable, although in recent years, thanks to state support, the industry has come out of the unprofitable threshold. The costs of animal husbandry depend not only on the significant impact of the activities of industrial enterprises, but also on the area of crop production (production of fodder crops).

The structure of the manufacturing cost of products agricultural enterprises of Ukraine for 2019 is shown in Table 2.

Table 2

The structure of the manufacturing cost of agricultural products (works, services) at enterprises of Ukraine for 2020

Expenditure heading	Enterprises		Incl. farms	
	UAH mln	percentage-wise to the total	UAH mln	percentage-wise to the total
Costs	441,529.6	100.0	76,567.4	100.0
Direct material costs	245,959.8	55.7	44,138.4	57.6
including				
seeds and planting material	35,749.1	8.1	8,076.6	10.5
feeding-stuffs	54,901.3	12.4	3,065.4	4.0
of them purchasable ones	23,107.3	5.2	1,492.6	1.9
other agricultural products	6,677.7	1.5	262.1	0.3
mineral fertilizers	60,290.1	13.7	14,805.8	19.3
fuel and lubricants	30,901.9	7.0	7,956.8	10.4
electricity	4,252.7	1.0	523.1	0.7
fuel and energy	1,892.5	0.4	190.5	0.2
spare parts, repair and construction materials for repair	21,089.4	4.8	5,030.1	6.6
Direct labor costs	29,932.5	6.8	4,682.1	6.1
Other direct costs	103,553.9	23.4	19,718.9	25.8
Total costs	62,083.4	14.1	8,028.0	10.5

Source: Office Statistics Service of Ukraine, 2020 [20]

As can be seen according to the obtained cost elements, the largest specific weight is material costs, the value of which is 57.7%. Stocks of mineral fertilizers and fodder constitute the largest specific weight in the cost structure. Thus, the specific weight of feed costs is 11.4%, which in total amounts to UAH 52,678.8 million. At the same time, the costs of self-made and purchased feed are divided in approximately equal parts. Costs for seeds and planting material in the field of crop production amounted to UAH 38,402.2 million on average (8.3%), and the specific weight of expenditures on mineral fertilizers was about 15.0% – UAH 69,506.2 million.

Quite significant are the costs of transport services, which are reflected in the elements: oil products and services of other organizations. Thus, the specific weight of petroleum products in the cost of production amounted to almost 8.7%. And the specific weight of costs for spare parts was 5.0%. In such conditions, there is an urgent need to develop effective means of managing implementation processes, minimizing costs, organizing effective logistic structures, etc. All this determines the creation of an effective logistics system for the supply of agricultural and industrial complex enterprises based on unified system characteristics.

The specificity of agricultural production allows us to highlight the main system characteristics of agricultural and industrial complex logistics: fulfillment of customer orders and organization of service facilities; forecasting demand for agricultural products and analysis of consumption volumes; product stock management (raw materials and materials) and minimization of losses due to irregular supply flow; communication links and the availability of information space for the regular inflow of orders; maintenance of warehouses and minimization of storage costs; traffic flow control; optimization of the geographical location of production and warehouse facilities; service management; financial flow management; personnel management.

The fulfillment of customer orders and the organization of service facilities are one of the main characteristics of effective agricultural and industrial complex logistics, as they reflect the effectiveness of the functioning and organization of the sales system with the aim of timely satisfying the customer at the required time with the required product with minimal costs. As a result of restrictions on storage terms, agricultural products need to comply with specific conditions of sale with the relevant settlement of trade, in particular:

1. Direct sales from the manufacturer at the local level. This product sales chart ensures minimum costs for transportation, packaging, warehousing and storage of products. However, it does not provide an appropriate level of sales prices and profitability. Such sales chart is used by farms when organizing the sale of plant products on the basis of self-delivery – removal by own transport from the fields or places of harvest.

2. The organization of brand-name trade through its own network is one of the most effective schemes for the sale of agricultural products,

which allows the producer to maintain a market balance between supply and demand at the expense of sales prices without excessive markups by intermediaries. However, such a scheme is too expensive due to suboptimal costs for maintaining warehouses and ensuring the quality characteristics of agricultural products over a long period of time – from the end of the harvesting to the moment of sale.

3. Sale through intermediaries, a scheme that allows for the greater part to transfer the risks of storage and warehouse management to the intermediary. However, if this option of trade is chosen, costs in the chains of intermediary services increase and pose a threat regarding an unjustified increase in selling prices.

Effective management of product stocks (raw materials and materials) minimizes losses due to irregular supply flow and unplanned movement of stocks. Taking into account the seasonality of the operating cycle, inventory management mechanisms solve the problem of periodicity of sales deliveries and supply of raw materials to processing enterprises. At the same time, the stock management mechanism is quite influential on fluctuations in demand and supply for agricultural products. Demand forecasting and analysis of consumption volumes characterize the possibilities of selling products in accordance with the expected demand. Seasonality, limited resources, and especially the risk of non-compliance with climatic conditions make the process of pricing agricultural products dependent not only on inflationary expectations and incomes of the population but also on production technology. Stocks are created in a variety of ways: serial stock, cyclical stock, capacity utilization stock, safety stock, precautionary stock [19]. Stock maintenance involves the corresponding costs associated with the following: maintaining the physical properties of the stock (expenses for depreciation, heating, electricity); with invested funds (assets withdrawn from the turnover of the enterprise until the moment of realization); with the risk of stock realization (taking into account the possibility of undemanding stock). Current liabilities and current assets of agricultural enterprises of Ukraine for 2018–2019 are shown in Table 3.

Most of the assets of agricultural enterprises in 2018–2019 are concentrated in current assets, where the largest share is taken up by accounts receivable (about UAH 297,732.6 million). The amount of accounts payable increased sharply and in 2019 amounted to UAH 182,410.2 million.

Table 3

Current liabilities and current assets of agricultural enterprises of Ukraine, 2018–2019, UAH million

No.	Indices	2018	2019	Departure of 2019 from 2018, %
1	Current financial investments	1,876.2	1,751.9	93.4
2	Cash	21,948.6	23,602.4	107.5
3	Payables	176,088.4	182,410.2	103.6
4	Current assets	654,180.7	640,995.1	98.0
5	Including inventories	255,983.4	270,742.5	105.8
6	Current biological assets	23,698.8	25,311	106.8
7	Receivables	325,880.5	297,732.6	91.4

Source: Office Statistics Service of Ukraine, 2020 [20]

(Compared to 2018, it increased by 3.6%). Short-term bank loans are quite significant in the structure of liabilities, accounting for about 20% of all current liabilities. It should be noted that for the period 2018–2019, UAH 270,742.5 million has been accumulated in the stocks of goods and material values of agricultural enterprises of Ukraine, which constitute 73.9% of the enterprises' current liabilities. At the same time, agricultural enterprises double the risks of sustainability, on the one hand, a sufficiently large payment debt accumulates, and on the other hand, the sale of the remaining finished products is not carried out. This indicates insufficient smooth inventory turnover in the operating cycle. Almost a third of the inventory consists of the remainder of the finished products, which pass into the new year and the storage conditions of which at the beginning of the new year require significant costs for maintaining warehouses.

Storage of products of agricultural enterprises is one of the most important issues of logistics management. First, the possibility of full compliance with product storage conditions ensures minimal risks of loss of product quality, and at the same time, the stability of sales prices under the influence of seasonal fluctuations. Secondly, a properly located warehouse in relation to sales stores or production facilities minimizes costs for transportation, packaging, sorting, etc. Thirdly, the optimal financing option (own or rented premises) minimizes depreciation costs for warehouse maintenance costs. All these factors to a certain extent increase the role of warehouse management in agricultural production.

There are no identical algorithms for solving storage issues for different types of products. Each type of product requires separate storage regimes, which depends on its chemical composition and properties. The main factors affecting the storage of products are the following:

1. Ambient temperature. It has a significant effect on the activity of enzymes, the speed of chemical and biochemical processes, the development of microorganisms and pests. A decrease in temperature reduces the rate of biochemical reactions, while the natural loss of mass due to drying of the product is reduced. One of the most important conditions is to maintain a constant temperature during the entire storage period of the product. Thus, the air temperature during storage of some types of agricultural products is in the range: potatoes – 5–7 °C, tomatoes – 10–12 °C, cabbage – 0 °C, beets – 1–2 °C, carrots – 0–1 °C, onions – 18–24 °C.

2. Air humidity. It affects the humidity of the product during storage. The higher the ambient humidity, the greater the probability of moisture absorption by the product itself. In the final case, this leads to the development of microorganisms, as a result of which the product spoils and increases losses during storage. In this regard, it is necessary to maintain a balanced humidity, as a result of which the ability of products to absorb and release excess moisture is balanced. When storing products that require different humidity regimes, separate storage facilities should be provided for them, for example, for vegetables and grain crops.

