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The logistics component of the geographic reference of the formed promising crop rotations

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Abstract. Developed countries are actively implementing the digital transformation of the real economy with the transition to an information management system with rational integration of data into a single structured space with new opportunities for obtaining information support for decision-making. Integration mechanisms of technologies for the formation of optimal crop rotations and logistics technologies, reflecting in recent years two of the main principles of the digital economy of countries, are discussed. Science-based crop rotations determine the technological processes in agriculture and must be informationally and algorithmically integrated. However, their effective application requires the creation of optimization models associated with optimizing digital logistics technologies that combine all factors of crop rotation formation. The relevance of logistics optimization is determined by the need to reduce the huge costs for it in Russia (about 20% of the country's GDP). The article presents a mathematical model for the formation of optimal crop rotations, which makes it possible to georeferencing the obtained promising crop rotations, considering logistics.

1 Introduction

Agriculture, following the leading sectors of the world economy, is becoming an active participant in the digitalization of production. Promising digital technologies (DT) based on precision production are increasingly being introduced: precision farming (PF), earth remote sensing and others. For their success, DH data require the development of tools for processing a large amount of heterogeneous data, considering intersectoral relations, the state of agricultural machinery and the level of competence of specialists. These problems were highlighted in [1] with the formulation of several principles of digital transformation common to all industries, including the formation of integration mechanisms based on the data management system and the strategic rethinking of economic management technologies based on the so-called complementarity of management algorithms and data [2, 3]. At the same time, the degree of complementarity should correspond to a certain

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pattern, when the use of algorithms increases the efficiency of data use, and the structuring and integration of data contribute to the improvement of algorithms.

An analysis of the developments of domestic IT companies in the field of digitalization of agriculture shows a significant digital gap between these elements of complementarity. Digital technologies in the industry are beginning to actively use data on the state of the soil and crops with a significant number of characteristics about the composition and the required amount of most resources when growing products [4-10]. But the applied algorithms for making managerial decisions of the company correspond to the traditional practices of using existing economic relations. Optimization mathematical models are used extremely rarely, and decision-making is left to the discretion of production specialists. Models for optimizing the structure of crop rotations (CR) have not been developed, although the system of science-based CRs is the basis of all agricultural production. CRs in agriculture determine all technological processes in the industry. The nature of soil cultivation and crop care, methods of protective measures against soil erosion, the structure and volume of fertilizers and plant protection products applied, the systems, machines and equipment used, the rational placement of production units and storage facilities depend on them. Proper management of CR increases the efficiency of all agricultural production, allowing more efficient use of the main resource - land and reduces financial costs, improves bioclimatic indicators, the quality of food and plant protection products, and increases the efficiency of using agricultural machinery.

Factors affecting the calculation of the number and size of CR areas: organizational and production structure of the enterprise, including the geographical location of production units (centers) with their buildings, fixed assets; quality of land resources and spatial coordinates of land ownership and land use; a logistics component that reflects the need to transport many resources (primarily crops) to and from fields. It is better not to place CRs with low transportable crops on remote lands. And the accelerated formation of agricultural holdings, which have a significant spatial distribution in several regions of the country, gives rise to additional logistical problems, since processing enterprises form the integration core. The level of spending on logistics in the country shows how much attention is paid to its optimization. Logistics costs in Russia are the largest in the world and account for about 20% of GDP, in China - about 15%, in the EU - 7-8%. [eleven]. Thus, the inefficiency of the logistics system is one of the key factors hindering the development of the agrarian industrial complex (AIC) and the entire Russian economy. If costs in this area are reduced to the world average, which is about 11% of GDP, Russia will save about $180 billion a year.

The article describes a mathematical model for optimizing the transport and logistics system, which makes it possible to georeferencing the formed promising CRs.

