

Model of optimization of materials and equipment for machinery fleet when servicing objects of reclamation systems

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Abstract. Factors defining business adaptability to economic changes were identified. Creation of service clusters will provide the balance of interests for all agencies using technological machines and increase their performance. The result of the study is a solution of the optimization task aimed at determining the criteria of economic activities of a network of enterprises that service objects of amelioration with the use of various equipment. This solution enables regulating the level of materials and equipment taking into account the expected demand for repair stock and expected minimization of transportation costs for distributing stocks with estimate of the function of flow rates accounting. The system of distributing dead stocks of materials and equipment is proposed. The authors elaborated the economic-and-mathematical model for storage costs optimization when warehousing and selling unused materials and equipment. Results of testing the distribution scheme for dead stock of materials and equipment belonging to Stroytekhnika company, who is a supplier of consumables, fuel and lubricants, as well as spare parts for reclamation and road construction machinery.

1 Introduction

The state of a machinery fleet is assessed in terms of a share of the main types of machines with a service life of more than 10 years in a total amount of machines. For instance, according to governing bodies of agribusiness in constituent entities of the Russian Federation, a machinery fleet of agricultural organizations is reequipped with new tractors, but in 2017 the share of tractors with a service life of more than 10 years remained the same as in 2016: 59.6% (National Report “On the course and results of the implementation of the State Program for the Development of Agriculture and the Regulation of Markets for Agricultural Products, Raw Materials and Food for 2013-2020.” M.: Federal State Budgetary Institution Rosinformagroteh, 2018. – 244 p., Table 1.) (National Report). A third part of a fleet of specialized machinery and vehicles for land reclamation and road construction, registered in certain organizations, has a depreciation rate of more than 75%; more than 50% of technical equipment fleet continues to be operated beyond their

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prescribed operating life (Results of implementation (2014-2017) of the Federal Target Program “Development of Reclamation of Agricultural Lands of Russia for 2014-2020”: Information Edition - M.: Federal State Budgetary Institution Rosinformagroteh, 2018. - 108 pp.) (FTP Development). Their operability is usually ensured due to technical repairs performed with the use of various material and technical resources (consumables, spare parts). According to the Russian Ministry of Agriculture (National Report, FTP Development), costs of field works in 2018 amounted to 185 billion rubles, of which 37.2 billion rubles was spent for spare parts. At the same time, service companies face some problems when organizing procurement and storage of consumables and spare parts that are necessary for maintenance works and post-failure damage control.

Dead stock accumulation leads to the efficiency decrease in using current assets, while the shortage of certain items of materials or spare parts entails the increase in time of post-failure damage control procedures or to impossibility of providing necessary services. For example, at CLAAS, the world's leading agricultural machinery manufacturer, average delivery time of spare parts usually lasts from few hours to 3 days, even at height of a field work season. These facts entail losses in operating companies and lower profits and spoilage of business reputation of service companies [1].

The purpose of the research is to develop an economic-and-mathematical model for optimizing storage costs under conditions of storing and selling the dead stock of materials and equipment.

2 Materials and methods

Sales of spare parts are notable for unevenness of their consumption during the operating life of equipment, which causes dead stock remaining in warehouses. Dead stocks are often formed because of management mistakes in forecasting the demand for volumes of a particular part. Researches performed by many scientists are devoted to the solution of these problems. The analysis of these research works is presented below.

The work of Siltala et al. [2] gives a concept of the formation of production resources. The elaborated base model is designed to solve the problems of creating modular production systems for stocks management in a form, which is neutral for a supplier.

A.P. Kuznetsov [3] offers a method for assessing the equivalence of resource efficiency and performance of equipment and production systems, based on the core provisions of the system theory and on the systematic approach.

This problem was also considered in terms of the aviation industry, particularly, V. Denkena et al. [4] give a description of manufacture's impact on environment, substantiate the presence of a resource and energy-efficient approach in the technological chain of machinery manufacturing, that contains additive and subtractive processes.