3. Gas composition and air exchange. Affects the shelf life of certain products. Carbon dioxide suppresses the action of harmful microflora, which is the causative agent of product spoilage. Oxygen causes a significant oxidation reaction. In this regard, it is necessary to maintain such a concentration of gas that will make it possible to increase the storage period. This is extremely important in cases of seasonality of production, since the harvest collected in a specific period of the year shall ensure a full annual cycle of sales and processing.

4. Light. A factor that can accelerate oxidation processes for unprotected products. In this regard, in most cases, artificial lighting regimes are established in agricultural product warehouses and darkening is observed.

5. Microorganisms and pests. Significantly reduce the quality of products and in some cases lead to its complete loss. The most likely are the process of spoilage due to the action of microorganisms that cause fermentation,

mold and rot. Also, cases of damage by pests are not rare. In this regard, it is necessary to pay for the disinfection of the premises.

6. Order of stacking and placement of products. As a result of irrational placement, deformation of the product, decrease in quality characteristics, etc. occurs. In this regard, the principle of separate storage of products according to chemical properties is used. So, those products that have specific smells are stored separately from those that are easily absorbing it. Depending on the condition of the products, the type of container and packaging, their arrangement may be different: in bulk, in boxes, on racks, etc.

7. Packaging and condition of containers. Their main goal is to preserve the quality of products, to achieve convenience during transportation, storage and sale. The optimal condition and size of the package allows to reduce product mass loss, reduce the threat of dirt, physical damage, increased humidity and drying, the appearance of extraneous odors, microorganisms and pests. Containers are classified the following way: according to purpose – internal and external; multiplicity of use – single and multiple use; hardness – soft, hard, semi-hard; design; sizes, etc.

Maintenance of warehouses is related to the choice of warehouses, especially in the decision-making process regarding the alternative of maintaining the proper state of operation of own warehouses or paying for rented premises. Also, to a large extent, the efficiency of warehouse activities is determined by the organization of warehouse operations: unloading, loading, packing, etc. The need for optimal use of warehouse space determines the calculation of the number of warehouses based on the size of the useful space. Taking into account the fact that in most cases the products of agricultural production have a short shelf life, attention is paid to the location of warehouses with optimal proximity to the place of sale.

The efficiency of traffic flow control is aimed at minimizing transport costs. The essence of the logistics control of the transport flow is to determine the optimal route of transportation from the supplier to the consumer, taking into account possible cases of the size of the transportation, the capacity of transshipment points, current costs of maintaining vehicles, etc. The availability of tractors and agricultural machines in agricultural enterprises of Ukraine in 2017–2019 is shown in Table 4.

Table 4

Availability of tractors and agricultural machines in farms of Ukraine in 2017–2019, units

No.	Type of farm machinery	2017	2018	2019	Deviation from 2019 to 2017, %
1	Tractors	347,111	377,306	310,607	89.5
2	Combines	51,611	42,925	41,110	79.7
3	Seed drills	193,809	195,922	189,013	97.5
4	Plows	336,646	351,830	310,249	92.2
5	Cultivators	189,093	210,156	192,660	101.9
6	Harrows	581,578	524,819	502,567	86.4

Source: Office Statistics Service of Ukraine, 2020 [20]

During the last 2017–2019 years, a tendency to reduce resource transport potential was observed. The number of tractors in 2019 decreased by 36,504 units and amounted to 89.5% of the level of 2017. The reduction of combines was significant (-10,501 units), which was 79.7% of the level of 2017. In 2019, compared to 2017, the number of plows decreased by 7.8%, seed drills decreased by 2.5%, harrows decreased by 15.6%. The growth of the insignificant amount of provision was followed only with cultivators, in 2019 their number increased by 1.9% compared to 2019. Thus, in the last 2017–2019, there was a reduction in the fleet of tractors and agricultural machines.

By region, in 2019, Vinnytsia, Poltava, Dnipropetrovsk, and Odesa regions had the greatest supply of equipment, these are regions where the activities of large agricultural complexes and agricultural holdings are most concentrated. Prospects for the development of agricultural and industrial complex transport logistics depend not only on the provision of a fleet of tractors and cars, but also on the development of work schedules for each type of equipment with optimization of work time. At the same time, attention should be paid to the performance of works in accordance with technological charts for each agricultural crop. At the same time, it is also necessary to take into account vehicle downtime during the transportation of products in the fields directly during working out with combines and due to the replacement of components due to breakdowns. In the case of transportation from harvesting points to warehouses or to direct points of sale, the problem of optimal traffic flow with minimal transport costs for the combined route is solved. Along with the increase in the number of machineries in agricultural enterprises of Ukraine, there is a reduction in the energy capacity of engines. The structure of electricity consumption in agriculture in Ukraine for 2010–2019 is shown in Table 5.

Table 5

Structure of electricity consumption in agriculture of Ukraine, 2010–2019, %

Years	Coal and peat	Oil products	Natural gas	Biofuel and waste	Electricity	Heat energy
2010	0.8	61.9	6.3	0.8	13.9	16.2
2011	0.7	62.0	7.9	0.7	13.6	15.0
2012	0.6	62.1	7.0	0.9	15.1	14.3
2013	0.5	62.3	9.0	0.7	15.1	12.4
2014	0.4	65.6	6.4	0.7	14.9	11.9
2015	0.5	66.4	6.6	1.0	14.7	10.8
2016	0.4	66.7	6.5	0.9	14.1	11.4
2017	0.4	62.4	7.1	1.4	17.0	11.8
2018	0.4	62.0	6.5	1.9	17.6	11.6
2019	0.4	66.5	5.1	1.5	16.7	9.9

Source: Office Statistics Service of Ukraine, 2020

Service management is based on the use of organizational forms: implementation of service through branches, which are an intermediary structure in communication with the consumer; organization of service through the central representative office (service locations visits); service through sales offices; service through separate representatives of the manufacturer (distributors) working on a contractual basis.

Communication links and the availability of information space ensure the coordination of the inflow of orders. The ability to provide timely access to information sources increases the level of competitiveness of the logistics system. The implementation of modern IT technologies in logistics requires the following issues to be resolved: minimization of order processing time;

consolidation of orders into one order; personalization of access; storage of large arrays of information; minimization of transaction time during order processing.

The management of financial flows involves the introduction of investments into the logistics of the agricultural industry with the aim of reproducing expanded agricultural production. The main tasks of managing financial flows in agricultural and industrial complex logistics can be considered the search for optimal alternative solutions for attracting financial resources and the efficiency of their use due to the implementation of effective projects. In recent years, the agricultural sector has become quite attractive for the reproduction of the funds involved. However, the growing volumes of investments require a more sophisticated mechanism for their use, which is due to the following: ensuring the protection of investors' rights, monitoring the fulfillment of obligations, implementing insurance mechanisms, compensating credit rates, reducing investment risks at various stages of production, etc.

Human resources management is effective as a result of targeting specific people to improve the quality of the functions they perform. One of the promising directions is the positioning of the personnel potential in the management hierarchy, subject to compliance with the appropriate competence, which includes the skills of a person making him of her able to perform the specified work regardless of race, age, and culture. The staff composition of agricultural and industrial complex logistics remains one of the difficult issues related to the following: first, search for qualified workers in accordance with the vacancy occupied; secondly, retention of the employee in the position held. In this regard, personnel management in the logistics of the agricultural sector can be considered at different levels: the level of workers; the level of middle managers; the level of senior managers. It is expedient to carry out activities to improve the qualification level: seminars, conferences, meetings of working groups, obtaining a new specialty in the field of logistics. Taking into account the specific features of agrarian business, the acquisition of competence in the organization of agricultural production with the basics of the technology of processes of crop production, animal husbandry, forestry, etc. is due in no small part in the training of personnel.

5. Modeling the functioning of a multi-level logistics system

The current state of agriculture is characterized by a significant decline in the rates and volumes of production, one of the causes, and at the same time the consequence of which, was the unsatisfactory supply of means of production, first of all, the active part. In recent years, the crisis situation of material and technical support has deepened, which leads to losses in the process of production of agricultural products.

At this stage, the economic mechanism in the field of material and technical support has a number of features and specific characteristics. Enactments and resolutions adopted by powerful administrative structures are not sufficiently implemented and cause a number of negative consequences. Among them are miscalculations in the supply charts of material and technical support. Thus, in rare cases, the supply of material and technical resources is a type of activity of enterprises that is not part of the technical service and do not have the relevant work experience. To date, there is a significant number of structures that coordinate flows of material and technical support. This causes some structures to oppose their actions to others. Therefore, there is a need to create a market-type logistical system of material and technical supply, which will be flexible, stable and qualitatively meet the needs of agricultural producers.

A large number of factors of the external environment affect the activity of the logistics system of material and technical support. The logistics system, in its turn, changes the external environment in the process of functioning. Thus, we observe feedback between the system and the external environment.