2 Materials and methods

Computer-aided design (CAD) systems are one of the areas of digital transformation in product design, and the US National Science Foundation called their appearance the greatest event, comparable to the advent of electricity [12]. Digital twins (DT) appeared with the development of the digital economy (DE), making it possible to describe the basic algorithms for the functioning of most objects and enterprises that use overlapping data. The concept of the CRs formation in agriculture is given in [13, 14]. This concept determines that the management of the development, implementation, and operation of CRs should be carried out using an Automated Control System (ACS) built on the basis of a unified digital control platform (DCP) of the agro-industrial complex. However, the current digital divide between information resources (IR) and algorithms makes it necessary to form the SR process manually with the involvement of specialized design organizations for each customer separately. Therefore, an appropriate CAD system should be developed to facilitate the process of preparing initial data for a specific agricultural producer. It should be the main link in the life cycle of the development, implementation and operation of crop rotations within the DCP, as shown in Fig. 1.

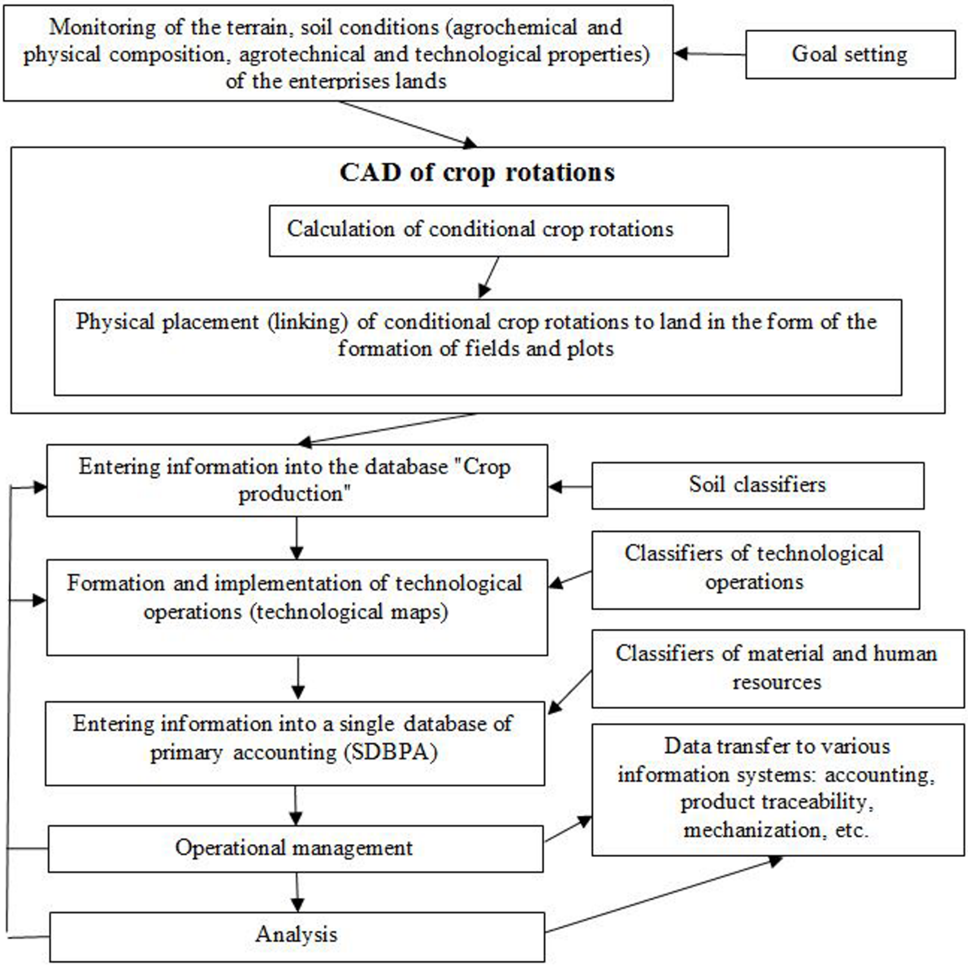

Fig. 1. The place of crop rotation CAD in the life cycle of their development, implementation and operation within the framework of the DCP.