Chris William Callaghan provides in his work “Surviving a technological future: Technological proliferation and modes of discovery” [5] presents the results of futures studies on technological development, using a scenario-based approach and focusing on threats and problems. He proposes to develop certain collective abilities in order to strengthen the collective mind, which reduces to zero the technological threat of uncontrolled consumption of sources. Caixia Mao et al. [6] propose in their work to improve the social welfare while promoting technological initiatives. A positive effect for society was detected: improved communications and productivity in the supply chain. It is proposed to consider welfare as a key factor, when deciding on the promotion of individual technologies aimed at common weal appreciation.

Golenko-Ginzburg et al. [7] noted in their work that the provision of production includes various levels of delivery times taking into account needs. Authors of this paper suggest minimizing non-operational average system costs through process modeling of

resource-limited planning.

When assessing the impact of a technical process on energy efficiency in construction, Weina Zhu, Zhihui Zhang, Xiaodong Li, Wei Feng, Jifeng Li [8] have applied the Cobb-Douglas model of the production function, choosing three key factors of technological progress (efficiency of machinery and equipment, changing proportions of energy structures and investments in research and development). They offer recommendations for advancing energy efficiency in the construction industry.

When developing the core principles of the circular economy, Harald Desing et al. [9] offered an integrated, cascading, resource approach aimed at creating an environmentally sustainable and socially profitable economy in a zone of limited resource consumption through limiting the capacity of material cycles.

Don Goldstein [10] proposes to apply the resource-scenario approach for technological change in small towns and settlements. The range of adaptive capabilities is proposed to expand through studying regional sources and applying a technologically connected inter-organizational dynamic approach to emerging clusters. This technique has been tested in northwestern Pennsylvania, on Lake Erie.

S. Repin, A. Zazykin and V. Gordienko in their work [11] presented the results of developing a method for assembling a fleet of trucks taking into account economic viability of procuring secondhand cars, considering their resource-intensiveness during their life cycle.

Based on previously conducted studies and results obtained, the authors carried out their research taking into account basic analytical theories in logistic, modular and system and target modeling of the formation of organizational structures. Modern methods for stock were analyzed and generalized. The basic principles of cluster analysis were used as an element of structuring that adds a disparate set of elements of various nature, yet interconnected to some extent, into the system. These elements actually are the material flows ensuring the functioning of enterprises that service objects of land reclamation systems. Stocks belonging to Stroytekhnika company were studied within the research. The methods of mathematical statistics were applied when assessing the optimization of organizational and storage activities of Stroytekhnika. This company stores and promptly delivers fuel and lubricants, consumables and spare parts for reclamation and road construction machinery produced in Russia or abroad.

3 Aspects of the formation of a regional cluster of service enterprises

The methods of forming organizational structures and evaluating their effectiveness allow concluding that elaboration of organizational structures is associated with solving problems of classification, ordering and grouping of a certain set of elements. Problems of this kind are the subject of the theory of pattern classification and recognition, which appeared in the 70-80s of the 20th century. Cluster analysis, which is widely used not only in the field under consideration, but also in biology, sociology, statistics, politics and other areas of nature and society, is a part of this theory [12].

According to M. Porter's definition, clusters are geographically concentrated groups of interconnected companies, as well as organizations related to their activities (for instance, universities, standardization agencies, trade associations) in certain areas that are competing, yet cooperating at the same time. The connectivity of objects or elements of a set can be of different nature (distance between objects, their technological connection or dependence, other indicators) [12, 13].

Cluster analysis involves the use of two types of models:

In order to develop organizational structures in the service sector, where connections of

elements have quantitative measures, the matrix method of cluster analysis was used, since it is the most effective tool for classifying objects [14, 15].

As an example, the authors wrote a matrix of 5 enterprises, structurally related to technological tasks of servicing the equipment and objects of land reclamation, united into a network. The attributes of uniting (clustering) are technological dependence (a_{TZik}) and territorial proximity of enterprises (a_{TBik}).