When considering input and output flows, two main ones that have the maximum impact on the system are taken into account [25]. The first is the material flow determined by applications from the regional enterprise to the producers, and the second is the flow from the branches of (district) agrotechnical service enterprises to the regional one. The main task that is solved here is the optimization of the receipt of material and technical resources from suppliers to the warehouses of the centralized (district) distribution level. At the same time, the system works according to the following principle: lower-level enterprises (branches) apply for the necessary material and technical resources to the central regional enterprise (coordinating enterprise) and transfer funds to the account of the regional enterprise, the coordinating enterprise in turn connects with suppliers and carries out purchase of resources, then the purchased resources arrive in the area of the enterprise, and through them to the final consumer. Therefore, we will assume that each district enterprise shall receive the necessary ordered equipment, spare parts in accordance with the demand of the given territory, which in turn is formed at a lower level of the system – by agricultural producers of a separate district. The determination of these flows was carried out on the basis of relevant statistical observations and criteria, the main of which is the determination of the total according to the Pearson's chi-square test [26].

One of the main issues of system research is the study of input and output information flows. The study of the behavior of the system and the description of its functioning depends on the incoming data flows. Their characteristics and interaction largely determine the choice of modeling methods that will be used in the formalization of the model as a whole and its individual blocks. The analysis of incoming flows allowed to reveal the main characteristics of incoming flows of data distribution.

The agricultural machinery supporting system at the regional level is a complex multi-level system. It is quite difficult to design the operation of the system based on analytical models. This is due to the definition of clear limitations under which the system functions, as well as the fact that the parameters used to describe the system are probabilistic in nature [27].

Since the operation of the system is considered for a certain time interval, there is a need to model system time accounting. It is problematic to do this by means of analytical modeling. When building a model of the functioning of the system of providing material and technical resources, one of the main problems is the determination of the process of receipt of goods in warehouses. Such processes are characterized as inventory management situations [27].

Since there are several facilities in the region engaged in the supply of resources at a lower level, their activity should in a certain way affect the formation of demand at the higher level of the system. Therefore, when forming the demand of the higher level, the demand of the lower levels of the system shall be determined. The demand for agricultural machinery is a discrete distribution, so let's form a statistical hypothesis regarding the comparison of the distribution of the input flow of data on the demand for material and technical resources with the Poisson law, which is used to describe discrete statistical values [26]. This is the first step in system modeling. In the logistics system of supply and maintenance of agricultural machinery at the regional level, the demand for material and technical resources from the district supply systems to the region, as λ and (r), is determined by the input data. At the same time, r is the number of district supply systems in the region.

Based on the data of the logistics supply system, the distribution of the incoming flow of applications was assessed using the Pearson chi-square test. The main goal of research is to prove that the demand for agricultural machinery is mathematically described by Poisson's law. Applying the methodology outlined in, we will perform calculations to determine the incoming flow of applications for tractors [5]:

1. Let's form two hypotheses N_0 and N_1. N_0 hypothesis lie in the fact that the experimental distribution corresponds to Poisson's law. N_1 hypothesis lie in the fact that the experimental distribution does not correspond to Poisson's law.

2. We will take the significance level equal to 0.05. As we do not need a perfectly accurate calculation like in technical studies.

Let's calculate $\chi^2_{pract.}$ and χ^2_{theor}, the practical and theoretical value of the Pearson chi-square test for testing N_0.

4. Let us determine the average value of the total number of applications for tractors from district organizations to regional organizations, according to the formula:

$$\lambda = \frac{\sum x_i n_i}{\sum n_i} = \frac{1623}{2555} = 0,635$$

where λ is the average value of the totality;

x_i is an element of the totality;

n_i is the experimental frequency of x_i.

5. Let us determine the theoretical probabilities and frequencies using the Poisson formula:

$$P(X{=}m) = \frac{\lambda^m e^{-\lambda}}{m!}$$

where P(X = m) is the probability according to Poisson's law;

m is the value taken by the value X from 0,1,2,3,4...m.

6. Let us calculate the value of pi for each sign of xi. Let us check the equation:

$$\sum_{i=1}^{1} P(X=m)=1 .$$

7. Let us define the theoretical frequencies as npi at n = 2555. The sum of npi is approximately equal to 2555.

8. Let us determine $\chi^2_{pract.}$ = 10.91.

9. Let us determine the number of degrees of freedom using the formula:

$$k = L-1-S = 7-1-1 = 5$$

where k is the number of degrees of freedom;

L is the number of classes (groups, intervals) of the sample;

S is the number of parameters used to calculate theoretical frequencies.

10. Let us compare the tabular value of the criterion: $\chi^2_{pract.} < \chi^2$ 0.05; 10.91 < 11.1. Thus, the experimental distribution coincides with the theoretical distribution, that is, it corresponds to Poisson's law. The general results of calculations of the mathematical distribution of applications for tractors in the Vinnytsia region are given in the Table 6.

Table 6

The results of calculations of the incoming flow of applications for tractors in Vinnytsia region obtained on the basis of Pearson's chi-square test

x_i	n_i	$x_i n_i$	p_i	$p_i n$	$(n_i-p_i n)^2/ p_i n$
0	1352	0	0,529816	1353,68	0,002086
1	862	862	0.336553	859.8918	0.005169
2	281	562	0.106893	273.1124	0.227798
3	50	150	0.022634	57.82928	1.059975
4	7	28	0.003594	9.183651	0.519220
5	3	15	0.000457	1.166737	2.880557
6	1	6	0.000048	0.123523	6.219153
Total:	2555	1623	0.999947	2,554.988	10.91396

Source: calculated by the authors

The results of calculations of incoming application flows for certain types of agricultural machinery in the Vinnytsia region are shown in Table 7.

Table 7

The results of calculations of the incoming flow of applications for tractors in Vinnytsia region obtained on the basis of Pearson's chi-square test

Type of machinery	x_i	n_i	$X_i n_i$	p_i	$p_i n$	$(n_i-p_i n)^2/p_i n$
Vehicles (λ=0,168297)	0	2156	0	0.845102	2,159.237	0.004852
	1	372	372	0.142229	363.394	0.203808
	2	23	46	0.011968	30.57915	1.878517
	3	4	12	0.000671	1.715464	3.042386
	Total:	2555	430	0.999971	2,554.925	5.129563
Combine harvesters (λ=0,114677)	0	2277	0	0.891654	0078.176	0.000607
	1	265	265	0.102252	261.2546	0.053694
	2	11	22	0.005863	14.97996	1.057419
	3	2	6	0.000224	0.57262	3.55806
	Total:	2555	293	0.999993	2,554.983	4.669781
Root harvesters (λ=0,034442)	0	2470	0	0.966144	2,468.499	0.000913
	1	82	82	0.033276	85.02004	0.107276
	2	3	6	0.000573	1.46413	1.611125
	Total:	2555	88	0.999993	2,554.983	1.719314
Forage harvesters (λ=0,24227)	0	2016	0	0.784844	2,005.277	0.05734
	1	468	468	0.190144	485.8185	0.653532
	2	62	124	0.023033	58.84962	0.168648
	3	9	27	0.00186	4.752499	3.796163
	Total:	2555	619	0.999882	2,554.698	4.675683
Tractor-mounted plough (λ=0,384344)	0	1776	0	0.680897	1,739.692	0.757751
	1	649	649	0.261699	668.6403	0.576903
	2	130	260	0.050291	128.4939	0.017652
	3	19	57	0.006443	16.46196	0.391306
	4	4	16	0.000619	1.581764	3.697055
	Total:	2555	982	0.992887	2554.87	5.440666
Tractor-mounted sower (λ=0,213699)	0	2070	0	0.807591	2,063.396	0.021136
	1	446	446	0.172581	440.9457	0.057935
	2	39	78	0.018440	47.11483	1.397658
	3	6	18	0.001314	3.356130	2.082770
	4	1	4	0.000070	0.179300	3.756532
	Total:	2555	546	0.998613	2,554.992	7.316030

(End of Table 7)

Type of machinery	x_i	n_i	X_in_i	p_i	p_in	$(n_i-p_in)^2/p_in$
Tractor-drawn cultivator (λ=0,351859)	0	1831	0	0.703379	1797.134	0.638183
	1	603	603	0.247490	632.3378	1.361150
	2	121	242	0.043541	111.2469	0.855066
	3	14	42	0.005107	13.04774	0.069499
	4	3	12	0.000449	1.147741	2.989231
	Total:	2555	899	0.999966	2,554.914	5.913130
Corn harvesting machinery (λ=0,068493)	0	2387	0	0.933800	2,385.859	0.000546
	1	161	161	0.063959	163.4146	0.035679
	2	7	14	0.002190	5.596379	0.352040
	Total:	2555	175	0.999999	2554.998	0.516036