The experience of the development of DTs shows [12, 14] that significant expenditures of finance, time, and high-quality human capital are required for its implementation, since the basis for digital design and modeling of DTs is complex multidisciplinary mathematical models that reflect real materials, structures, and physical and mechanical processes with sufficient accuracy. Such models correspond to the knowledge that is used in the design, manufacture and operation of the product, considering the complex goals of the project. The DCP, formed using mathematical modeling, includes hundreds of control tasks, thousands of IR attributes, dozens of classifiers, dictionaries and reference books, which also indicates the high costs of developing the DCP. Because of this, in this work we will consider only the most important parts of the future CRs CAD: a mathematical model for optimizing the structure of crop rotations and a mathematical model for optimizing logistics activities.

The first model is considered in [6], as a result of which conditional SSs will be obtained without geographic reference to land in the form of x_{nm} – lands (the desired variable) allocated under the n_m -th CR, where m is the number of the agroecological group of land of the enterprise, $m \in M$, n_m -th is the number of CR , included in the *m*-th agroecological group. Also in this work it is shown that in the simulation mode it is possible to obtain x_{inm} as the *i*-th conditional fields ($i \in I^{nm}$) n_m -th CR, again without geographic reference to land. At the same time, we will assume that, based on the data obtained x_{inm} , the design organization will cut geographically referenced fields and plots of appropriate sizes, but without placing CR crops on them. In the future, in order not to introduce more variables separating fields, sections and subsections, we will consider them fields. Then we get S_{bnm} both geographically cut fields *b* that match in size x_{inm} .

Logistics was one of the first industries to adopt an integrated, systemic approach to management based on information technology. This is due to the fact that digital technologies provide the ability to constantly monitor material flows in real time in remote access modes and consider the potential for production, supply, and consumption [11].

3 Results and discussion

Let us formalize the logistic component of the geo-referencing of previously formed promising crop rotations [6] in order to more effectively plan and analyze the life cycle of CRs, considering supply chains. Let us refer to the participants of the logistics chain: suppliers of products from the fields of CR, consumers of products in the form of processing enterprises, retail chains, livestock farms, elevators, warehouses, in particular, currents, silo pits (trenches), transport companies.

We will consider a system consisting of a certain set of suppliers, consumers, transport companies (TC), warehouses. Statement of the problem: to form optimal supply chains for future products from the CR fields of various TC consumers using warehouses based on the criterion of minimizing the total costs for products, their transportation, and storage services. The choice of physical CR fields should come from previously calculated conditional fields, warehouses, shopping malls with the loading of vehicles should be selected. The following tasks are solved in the complex: tracking the vehicle, managing orders (requests), managing the costs of the vehicle and warehouse services.

We believe that the redistribution of products and changes in their volumes do not occur in warehouses, that outside shopping malls will be involved in outsourcing deliveries, in addition to their own transport, given the accelerated formation of agricultural holdings and the extensive territorial distribution of their enterprises. In this case, we will consider from all the characteristics of the vehicle only the actual carrying capacity, considering the specific volumetric carrying capacity, such as carrying capacity, the volume of cargo transported, etc. If necessary, other characteristics can be considered, which will lead to the complication of the model.

Let's proceed to the formalization of the model:

j – the crop number, $j \in J^{nm}$, where J^{nm} is the set of crops in crop rotation n_m ;

y^1_{jnm} – the planned yield of the *j*-th crop grown in the n_m -th crop rotation on the arable land of the *m*-th agroecological group;

e – culture consumer number, *e* = (1, 2, 3, …, *E*);
k –number of TC, *k* = (1, 2, 3, …, *K*);
l – warehouse number, *l* = (1, 2, 3, …, *L*);

r – is the number of the vehicle type, $r = (1, 2, 3, \dots, R)$;

v_{ej} – the volumetric demand of the e-consumer in the j-th culture;

α_{ibnm} – the variable equal to 1 if the i-th conditional field of the n_m CR is located on a geographically divided field S_{bnm}, 0 otherwise, $b \in J^{nm}$;

w_{jbnm} – the volume of available j-th crop from the b-th supplier of the field n_m, $b \in J^{nm}$, $w_{jbnm} = \alpha_{ibnm}\ y^1_{jnm}\ S_{bnm}$;

p_{jbnm} – unit price of the j-th crop from the b-th supplier of the field n_m;