The technological dependence is shown in Figure 1. The incidence matrix notionally named ATD corresponds to it:

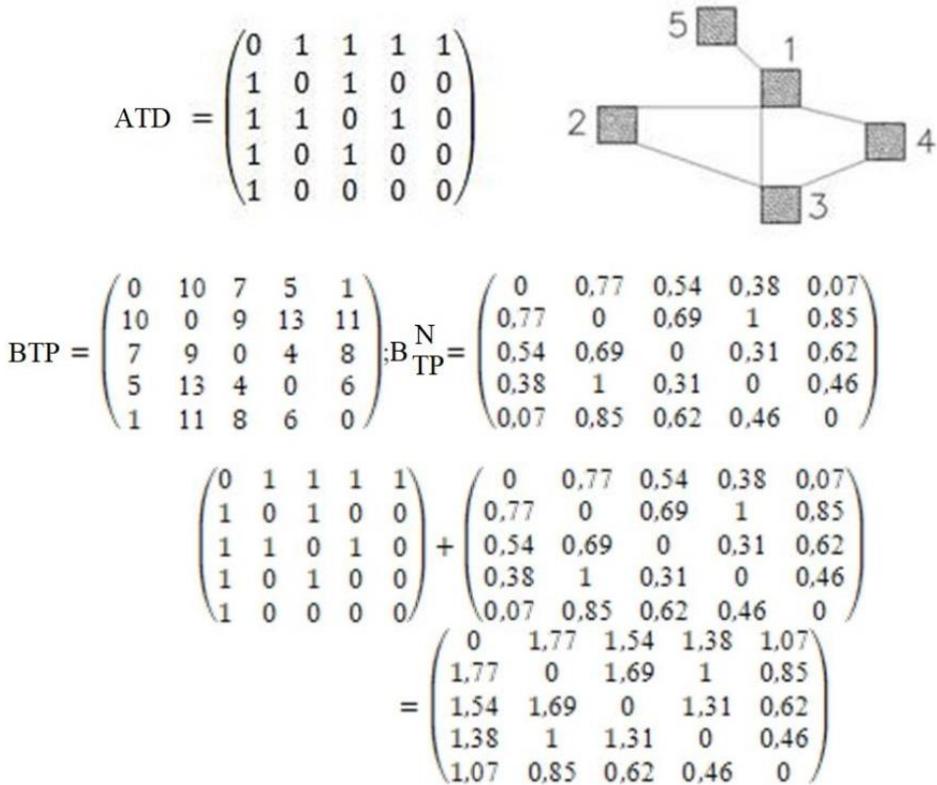


Fig. 1. Graph of technological dependence of service enterprises

The territorial proximity of companies is shown in the matrix BTP (distances are indicated in kilometers). The matrix should be normalized for calculations, expressing all values of a_{TBik} in unit fractions. All values of a_{TBik} should be divided by the maximum distance between companies (km). The result is a normalized matrix B_{TP}^N .

Since it is necessary to combine companies, which are technologically dependent and located close to each other, in one cluster, a generalized proximity indicator for enterprises should be formed. This means that the addition of matrices A_{TD} and B_{TP}^N should be carried out.

The summed matrix displays the strength of companies' connection according to a generalized criterion. Elements 1 and 2 are the most strongly connected ($a_{1,2} = a_{2,1} = 1,77$). This means that these enterprises (Figure 1) should become the first ones united into a network. The second most strongly connected enterprises are elements 2 and 3 ($a_{2,3} = a_{3,2} = 1,69$), etc.

The enterprises of technical and technological support of objects of land reclamation, experienced changes in the organization of their activities during the development of

market relations.

A network of enterprises servicing land reclamation objects can be considered as a comprehensive dynamic system [1, 16]. The fundamental idea of various directions of the general theory of systems is confirmation of interconnections and interdependencies between elements of the system, subsystems and for the entire system including external environment. Therefore, the effectiveness of activities of an organization as an integral system is determined by two areas. The external environment is a source of production factors and information (resources); the characteristics of the internal environment determine the ability to convert these resources into products [17].

The internal environment is an enterprise system, which implies a strictly defined interconnection of components that directly affect the process of converting resource flows into product flows. The external environment is a set of variables interconnected with the enterprise system, affecting its characteristics, but not directly affected by the enterprise managers [12, 13, 17].