As can be seen from the Table 2 on vehicles with an average value of 0.168 and a sum of experimental frequencies of 2,555, the experimental value of the Pearson criterion $\chi^2_{pract.} < \chi^2_{theor}$ was 5.12 < 6.0 at a significance level of 0.05 and k = 2. For combine harvesters, the calculation results showed that with an average value of 0.115 and a sum of experimental frequencies of 2,555, $\chi^2_{pract} < \chi^2_{theor}$ was 4.67 < 6.0 at a significance level of 0.05 and k = 2 (Table 7). The results of calculations of requests for root harvesters showed that with an average value of 0.034 and n = 2555, $\chi^2_{pract} < \chi^2_{theor}$ was 1.72 < 3.8 at a significance level of 0.05 and k = 1 (Table 8). The results of calculations for forage harvesters showed that with an average value of 0.242 and the sum of experimental frequencies of 2555, $\chi^2_{pract} < \chi^2_{theor}$ was 4.676 < 6.0 at a significance level of 0.05 and k = 2. According to requests for tractor mounted plows with an average value of 0.384 and n = 2555, $\chi^2_{pract} < \chi^2_{theor}$, was 5.441 < 7.8 at a significance level of 0.05 and k = 3 (Table 8). With an average value of 0.213 and the sum of experimental frequencies of 2555, $\chi^2_{pract} < \chi^2_{theor}$ was 7.316 < 7.8 at a significance level of 0.05 and k = 3. The results of calculations of the incoming flow of requests for tractor drawn cultivators (Table 7) showed that with an average value of 0.352 and the sum of experimental frequencies of 2555, $\chi^2_{pract} < \chi^2_{theor}$, was 5.914 < 7.8 with a significance level of 0.05 and k = 3. According to the corn harvesting machinery with an average value of 0.068, the sum of experimental frequencies was 2555, significance levels of 0.05 and k = 1 (table 7), $\chi^2_{pract} < \chi^2_{theor}$, was 0.516 < 7.8. Thus, it was established that the experimental distribution of requests for the above-mentioned types of machinery complies with the Poisson's law.

The conformity of the flow of requests entering the regional security system with the Poisson's law has been proven theoretically [27]. Let's introduce a parameter that characterizes the demand for agricultural machinery, as the intensity of demand, that is, the number of requests for a certain time interval. The parameter that characterizes the supply of material and technical resources will be called the supply intensity, that is, the number of supplies per time interval. The intensity of demand for any item from each enterprise consists of the sum of the intensity of demand for an individual item from each customer. Let's assume that in the region, there is a certain number of service enterprises for the provision of material and technical resources, which order such *i-th* machinery. Then the total intensity of demand for the *i-th* machinery in the region will be equal to:

$$\mu_i = \sum_{J=1}^{N} \mu_{ij}$$

Where μ_i is the demand for the *i-th* type of the machinery in the region;

N is the number of districts in the region;

J is a variable with a value from 1 to N;

μ_{iJ} is the demand for the *i-th* type of the machinery in the district.

The demand for the *i-th* type of the machinery in the district is determined as the sum of the demand of all agricultural enterprises located there. At the same time, the boundary theorem for the total flow [27] determines the conditions under which the sum of independent, ordinary, stationary arrivals of events converges to a Poisson's stationary arrival. At the same time, the restrictions that exist for summing arrivals are similar to the conditions stipulated in the central boundary theorem, that is, the corresponding quantities shall have approximately the same effect on the summing arrival. Among them, there should be no arrivals, both with too much intensity and with too little absorption. The approach to the Poisson arrival is carried out much faster with an increase in the number of arrivals that make up the sum of the total arrival. In practice, the sum of 5-7 arrivals is perceived as a Poisson arrival, if they are independent and their intensities are of the same order.

According to the analytical justifications, the main arrivals operating in the logistics system at the regional level are distributed according to Poisson's law. According to the choice of formalization methods, we can draw a conclusion: with input of independent, ordinary, stationary arrivals, the system can function as a mass service network. Thus, the formalized system of logistical support at the regional level can be considered in accordance with the process of functioning as a mass service network [27].

6. Determination of the criteria for the analysis of the operation of the material and technical support logistics system

The material and technical support logistics system plays a significant role in the process of supplying resources to agricultural enterprises and acts as a coordinator of the relationship between the agricultural goods producer and the agricultural machinery manufacturer. A characteristic feature of such systems is the presence of clearly established multi-level connections and an extensive network of service of orders and deliveries. Increasing the efficiency and coordination of the work of these organizational structures is inextricably linked to the forecasting of demand for specific types of material and technical resources and services, the determination of economic criteria for evaluating the service system, the development of mathematical models for the rational supply of agricultural machinery, the planning of supply volumes and warehouse capacity. In accordance with the above, the formulation of the problem includes:

1. Determination of the main economic criteria that evaluate the functioning of economic systems of this type.

2. Forecasting demand for certain types of material and technical resources, planning supply volumes and warehouse capacity.

3. Evaluation of the effectiveness of the regional system in combination with the analysis of internal relationships based on defined criteria.

4. Formalization of processes that reflect the work of enterprises providing material and technical resources. Establishing criteria for assessing supply and demand for agricultural machinery based on methods of forming hypotheses and substantiating the mathematical law of distribution of input data for modeling. Designing a model of the functioning of the regional supply system based on them, which will fully reproduce the interactions of

supply enterprises at the district and regional level during the time period for which the system is planned to operate.

Evaluation of system performance according to the model in real life is associated with significant financial costs, in addition, there is a problem of uncertainty of system behavior under the influence of selected factors. Therefore, in this case, it is advisable to reproduce the behavior of the system with the help of computer technology using simulation modeling according to the developed algorithms of system behavior. This will make it possible to determine the main probabilistic and temporal characteristics of the system.

5. Development on the basis of created algorithms of software for modeling the processes of providing agricultural machinery, fuel and lubricants, spare parts.

6. Carrying out a computer experiment based on sample statistical data of the company's work.

7. Assessing the adequacy of the created model, i.e. determining how closely the designed model corresponds to the real object, reflects its internal and external connections.

In the process of modeling, it is necessary to determine the economic characteristics of the studied system. Basing on the ratio of indicators in real life, the optimal operating conditions of the systems under market conditions are chosen, the expediency of the existence of these extensive supply systems is evaluated with the predicted share of demand satisfaction.

The main indicators characterizing the company's activity in providing material and technical resources are the indicators of supply and realization of material and technical resources. In organizations of material and technical support, the indicator of the volume of implementation is a priority among other economic indicators, such as gross income, profit, profitability and others. It testifies to the timely service of orders from agricultural producers, the establishment of a supply system by factories producing material and technical resources, and ensuring the regularity of product deliveries.

Goods shipped to the buyer are considered sold. The volume of sales is calculated in physical and monetary terms on the basis of serviced orders and works completed. The sold products are the end of the circulation of funds of the supply enterprises, which depends on the financial situation of the enterprises and the well-being of their employees. The volume of implementation is determined by the cost of material and technical resources allocated by the supplier organization to ensure customer service. In addition, the volume of sales is influenced by the factor of material and technical resources stocks.

When optimizing the system of providing material and technical resources, indicators of the intra-system movement of resources are of great importance, the improvement of which increases the rational placement of the freight network and plans the supply of resources to customers according to zones, districts, regions [5]. As a result of the irrational placement of supply bases and an extended freight network, goods reach the final customer through 3-5 supply points, as a result of which farms are not provided with the necessary material and technical resources in a timely manner, the turnover of goods is delayed and turnover costs increase. The increase in the level of intra-system release and movement of goods indicates an imperfect form of organization of material and technical support, leads to an increase in circulation costs and a decrease in efficiency.

In this case, the main indicator is the volume of intra-system sales, as well as the level of intra-system sales, which shows the volume of intra-system sales of products in relation to warehouse sales and is equal to Expression 1:

$$Kintra.syst = \frac{O_{warehouse}}{O_{wintra.syst.}} 100\% , \quad (1)$$

where $K_{intra.syst.}$ is the level of intra-system release, %;

$O_{warehouse}$ is the volume of deliveries from the warehouse, UAH thou;

$O_{intra.syst.}$ is the intra-system release of resources, thousand UAH thou.

Since the main thing in improving the system's activity is to increase the efficiency of its work, it is necessary to determine the performance evaluation indicators. The main one is the amount of gross income, that is, the excess of the volume of sales of goods at cost over the volume of sales of goods at wholesale prices of industry. The determining source of gross income in material and technical supply is supplier mark-ups received from buyers for goods sold from sales organizations. The indicator that characterizes the supplier mark-up is the level of the mark-up, which characterizes the amount of gross income in relation to total sales minus value added tax, which is calculated according to Formula 2:

$$L_{markup} = \frac{R_{gross}}{V_{sales}} 100\% \qquad (2)$$

where L_{markup} is a mark-up level, %;

R_{gross} is gross revenue of the organization, UAH thou;

V_{sales} is total volume of sales less value added tax, UAH thou.

One of the most important indicators characterizing the operation of supply systems under market conditions is the amount of profit from sales, calculated in cost measurement. It is calculated as the difference between gross income and circulation costs according to Formula 3:

$$P_{real} = R_{gross} - S_{vol}, \qquad (3)$$

where P_{sales} is sales proceeds, UAH thou;

R_{gross} is gross revenue, UAH thou;

S_{vol} is sales volume costs, UAH thou;

It not only characterizes the financial situation of enterprises, but is practically the main source of development of production and improvement of the social situation of the labor team.