R_k – the number of types of vehicle in the k-th TC;

N_{rk} – the number of vehicle of the r-th type in the k-th TC;

μ_r – specific volumetric carrying capacity of the r–th type of vehicle, is calculated as the ratio of the total weight of the cargo to their volume, intended for transportation by the r-th type of vehicle;

A_l – warehouse capacity l (in specific volumetric carrying capacity), which is calculated in accordance with the table for converting the carrying capacity of containers (pallets) into specific volumetric carrying capacity;

G_r – passport carrying capacity of the r-th type of vehicle;

V_r – the volume of the body of the r-th type of vehicle;

$d_r = \min(\mu_r, G_r / V_r)$ - the actual carrying capacity of the r-th type of vehicle, considering the specific volumetric carrying capacity;

D_{rk} – the total actual carrying capacity of all vehicles of the r-th type at the k-th TC, considering the specific volumetric carrying capacity: $D_{rk} = d_r \times R_k$;

d_{jl} – prices for storage and handling of a unit of the j-th crop in the l-th warehouse;

f^1_{lrke} – prices for the transportation of a unit of production from point l to point e by the r-th type of vehicle at the k-th TC, based on the specific volumetric carrying capacity of the r-th type of vehicle;

f^2_{bnmrkl} – prices for the transportation of a unit of production from point b of the field to point l with the r-th type of vehicle at the k-th TC, based on the specific volumetric carrying capacity of the r-th type of vehicle;

f^3_{bnmrke} – prices for the transportation of a unit of product (without transshipment) from point b of the field to point e with the r-th type of vehicle at the k-th TC, based on the specific volumetric carrying capacity of the r-th vehicle.

Variables:

u_{bnmje} – the volume of deliveries of the j-th product from point b of the field n_m to point e;

y^4_{lrke} – the volume of deliveries of products from point l to point e with the r-th type of vehicle of the k-th TC;

y^5_{bnmrkl} – the volume of direct deliveries of the products from point b of the field n_m to point l with the r-th type of vehicle of the k-th TC;

y^6_{bnmrke} – the volume of direct deliveries of the products from point b of the field n_m to point e with the r-th type of vehicle of the k-th TC;

y^7_{jl} – storage volumes of the j-th product in the l-th warehouse;

c_1 – the cost of deliveries of all products from all points l to all points e;

c_2 – the cost of deliveries of all products from all fields to all points l;

c_3 – the cost of deliveries of all products from all fields to all points e;

c_4 – the cost of storing all products in all warehouses;

c_5 – the total cost of all products supplied;

c_0 – the total cost of the entire supply chain.

Equations and inequalities:

$$\sum_{bnm} u_{bnmje} = v_{ej};$$

$$\sum_{e} u_{bnmje} \leq w_{jbnm};$$

$$\sum_{is} y^4_{lrke} + \sum_{bnml} y^5_{bnmrkl} + \sum_{bnme} y^6_{bnmrke} \leq D_{rk};$$

$$\sum_{lrke} y^4_{lrke} = \sum_{bnmrkl} y^5_{bnmrkl};$$

$$\sum_{bnmj} u_{bnmje} = \sum_{lrk} y^4_{lrke} + \sum_{bnmrk} y^6_{bnmrke};$$

$$\sum_{je} u_{bnmje} = \sum_{rkl} y^5_{bnmrkl} + \sum_{rke} y^6_{bnmrke};$$

$$\sum_{bnmrk} y^5_{bnmrkl} = \sum_{j} y^7_{jl};$$

$$\sum_{ern} y^4_{lrke} = \sum_{j} y^7_{jl};$$

$d_r - \varepsilon_r \leq y^6_{bnmrke}$ - requirement for almost full load (ε_r - permissible not full load) of direct deliveries of the product from point b of the field n_m to point e of the r-th type of vehicle of the k-th TC;