Enterprise's adaptability to market requirements lies in the ability to respond to changes in the external environment promptly and with minimal costs.

The comprehensive indicator of adaptability is calculated according to the method of distances. Values of the selected adaptability indicators are normalized, which means that their ratio to the normative value is determined. As standards, maximum or minimum values can be chosen from the limit set, one can also start from the reference values [1].

$$l_i = \frac{a_i^f}{a_i^N}, \quad (1)$$

where a_i , $i = 1, \dots, n$ are indicators included in the system for assessing adaptability, actual and normal values;

l_i is for normalized values of adaptability indicators.

A comprehensive indicator of adaptability can be conveniently represented as a point in the n -dimensional space. Coordinates of this point are a set of normalized values: $A(l_1, l_2, l_3, \dots, l_n)$. Then, the point with coordinates $(1, 1, \dots, 1)$ would correspond to the ideal adaptability level, fully corresponding to the reference value, while the lowest adaptability level would have the coordinates $(0, 0, \dots, 0)$. In this regard, value of the comprehensive adaptability indicator is equal to:

a) the distance from the origin (the lowest level of adaptability) to the point of the real adaptability level of the enterprise:

$$KF_r = \sqrt{l_1^2 + l_2^2 + \dots + l_n^2}, \quad (2)$$

b) the distance from the point of the real adaptability level to the point of the reference adaptability level:

$$KF_z = \sqrt{(1-l_1)^2 + (1-l_2)^2 + \dots + (1-l_n)^2}. \quad (3)$$

When developing a comprehensive adaptability indicator of enterprises serving objects of land reclamation, it is necessary to take into account the industry specifics.

4 Results and discussion

The network of enterprises, that service areas under reclamation, involves the use of various technical means. It should be noted that at the objects of reclamation, e.g. channels, work is carried out to remove vegetation and grass cover, trees, stumping, cleaning silt, restoring concrete reinforcements of slopes, etc. The equipment will function in the state of high loading, wear and other factors causing machine failures in order to perform the above work. Therefore, the issue of resource support while maintaining operating conditions of

the machinery becomes a major one in the set of objectives for the uninterrupted functioning of reclamation systems [15-17].

Currently, creating a system of effective redeployment of resources is the main direction for improvement of the network of involving unused stocks of materials and equipment. This tackles the deficiency of material and technical resources. They are redistributed between the enterprises in the region and the neighbors by using information technologies, economic and mathematical models for optimization and providing new options for logistics companies. The proposed system for dealing with the unused materials and equipment (hereinafter UME) should provide [1]:

- effective collection, processing and updating the information on the availability of unused materials at enterprises, components in the assortment range. This information will improve redistribution and help conduct the exchange and loan operations;

- effective collection and processing of information about the shortage of spare parts necessary for the performance of production tasks at enterprises;

- the formation in an automated mode of options to redeploy UME among same network enterprises. The decision is made by various criteria, such as: the maximum reduction of UME; maximum profit of logistics companies from involvement in the production of UME;

- the formation in an automated mode of options for mutually beneficial exchange of the same product between same network enterprises. the implementation of which will ensure the maximum effect of the logistics companies, as well as conducting borrowing in an automated mode;

- minimization of transport expenses for the implementation of redistribution options; optimization of warehouse costs in the conditions of storage and sale of unused inventories of material and technical resources.

The main parameter to assess efficiency of the redistribution in the task of determining the optimal implementation option for regional redeployment of resources is the criterion for minimizing transport costs. As a result of solving the first redistribution problem, the characteristics of optimal satisfaction of the resource shortage at enterprises (x_{ik}) are formed. Next, the second objective is to find the optimal way to pull off the adopted redistribution.