The decrease in profit is significantly affected by the increase in circulation costs, which include the costs of supply enterprises for the main production, determined in monetary terms. Therefore, the analysis and systematic study of the cost structure is an integral part of achieving effective results. The indicator characterizing the main costs of production is the level of circulation costs, which shows the share of circulation costs in the volume of total sales and is calculated according to Formula 4:

$$L_{cost} = \frac{S_{vol}}{V_{sales}} 100\% \qquad (4)$$

where L_{cost} is level of costs %;

S_{vol} is sales volume costs, UAH thou;

V_{sales} is volume of sales, UAH thou;

The main indicator that characterizes the economic stability of supplier organizations under market conditions is the level of trade profitability, which is calculated according to Formula 5:

$$R_{prof} = \frac{P_{sales}}{V_{sales}} 100\% \qquad (5)$$

where R_{prof} is the level of trade profitability, %;
P_{sales} is the profit from sales, UAH thou;
V_{sales} is volume of sales, UAH thou.

Thus, the study of the functioning of the regional system of material and technical support with the application of economic and mathematical methods will allow to increase the efficiency of the process of supplying material and technical resources in the Vinnytsia region and can be used in the process of analyzing the activity of branched systems both by the heads of enterprises of district supply organizations and heads of the region.

7. Development and formalization of the system functioning model

The logistics system model functions like a mass service network. The building block principle was used in the modeling. The basic unit is a block that reflects the operation of a single-phase multi-channel mass service network. At the same time, the functioning of the system is considered on the basis of the following links: region organization of agrotechnical service ↔ district organizations of agrotechnical service. Taking into account the links between region organizations of agrotechnical service ↔ agricultural commodity producers, the system turns into a multi-phase mass service network, in which the first phase is the process of agrotechnical service at the level of agricultural commodity producer ↔ district organization, the second is the process at the level of region organization ↔ district organization.

The main element of the simulation is the application execution process in the intermediary system. At the same time, the requests of the central organization are the volumes of equipment, fuel and lubricants, spare parts needed by the district unit, drawn up on a document form, or transferred via communication lines. At the same time, the task channels are the number of employees in the organizational divisions of the central organization, who are engaged in marketing activities for the provision of material and technical resources. In the process of simulation, it is assumed that requests come into the network according to Poisson's law, as a result of which the time intervals between request arrivals are distributed according to the exponential law. In the model, requests come at the system at random points in time, enter a line, and are processed in the order they are received.

The formalized model of the main block of the agrotechnical service system is shown in Figure 1.

The simulation interval is the time period for which the system is planned to operate. Input parameters for modeling are the following data: number of requests, task channels, waiting time, completion time, inventory of material and technical resources at region warehouses.

The number of requests, which is determined by the number of existing the agrotechnical service enterprises of the district level in the region, $\lambda_i^{(r)}$, where λ is the intensity of requests for material and technical resources, r is the number of supply and service enterprises of the district level in the region.

Task channels are equal and independent. Their number is described by the value S_i, where i is a variable that takes the value 1,2,3...s, S is the number of types of material and technical resources supplied by the district agrotechnical service. The request is considered fulfilled in the event that the required type of material and technical resources is available in the warehouses of the region supply systems. If the ordered product is not available, the delivery time is increased by the time interval during which the missing product is received from the manufacturers.

If the fulfillment time exceeds the waiting time, the application is considered unfulfilled. The request may also be considered not fulfilled in the event that the system for a specific request generates a fulfillment time that will exceed the waiting time.

Waiting time, tpredelt is the maximum time period during which the district agrotechnical service is waiting for the delivery of the ordered goods. This time can be set separately for each enterprise. It can be the same for everyone, or a series of random values generated by the system with a uniform distribution relative to a given average value (the specific method is selected during model generation).

Execution time, $t_{service}$ is the maximum time period during which the region agrotechnical service processes and ships the goods ordered by the regional agrotechnical service. The fulfillment time is generated as an exponentially distributed random variable with the $t_{service}$ parameter.

There is a nomenclature of material and technical resources in the warehouse of the region agrotechnical service. It is described by the value m_j, where m is the nomenclature of a certain resource, j is a variable that takes values from 1,2,3....m.

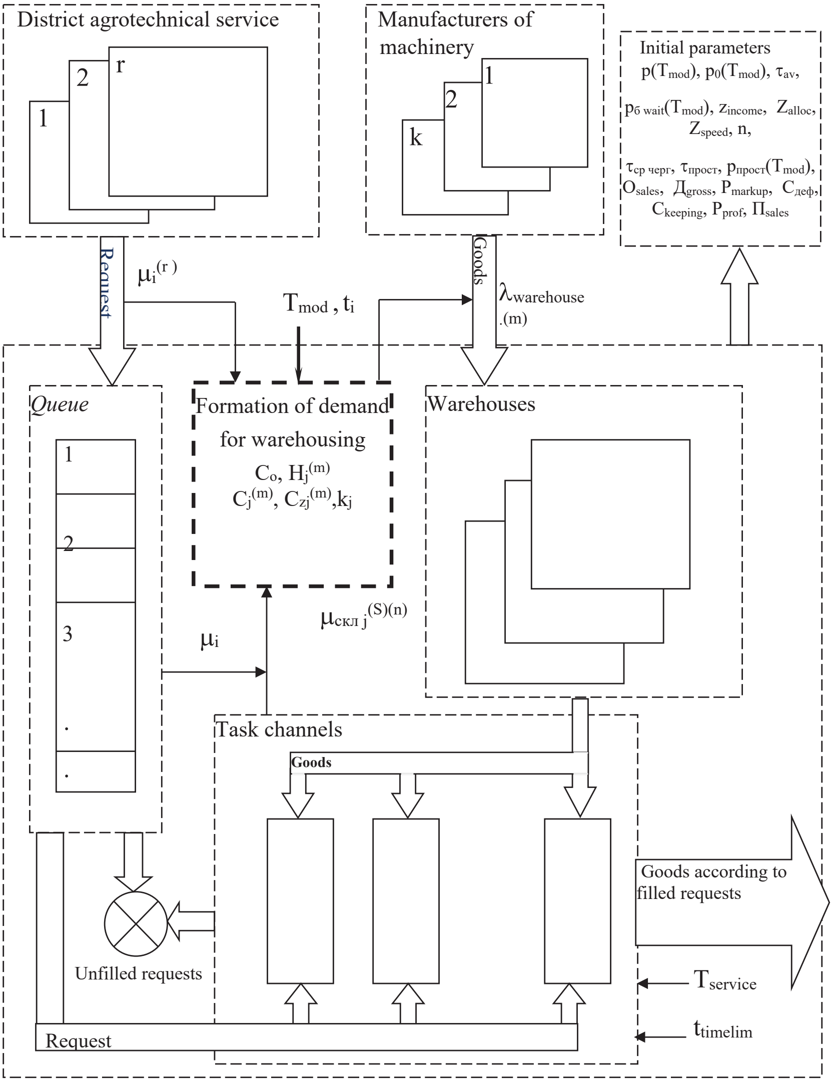

Figure 1. Formalized model of the main block of the logistics system of the agrotechnical service of the region

Source: developed by the authors

The general algorithm for modeling the supply and service system with material and technical resources is shown in Figure 2.

Before the simulation, the start date and the number of working days are set, the system generates preliminary data for the receipt of the first requests. The designed model uses the following principle of determining the moments of receipt of requests in the system: a random number distributed according to the selected exponential law is generated, which is interpreted as a time interval from the current simulation date to the moment of receipt of the request. By summing the received value with the current date, the date of receipt is formed, which is remembered by the system. In the event that the system time is equal to the date obtained, the request coming process begins.

With the start of the simulation, requests begin to enter the line. The length of the line will be considered as the maximum number of requests that can be accepted by the region agrotechnical service for fulfillment. The length of the line is described by the value ni, where n is the length of the line, and i is a variable that takes the value 1,2,3....n.

General processes in the system can be divided into those related to the passage of requests, and those related to the arrival of resources to warehouses.

The following processes occur simultaneously in the system:

a) the process of receiving material and technical resources in the warehouse;

b) the process of receiving a request to the line;

c) checking the status of requests in the line;

d) checking the status of requests in channels;

e) fulfillment of requests in channels;

g) generation of subsequent requests;

h) calculation of economic characteristics of the system.

For all processes, the initial action is to set the simulation interval. In accordance with the above principles, the condition is checked according to Formula 6:

$$t_i = t_{start}, \tag{6}$$

where t_i is the current simulation date;

t_{start} is the start date of the simulation.