$d_r - \varepsilon_r \leq y^4_{lrke}$ - requirement for almost full load (ε_r - permissible not full load) of the r-th type of vehicle of the k-th TC when delivering the product from point l to point e; similarly, $d_r - \varepsilon_r \leq y^5_{bnmrkl}$;

$$\sum_{j} y^7_{jl} \leq A_l;$$

Efficiency criterion: $c_0 = c_1 + c_2 + c_3 + c_4 + c_5 \rightarrow min$, where

$$c_1 = \sum_{lrke} f^1_{lrke}\, y^4_{lrke};$$

$$c_2 = \sum_{bnmrkl} f^2_{bnmrkl}\, y^5_{bnmrkl};$$

$$c_3 = \sum_{bnmrke} f^3_{bnmrke}\, y^6_{bnmrke};$$

$$c_4 = \sum_{jl} d_{jl}\, y^7_{jl};$$

$$c_5 = \sum_{bnmje} p_{jbnm}\, u_{bnmje};$$

As a result of solving this problem, we will obtain specific values of u^{*}_{bnmje}, y^{*4}_{lrke}, y^{*5}_{bnmrkl}, y^{*6}_{bnmrke}, y^{*7}_{jl} , as a geographic reference of conditional CRs to land areas.

4 Conclusions

A mathematical model for optimizing the formation of optimal supply chains for future products from the fields to various consumers with the integration of chains with technologies for the formation of optimal crop rotations has been developed. It allows to carry out a geo-referencing of the obtained conditional CRs to land areas. At the same time, the formation of optimal supply chains for various consumers occurs using existing storage sites and own or attracted transport. Both models can be further expanded by including an investment block that allows optimizing the entire organizational and production structure of the enterprise.

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References

1. V.I. Medennikov, A.N. Raikov, *Analysis of the experience of digital transformation in the world for Russian agriculture,* Proceedings of the III All-Russian Scientific and Practical Conference with international participation "Trends in the development of the Internet and digital Economy", 04-06 June 2020, Simferopol- Alushta (2020)
2. A.A. Akaev, A.I. Rudskoy, International Journal of Open Information Technologies, **5(1)** 1-18 (2017)
3. Erik Brynjolfsson, Lorin Hitt, Shinkyu Yang, Brookings Papers on Economic Activity **2(1)** (2002)
4. Y. Huang, Z. Chen, T. Yu, X. Huang, X. Gu, Journal of Integrative Agriculture **17(9),** 1915–1931 (2018)
5. M.S. Boori, K. Choudhary, A.V. Kupriyanov, Computer Optics **44(3),** 409-419 (2020)
6. V.I. Budzko, V.I. Medennikov, High Availability Systems **18(4),** 5-15 2022
7. A. Kumar, K.C. O. Reddy, G.P. Masilamani, P. Satish, Y. Turkar, P. Sandeep, Advances in Space Research **67(1),** 298-315 (2021)
8. T. Javed, Y. Li, S. Rashid, F. Li, Q. Hu, H. Feng, X. Chen, S. Ahmad, F. Liu, B. Pulatov, Science of the Total Environment **759,** 143530 (2021)
9. B. Černilová, J. Kuře, M. Linda, R. Chotěborský, Agronomy Research **20(3),** 519–530 (2022)
10. R. Kägo, P. Vellak, H. Ehrpais, M. Noorma, J. Ol, Agronomy Research **20(2),** 261-274 (2020)
11. Yu.I. Toluev, S.I. Plankovsky, *Modeling and simulation of logistics systems* (Millennium, Kiev, 2009)

12. A.I. Borovkov, A.I. Borovkov, Yu.A. Ryabov, K.V. Kukushkin, V.M. Maruseva, V.Yu. Kulemin, Digital twins and digital transformation of defense industry enterprises **1,** 6-23 (2018)
13. N.A. Alekseeva, A.K. Osipov, V.I. Medennikov et al., *Economic and managerial problems of land management and land use in the region* (Izhevsk, Shelest 2022)
14. V.I. Medennikov, *The need to form a single digital twin of an agricultural enterprise,* Materials of the V All-Russian (National) Scientific and Practical Conference "Land Management, economics and Management in the agro-industrial complex during global challenges", March 01, 2023, Izhevsk, USAU, 236-243 (2023)