The model for solving the problem of resources will be as follows:

$$\begin{aligned} \sum_j x_{ijk} &= x_{ik}; & \sum_j x_{ijk} &= r_{ij}; \\ x_{ijk} &\geq 0; & \sum_i \sum_j \sum_k C_{ijk}^{TP} x_{ijk} &\longrightarrow \min; \end{aligned} \quad (4)$$

where: x_{ijk} is the volume of satisfaction of shortage by the i -th type of resource of the k -th enterprise; r_{ij} is the overstock of the i -th resource at the j -th enterprise; C_{ijk}^{TP} - the cost for transporting a unit of the i -th resource from the j -th enterprise to the k -th enterprise. The first constraint reflects the balance of the import of the i -th resource to the k -th enterprise, the second one does the balance of the export of the i -th resource from the j -th enterprise.

An expression is proposed for the costs for the i -th item. It takes into account the expenses for acquisition and storage for the time period t , before sale, minus proceeds from the sale of the i -th item of materials and equipment:

$$\hat{A} = \tilde{N}_i \tilde{O}_i + tS_i X_i - C_i(t) X_i, \quad (5)$$

where C_i and $C_i(t)$ are the prices at which the stock is acquired and sold, respectively; S_i is the cost per unit of stock, X_i is the volume of stocks.

The selling price is determined by the time of storage (t). As a result, the wear and tear and obsolescence of the stock occurs. The price of the stored materials and equipment can

vary according to linear and nonlinear laws. The linear law of price change is applied more often in the form:

$$\tilde{N}_i(t) = K_i(t)C_i^o, \tag{6}$$

where C_i^o is the price at the beginning of the storage period; $K_i(t)$ is the discount (reduction) coefficient of the price.

The objective function, taking into account all types of stored materials and equipment, will be as follows:

$$\sum_{i=1}^n (C_i X_i + t_i S_i X_i - C_i(t) X_i) \rightarrow \min, \tag{7}$$

Assigning: $C_i + t_i S_i - C_i(t) = \tilde{C}_i^t$, the objective function will tend to minimize, i.e.

$$\sum_{i=1}^n \tilde{C}_i^t X_i \rightarrow \min$$

The costs per unit of stock S_i consist of elements of the system of constraints for this model: basic and additional wages, including all types of relevant taxes; energy bills for lighting, heating, ventilation; loading and unloading costs; expenses for the maintenance and operation of fixed assets; payment of interest for a loan during the storage period, etc.

The results of using the developed methodology are considered on the example of Stroytekhnika company, which was selling consumables, fuel, lubricants and spare parts for reclamation and road construction machines in 2017-2018. (fig. 2-4).

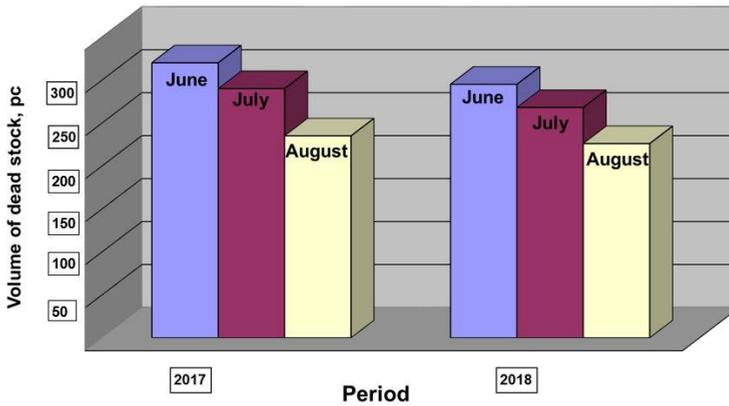


Fig. 2. Evaluation of the efficiency of use of material resources distribution system: volume of dead stock (pc) before optimization of distribution system (2017) and after (2018)