The input parameter for the generation of the process of the receipt of material and technical resources to the warehouse of the region supply and

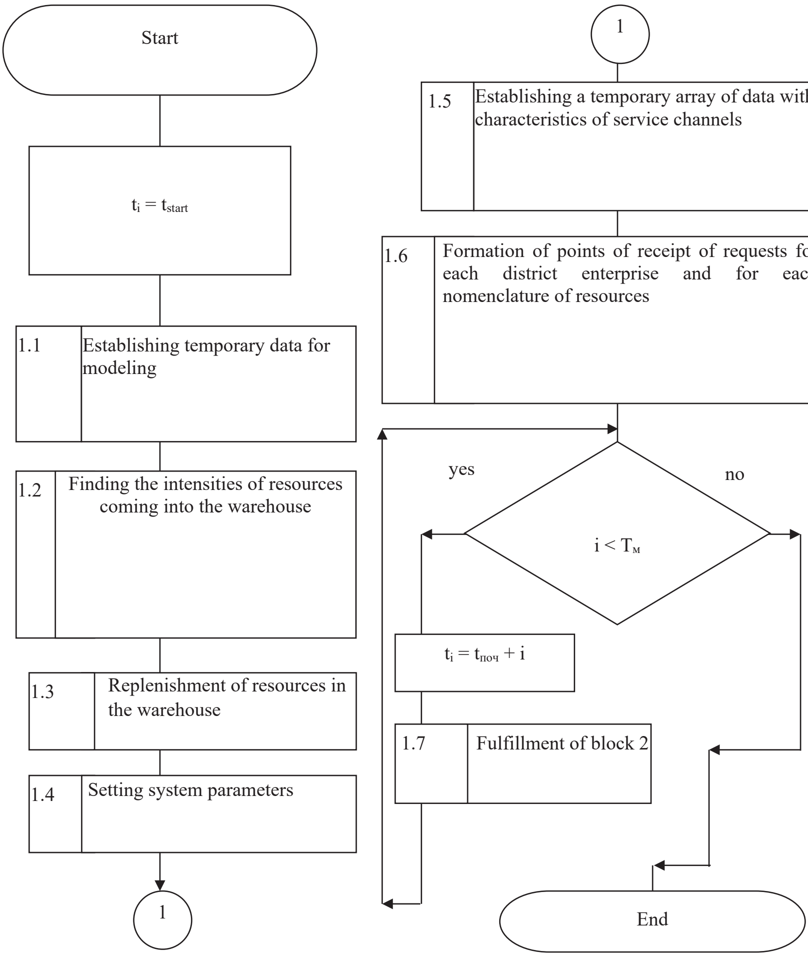

Figure 2. The general algorithm of simulation modeling of the supplying material and technical resources logistics system

Source: developed by the authors

sales organization is $\mu_{warehouse}^{(m)}$ i.e. the intensity of the receipt of the request to the warehouse for the jth resource, which is determined based on the values:

1. Intensity of applications entering the system, $\lambda_i^{(r)}$.
2. Amount of free working capital of region agrotechnical service, C_o.
3. The coefficient of storage costs, defined as a share of the price of the jth type of material and technical resource, k_j.
4. The intensity of the arrival of the jth resource to the warehouses of the central organization of the agricultural technical service, $\mu_{warehouse}^{(m)}$.
5. Costs due to the shortage of the jth resource, $C_{zj}^{(m)}$.
6. The price of the jth resource, $C_j^{(m)}$.

The following time tracking algorithm functions in the model to reproduce the principle of formation of time intervals with an exponential distribution. The date of receipt of the resource is determined by the formula:

$$t_{next} = t_{prev} + \eta, \quad (7)$$

where t_{next} is the next date of receipt of the resource;
η is the time interval generated by exponential distribution;
t_{prev} is the previous date of receipt of the resource.
The condition is checked according to the formula:

$$t_i = t_{next}, \quad (8)$$

where t_i is the current simulation date;
t_{next} is the next date of receipt of the resource.

In the case when assumption 8 is valid, the amount of a certain type of agricultural machinery, spare parts in the warehouse increases. The availability of the resource in the warehouse is calculated according to the formula:

$$m_j = m_j + 1, \quad (9)$$

where m_j is the presence of the *j-th* resource in the warehouse of the regional enterprise at the beginning of the simulation.

In the opposite case, $m_j = m_j$, that is, no changes occur. After the execution of action (9), the moment of receipt of the next request is generated, and if the next request is received on the same date, the entire process of receipt is initiated again. The value $\mu_{warehouse}^{(m)}$ is determined at the beginning of the modeling process.

The process of receiving requests to the line is carried out according to a similar rule and is characterized by the value $\lambda_i^{(r)}$ – the receipt of requests into the system for each type of equipment and for each district enterprise. This value is used as a parameter of the exponential distribution when generating a random η. These intensities are determined during generation on the basis of input data, which are determined on the basis of forecasted data or on the basis of expert assessments by each district agrotechnical service separately. The total intensity for the region agrotechnical service based on a single type of machinery will be equal to the entered data with some error due to the statistical nature of the distribution of individual intensities for each district. When checking the status of requests in the line, the waiting time of the relevant district agrotechnical service enterprise for each request is monitored, and the possibility of transferring the request for the fulfillment to the agrotechnical service in the event of the presence of an unoccupied task channel. The absence of requests for a specific type of material and technical resources in the organizational unit of the region agrotechnical service is considered an unoccupied task channel. As mentioned above, the line is limited by a certain value, and upon receipt of a request, the current length of the line is compared with the maximum specified by the formula:

$$n \geq n_i, \tag{10}$$

where n is the maximum specified line length;

n_i is the current length of the line.

In the case when assumption (10) is being fulfilled, the request is sent to the system and the current length of the line is increased by one according to the formula:

$$n_i = n_i + 1, \tag{11}$$

where n_i is the current length of the line.

Similarly, the number of requests entered into the system is calculated according to the formula:

$$z_{receipt} = z_{receipt\ j} + 1, \tag{12}$$

where $z_{receipt}$ is the total number of requests received in the system;

$z_{receipt\ j}$ is the current number of requests received in the system.

If assumption (10) is not fulfilled, the request is considered not fulfilled and is not entered into the system. Verification of the request for overdue is carried out according to the rule:

$$t_i > t_{received\ i} + t_{wait\ j}, \tag{13}$$

where t_i is the current simulation date;

$t_{received\ i}$ is the time of receiving the request in a line;

$t_{wait\ j}$ is the maximum waiting time for a request in the system for the jth company.

If condition 10 is met, the application leaves the system and the values are calculated:

1. Number of unfulfilled requests by the system according to the rule:

$$z_{not\ syst} = z_{not\ syst} + 1, \tag{14}$$

where $z_{not\ syst}$ is the number of requests not fulfilled by the system.

2. The number of unfulfilled requests in the line according to the rule:

$$z_{not\ line} = z_{not\ line} + 1, \tag{15}$$

where $z_{not\ line}$ is the number of unfulfilled requests in the line.

The algorithm of the request processing process in the line and channels is shown in Figure 3. In the event that the line length exceeds the set limit, the line is considered full and the request leaves the system. The process of checking the status of requests in the channels monitors the availability of the corresponding resources in the warehouse and, if this assumption is met, a random lead time is generated. The request is marked as verified, that is, accepted for fulfillment, but occupies the channel during the entire fulfillment time. During the following checks, the waiting time and the fulfillment end date are monitored.

Overdue requests in the channels are checked according to the rule:

$$t_{received\ i} + t_{receipt\ i}^{(s)} + t_{wait\ j} < t_i, \tag{16}$$

where $t_{received}$ i is the time of receiving an request in a line;

$t_{receipt\ i}^{(s)}$ is the date of receipt of the request in the channel;

$t_{wait\ j}$ is the maximum waiting time for an application in the system for the jth enterprise;

t_i is the current simulation date.

If assumption 16 is fulfilled, the request is considered not fulfilled and znot system is calculated according to Formula 14.

To determine whether the request is fulfilled or not, the sign $\Psi_{service}$ is entered.

The sign takes the following values:

a) $\Psi_{service}$ =.f., in case the request is not fulfilled;

b) $\Psi_{service}$ =.t., in the case when the request is fulfilled.

The request fulfillment algorithm in the system is shown in Figure 4.

Since the fulfillment of request s is carried out during the simulation interval, the assumption is checked:

$t_i = t_{end}$, (17)

where t_i is the current simulation date;

t_{end} is the end simulation date.

In the event that the fulfillment time has elapsed, the amount of the corresponding material and technical resource in the company's warehouse is reduced by the number of orders in the request according to the Formula:

$$m_j = m_j - order_j, \tag{18}$$

where m_j is the availability of the j-th resource in the warehouse of the regional enterprise at the beginning of the simulation;

$order_j$ – the number of orders for the j-th type of material and technical resources.

After fulfillment, the request leaves the system, the channel is free and the values are calculated:

1. The total number of completed requests for the simulation interval according to the Rule:

$$R_{alloc} = R_{alloc\ i} + 1, \tag{19}$$

where R_{alloc} is the number of requests fulfilled for the simulation interval;

$R_{alloc\ i}$ is the current number of requests fulfilled.

2. The number of requests fulfilled without waiting for the simulation interval according to the Rule:

$$R_{speed} = R_{speed\ i} + 1, \tag{20}$$

where R_{speed} is requests fulfilled without waiting for the simulation interval;

$R_{speed\ i}$ is the current number of requests fulfilled without waiting.