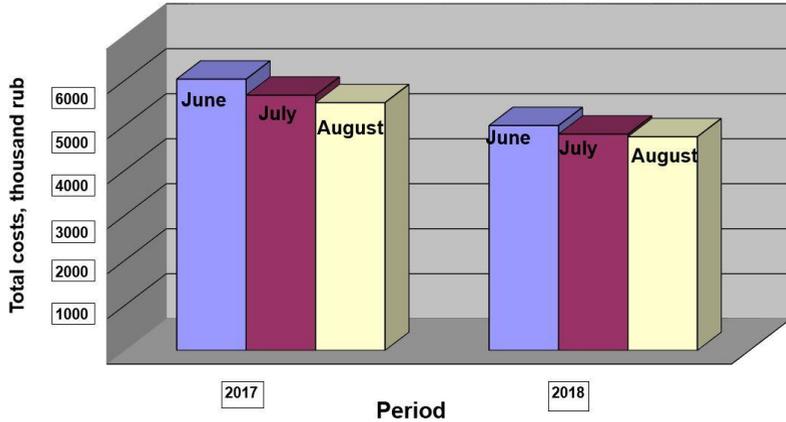


Fig. 3. Evaluation of the efficiency of use of material resources distribution system: amount of total costs (thousand rubles) before optimization (2017) and after (2018)

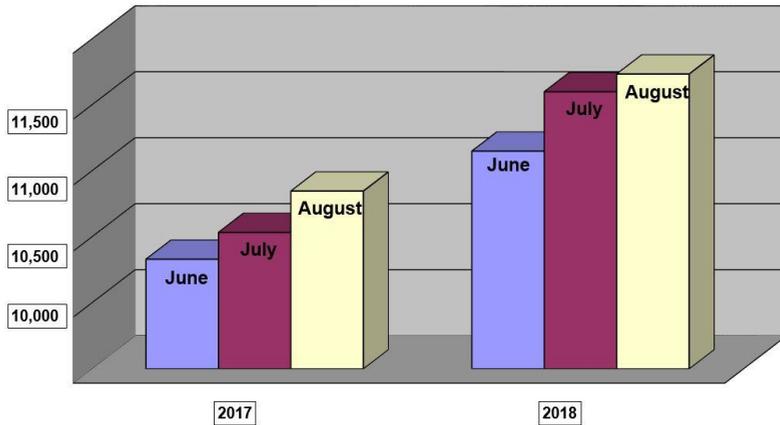


Fig. 4. Evaluation of the efficiency of use of material resources distribution system: volume of supplies (thousand rub) of Sroytekhnika in summer before optimization (2017) and after (2018)

The above approach to solving the problem of optimal redistribution is the main one to tackle the questions of the optimal conduct of exchange and loan operations. The process of developing decisions is iterative: the refinement or change of the initial data and the analysis of intermediate results are carried out repeatedly before a balanced version is obtained; the outcome should meet the various aspects. Thus, the combination of an expert and computer is needed. The expert will contribute the experience and intuition while the machine will provide fast operation, data processing speed, and data storage volumes. It is advisable to implement the means of Intranet and Extranet for large-scale data-search system for distribution of resources. Intranet and Extranet are, in fact, corporate networks which provide access to the data of the system and can be reached via Internet. Network access will be granted only to certain workers. Web-technologies will increase the efficiency of the system. In addition, a companion problem should be highlighted. It is storage. The factor of stock plays a significant party in determining efficiency of involving the unused materials and equipment in the economic turnover [18-22].

5 Conclusion

1. The optimization problem is solved that determines the criterion for economic activity of enterprise network which use various service machinery for reclamation. The volume of materials and equipment can be adjusted with an account of expected spare parts and the need to minimize transportation costs for redistribution of the resources with an estimated valuation accounting functions of flow numbers.

2. An economic and mathematical model for optimizing storage costs in the conditions of stock and sale of unused materials and equipment was developed. The model allows to optimize storage costs and minimize transportation costs for redistribution of the stocks.

3. It is suggested to optimize the flow matching parameters by allowing the desired values of the enterprise performance indicators. It will minimize losses and total costs for ensuring flow compliance.

Considering that attempts to manage a system or modernize it often run into constraints on financial, material and human resources, one can expect from the introduction of an enterprise quality management system to minimize the impact of changes in the external and internal environment by arranging the compliance of flow processes with minimal costs.

4. The calculations showed that the use of the developed methodology in Stroytehnika for the sale of consumables, fuels, lubricants and spare parts for reclamation and road construction machines reduces the volume of unused material and equipment by 20% and the volume of supplies increases by 13%.

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