The process of generating the next request is initiated after each request is submitted to the line according to the above algorithm. In the event that the generated request receipt date is equal to the current date, the previous request is increased by reqj i.e. the number of requests in the request.

The process of finding a free channel at the time of receiving a request to the channel is carried out according to the Rule:

$$t_{receipt}^{(s)} = 0, \tag{21}$$

where $t_{receipt}(s)$ is the date of receipt of the request in the channel.

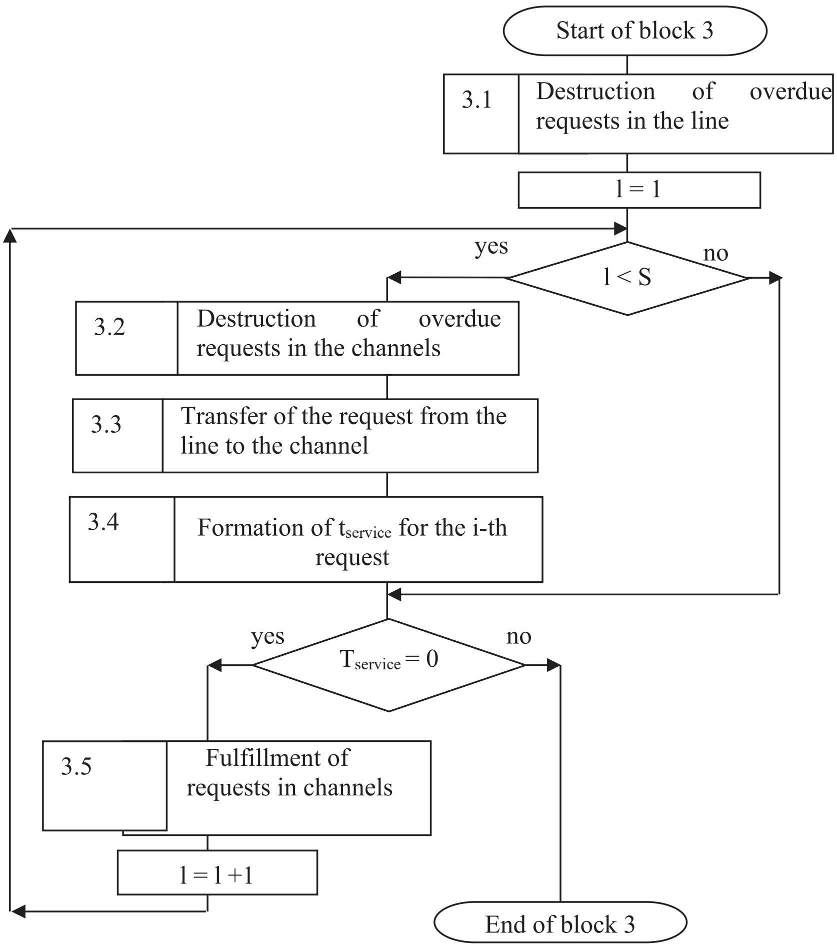

Figure 3. Algorithm of the request fulfillment process in the line and channels

Source: developed by the authors

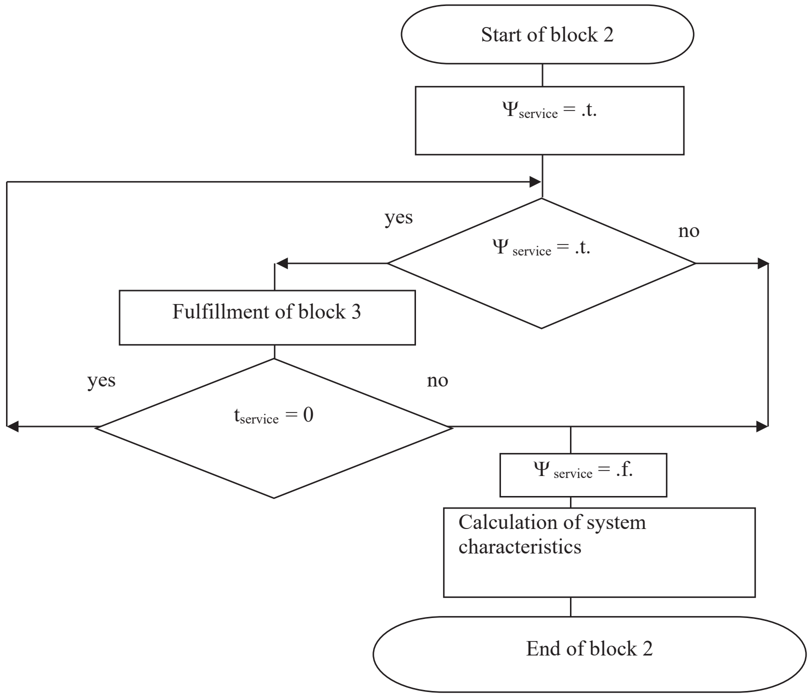

Figure 4. Request fulfillment algorithm in the system

Source: developed by the authors

The direct generation of requests in the channels requires the fulfillment of the following conditions:

$$T_{receipt}^{(s)} \neq o$$
$$\Psi_{service} = .t., \qquad (22)$$

where $t_{receipt}^{(s)}$ is the date of receipt of the request in the channel;

$\Psi_{service}$ is a sign of a request fulfillment.

The Ψ_{chan} parameter is entered to generate the stay of the request in the channel. It is equal to the minimum time the request is in the channel, $t_{min}^{(s)}$ and is generated according to the exponential distribution. In the case when the request is not fulfilled by the system and it is in the channel, the request fulfillment time is calculated according to the Formula:

$$t_{service\ i} = t_i + t_{min}^{(s)} \qquad (23)$$

where $t_{service}$ is the request fulfillment time;

t_i is the current simulation date;

$t_{min}^{(s)}$ is the minimum time the request stays in the channel.

The time of end of the fulfillment of the request is determined by the Formula:

$$t_{service\ i} = 0, \qquad (24)$$

where $t_{service}$ is the request fulfillment time.

At the end of the modeling process, the characteristics of the system are determined [5]:

1. The average length of stay of the request in the system according to the Formula:

$$\tau_{av} = \frac{1}{Z_{allok}} \Sigma_i \tau_{av\ i} \qquad (25)$$

where τ_{av} is the average length of stay of the request in the system;

Z_{allok} is the number of requests fulfilled for the simulation interval;

$\tau_{av\ i}$ is the average length of stay in the system during the simulation period of the i-th fulfilled request.

2. Root mean square deviation τ_{av} according to the Formula:

$$\delta\tau_{av} = \sqrt{\frac{1}{Z_{allok}} \sum_i \left(\tau_{av\ i}^2 - \tau_{av}^2\right)} \qquad (26)$$

where $\delta\tau_{av}$ is the root mean square deviation of τ_{av};

Z_{allok} is the number of requests fulfilled for the simulation interval;

τ_{av} is the average length of stay of the request in the system;

$\tau_{av\ i}$ is the average length of stay in the system during the simulation period of the i-th fulfilled request.

3. The average duration of a request in the line according to the Formula:

$$_{av\ line} = \frac{1}{Z_{receipt}} \sum_i t_{predelt} \qquad (27)$$

where τ_{av} line is the average length of stay of the application in the line;

$Z_{receipt}$ is the total number of requests received in the system;

$t_{predelt}$ is the maximum period of time during which the system waits for supplies of missing material and technical resources.

4. Root mean square deviation according to the Formula:

$$\delta\tau_{av} = \sqrt{\frac{1}{Z_{receipt}} \sum_i \left(\tau^2_{av\ ci} - \tau^2_{av\ c}\right)} \qquad (28)$$

where $\delta\tau_{av\ ci}$ is the root mean square deviation of $\tau_{av\ c}$;

Zreceipt is the total number of requests received in the system;

$\tau_{av\ ci}$ is the average length of stay of the i-th request in the line during the simulation period;

$\tau_{av\ c}$ – the average length of stay of the application in the line.

5. The line length according to the Formula:

$$n = \frac{1}{Z_{receipt}} \sum_i n_i \qquad (29)$$

where n is the line length;

$Z_{receipt}$ is the total number of requests received in the system;

n_i is the current length of the line.

6. Root mean square deviation n according to the Formula:

$$\delta_n = \sqrt{\frac{1}{Z_{receipt}} \sum_i \left(n_i^2 - n^2\right)} \qquad (30),$$

where δ_n is the root mean square deviation of n;

$Z_{receipt}$ is the total number of requests received in the system;

n_i is the current length of the line;

n is the length of the line.

7. Probability of fulfillment of a request by the system according to the Formula:

$$p\left(T_{mod}\right) = \frac{Z_{allok}}{Z_{receipt}}, \qquad (31)$$

where $p(T_{mod})$ is the probability of a request fulfillment by the system;

Z_{allok} is the number of completed applications for the simulation interval;

$Z_{receipt}$ is the total number of requests received in the system.

8. Probability of a request rejection by the system according to the Formula:

$$p0\left(T_{mod}\right) = 1 - \frac{Z_{allok}}{Z_{receipt}}, \qquad (32)$$

where $p_0(T_{mod})$ is the probability a request fulfillment by the system;

T_{mod} is modeling interval;

Z_{allok} is the number of fulfilled requests for the simulation interval;

$Z_{receipt}$ is the total number of requests received in the system.

9. The probability of completing an application without waiting according to the Formula:

$$p_r\left(T_{mod}\right)=\frac{Z_{speed}}{Z_{receipt}}, \tag{33}$$

where $p_r(T_{mod})$ is the probability of fulfillment without waiting;

T_{mod} is the modeling interval;

Z_{speed} is the number of fulfilled requests per simulation interval;

$Z_{receipt}$ is the total number of a requests received in the system.

10. The average idle time of the fulfillment channel according to the Formula:

$$\tau_{idel}=\frac{1}{Z_{receipt}}\sum_{i}\tau_{idel\,i}\ , \tag{34}$$

where τ_{idle} is the average idle time of the execution channel;

$Z_{receipt}$ is the total number of requests received in the system;

τ_{ideli} is duration of downtime of the execution channel for the i-th application.

11. The root mean square deviation τ_{idle} is simple according to the Formula:

$$\delta\tau_{av}=\sqrt{\frac{1}{Z_{receipt}}\sum_{i}\left(\tau_{idel\,i}^{2}-\tau_{idel}^{2}\right)}\,, \tag{35}$$

where $\delta\tau_{idel}$ is the root mean square deviation $\delta\tau_{idel}$ prost;

$Z_{receipt}$ is the total number of requests received in the system;

τ_{idel} is the average idle time of the fulfillment channel;

$\tau_{idel\ i}$ is duration of downtime of the fulfillment channel for the i-th request.

12. The probability of downtime of the fulfillment channel according to the Formula:

$$p_{r\,idel}\left(T_{mod}\right)=\frac{\tau_{idel}}{T_{mod}}, \tag{36}$$

where p τ_{idel} is the probability of idle time of the fulfillment channel;

τ_{idel} is the average idle time of the fulfillment channel;

T_{mod} is the modeling interval.

13. The level of profitability and the level of markup for the modeling interval are determined in accordance with Formulas 5 and 2;

14. The total volume of sales according to the Formula:

$$\mathrm{O}_{\mathrm{sale}} = \sum_{\mathrm{i=1}}^{Z_{\mathrm{allok}}} \sum_{\mathrm{j=1}}^{\mathrm{m}} q_j^m \left(C_{ij}^m - H_{ij}^m \right), \tag{37}$$

where $\mathrm{O}_{\mathrm{sale}}$ is the total volume of sales;

Z_{allok} is the number of requests fulfilled for the simulation interval;

i is the number of the requests fulfilled;

m is the nomenclature of material and technical resources;

q_j^m is a parameter that takes on the value:

$$q_j^m = \begin{cases} 1, & \text{in the case of sale of the j-th product} \\ 0, & \text{in all other cases} \end{cases} \tag{38}$$

$\mathrm{C}_{\mathrm{ij}}^{\mathrm{m}}$ is the purchase price of the j-th material and technical resource of the m-th nomenclature and the request fulfilled;

$\mathrm{H}_{\mathrm{ij}}^{\mathrm{m}}$ is the markup on the j-th material and technical resource of the m-th nomenclature and the request fulfilled;

15. Gross income from sales for the modeling interval according to the Formula:

$$\mathrm{D}_{\mathrm{gross}} = \sum_{\mathrm{i=1}}^{Z_{\mathrm{allok}}} \sum_{\mathrm{j=1}}^{\mathrm{m}} H_{ij}^m, \tag{39}$$

where $\mathrm{D}_{\mathrm{gross}}$ is gross income from sales for the simulation interval;

Z_{allok} is the number of fulfilled requests for the simulation interval;

i is the number of the fulfilled requests;

m is the nomenclature of material and technical resources;

$\mathrm{H}_{\mathrm{ij}}^{\mathrm{m}}$ is the markup on the jth material and technical resource of the mth nomenclature and the fulfilled request.

16. Total losses due to deficit according to the Formula:

$$\mathrm{C}_{\mathrm{def}} = \sum_{\mathrm{i=1}}^{Z_{\mathrm{n\ syst}}} C_{Z_i}^{(m)}, \tag{40}$$

where $\mathrm{C}_{\mathrm{def}}$ means total losses due to deficit;

$Z_{\mathrm{n\ syst}}$ is the number of requests not fulfilled by the system;

$C_{Zi}^{(m)}$ means losses due to the shortage of the material and technical resource of the m-th nomenclature and the unfulfilled request.

17. Total costs of storing goods for the simulation interval according to the Formula:

$$C_{stor} = \sum_{i=1}^{T_{mod}} \sum_{j=1}^{m} C_j^m x_j k_j, \qquad (41)$$

where C_{stor} is the total cost of storing goods for the simulation interval;

T_{mod} is the modeling interval;

m is number of all nomenclatures of material and technical resources in the warehouse;

C_j^m is the purchase price of the jth material and technical resource of the mth nomenclature;

x_j is the quantity of goods of the jth nomenclature in the warehouse;

k_j is cost factor of storing goods of the jth nomenclature in the warehouse;

18. Profit for the modeling interval according to the Formula:

$$P_{sales} = D_{gross} - \left(C_{def} + S_{stor}\right), \qquad (42)$$

de P_{sales} is the profit for the simulation interval;

D_{gross} is the gross income for the simulation interval;

C_{def} means total losses due to deficit for the simulation interval;

S_{stor} is the total storage costs for the simulation interval.

8. Conclusions

Thus, the development of the agrarian sector of the economy is a priority area of the state economic policy. This confirms the exceptional, according to world standards, natural and economic potential, as well as human resources. World practice and historical experience of the development of agriculture in Ukraine indicate that the formation of a multi-system economy is inextricably linked to the solution of the issue of the formation and development of the material and technical base of farms. At the same time, it becomes necessary to consider the current state of material and technical support of agriculture and the existing organizational forms of agrotechnical service, which should solve this issue under market conditions.

The integration properties of agrilogistics systems make it possible to achieve the main goal of logistics: to deliver products of the required quality in the specified quantity at the specified time to the specified location with minimum costs. At the same time, the construction of an agrilogistics system runs through all stages of process management. However, the logistics support system plays an important role in the “production-processing-sales” chain. The possibility of setting up the production of products with added value and the formation of export batches of products depends on the level of logistical support. In the conditions of market competition, a significant number of domestic integrated formations of agrarian business, adapting to market conditions, are actively developing their own logistics capacities.

The conducted analysis of the harvesting agricultural crops and the available capacity for product storage allows us to conclude that small producers and farms have significant problems with logistical support in the cultivation and sale of agricultural products. Small farms do not have working capital and experience difficulties in attracting loans in the conditions of a limited credit environment and cannot finance the construction of new elevators and granaries. Access to the logistics network among small commodity producers and agricultural holdings is uneven. The specified situation requires state regulation and the establishment of a mechanism of cooperation between farms for the purpose of building logistics infrastructure.

The implementation of modern IT technologies in logistics requires the following issues to be resolved: minimization of order processing time; consolidation of orders into one order; personalization of access; storage of large arrays of information; minimization of transaction time during order processing.

The main tasks of managing financial flows in agricultural and industrial complex logistics can be considered the search for optimal alternative solutions for attracting financial resources and the efficiency of their use due to the implementation of effective projects. Growing amounts of investments require a more sophisticated mechanism for their use.

Human resources management is effective as a result of targeting specific people to improve the quality of the functions they perform. The staffing of agricultural and industrial complex logistics remains one of the difficult issues related to: first, the search for qualified workers in accordance with the vacancy; secondly, with retention of the employee in the position held. Taking into account the specific features of agrarian business, the acquisition of competence in the organization of agricultural production with the basics of the technology of processes of crop production, animal husbandry, forestry, etc., is due in no small part in the training of personnel.

Thus, the agricultural sector needs more advanced research in the area of logistics processes, the analysis of which is not possible without determining the system characteristics. The identification of such characteristics makes it possible to form the basis for a formalized description of the general criterion of the efficiency of the logistics system, the functioning of which is inextricably linked to the eventual profit-making due to the optimization of supply chains in agricultural formations from the production of raw materials to the manufacture of the final product.

The process of material and technical support is reproduced by organizational forms, the work of which is reduced to the functioning of a multi-level supply and service system. The crisis factors affecting the operation of the system are the insolvency of agricultural commodity producers, the absence of a clear state mechanism for regulating relations in the field of agrotechnical service, as well as an unregulated internal management mechanism. In view of this, there is a need to adjust the operation of the systems, which will be able to quickly adapt to market conditions, provide producers with agricultural machinery in a timely manner, and at the same time will be profitable.

The process of functioning of the logistics system is described by probabilistic indicators, the value of which is obtained as a result of a machine experiment based on simulation modeling.

The model is a separate block and can be used in the analysis of the behavior of branched systems having the nth number of control levels. At the same time, modeling should be carried out separately for each control unit and combined for the entire model.

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