Substantiation of models of formation of the agroindustrial complex using digital technologies

A A Alabugin, K Zheng, H Wu, C Zhu
South Ural State University, 76, Lenina Ave, Chelyabinsk, 454080, Russia
E-mail: alabugin.aa@mail.ru

Abstract. Necessity definition of a compromise zone of indicators of effectiveness and innovation in the processes expanded use of digital technologies in agro-industrial complexes is substantiated. The feasibility of two types of processes for the introduction of such technologies: evolutionary modernization and a jump increase in the level of technologies and management methods is identified. Complication of processes is an actual problem of insufficient quality management of long-term development of complexes. This determined the goal of developing the concept of methodology for integrating and balancing management of technologies and cyclical innovations in agro-industrial complexes. It is suggested to use the theoretical model of spatio-temporal integration of resources of complex objects. The concept of integration justifies methods of combining models of organizational and mathematical research to develop the methodology.

1. Introduction
The improvement of organizational models in agriculture is due to the steady growth of the population of the world and Russia. Population forecasts of about 10 billion people determine the need for high-tech agro-industrial food production. By 2050, humanity will need about 2 times more food than they did in 2020. Modernization of individual agricultural facilities is not enough for such an increase in output. Organizational models and structures that ensure the cyclical development of a complex of objects with innovative and science-intensive technologies that multiply increases labor productivity are needed [1,2].

The relevance of improving the methodology of management of systems development is a justified concept by the challenges of the integration-balanced organizational and technological management concept (IBMC). We formulate it as an increase in the importance of the results of combining a set of generally recognized scientific achievements in the theory of technology and innovations in agriculture management in the formation agriculture complex (ACC). That is aimed at ensuring the stability of the results of the long-term development of systems by combining evolutionary and revolutionary processes. The processes of the first type mean the modernization of production or management technologies of mainly low or medium levels of innovation on a constant technical, technological and organizational basis. Processes of the second type are characterized by the replacement or abolition of existing methods and technologies of educational, research and production activities. For the efficiency processes of ensuring results with high added value it is necessary to have complementary integration of diversified resources of high-tech innovation development (HTID) of objects of different purposes in the ACC. This substantiates the methods of combining the capabilities
of the proposed theoretical models in a single methodology of organizational and mathematical research management of ACC.

2. The relevance of the integration of resources of the agro-industrial complex and the combination of analog and digital models

The long-term project of creating a national platform "Digital Agriculture" until 1924 sets the goal of a revolutionary leap-transition to structures and technologies in the ACC, which ensure an increase in labor efficiency at least 2 times [1]. The creation of a digital platform provides for the integration of resources for managing the digital interaction of objects and technology elements. A review of business tools for the use of digital technologies in ACC by experts in this area confirms the relevance of the research topic [2]. Information technologies are still used only to support financial and commercial transactions and monitor individual processes. It is necessary to model the business processes of creating and applying breakthrough technologies such as HTID in the network of ACC elements and objects. An important area is the geographical information methods of information support for decision-making on planning and monitoring of a set of processes in ACC facilities. Further expansion of the composition of elements and objects requires an expanded integration of applied science resources and developers of smart monitoring devices in IoT systems, unmanned tractors, cloud storage platforms and related software. For this, it is necessary to represent the processes of integration of objects and methods in the development cycle, which allows them to be positioned according to stages, differing in performance indicators by stages of development.

3. Scientific novelty

The concept and methods are based on the anthropic principle of philosophy in terms of similarity of complex material systems of the Universe, organizations and man in the objectively existing space of all possible and interacting variants of development [3]. We have proved the possibility of using mathematical models that interpret organizational and technological processes in the methods on the approximation of step and generalized functions in the simulation of dynamic processes [4,5]. The models allowed one to develop new methods that improve the quality of management decisions in the organization of spasmodic processes of the HTID on the basis of the integration of intellectual resources (educational, research and design) and production facilities. This is necessary because of the imbalance of their interests as measured by development goals. The imbalance is manifested in the assessments of the opposite of the goals of increasing innovation, efficiency and sustainability of each object even in the conditions of their cooperation [6,7].

4. Substantiation of the cyclical model of processes of improving the quality of management tools of resource integration in the agro-industrial complex

The theoretical model of the unified methodology should provide the possibility of multiple-cyclical expansion of space, time and number of factors – the impact of innovation technology indicators and methods of the organization on the performance indicator-property of the evolutionary and abrupt development processes. The existence of such a possibility is confirmed by the methods of geometric algebra of multidimensional space, which studies computational approaches to compression and stretching as a kind of space transformation [8,9]. Subsequently, these approaches formed the mathematical foundations of quantum mechanics. For the first time such algebra is proposed by W. Clifford [10], the author of the term "divergence" and vector analysis (together with Gibbs and Heaviside [11,12]).

In mathematical and organizational studies, we have identified the possibility of using the tools of generalized functions, which allows to describe the singular variants and scenarios in relation to technological and organizational development. Such functions are in many cases purely abstract, separated from their organizational and physical content. It is necessary to use new opportunities for digital transformation of ACC objects and business intelligence. A digital toolkit Data Science is required, which gives at the output solutions available for programming based on algorithms for the
development of the complex [13]. In practice, the following interrelated subsystems and tasks of the toolkit are distinguished: 1 - substantiation of specialized mathematical models for the algorithmization of actions for the formation and functioning of the ACC; 2 - organization of the development of projects and computer programs based on the results of modeling and algorithmization (it is possible to use existing software products, for example, Prognoz Platform, etc.); 3 - using the capabilities of Machine Learning, modeling methods and examination of the progress of projects and the results of their implementation in the technology of artificial intelligence neural networks. The use of such tools makes it possible in real time for several days (not months, as before) the implementation of measures for the preparation of the production of innovative products and services. The results of multivariate and multicriteria analysis are achieved in the absence of primary filtering of the initial data. The standard steps and results of solving the three specified problems are presented in this and two other articles published in the materials of this conference.

The first task is to develop and adapt specialized software for the subsequent algorithmization of actions. For a better understanding of the generalized functions and conscious solution of practical problems proposed a method of their approximation by analytical functions. Representation of the nature of generalized or the delta-function allowed one to use their features to describe the spasmodic processes of organizational behavior [14,15]. To construct such a sequence, we use the fact that the delta function is the derivative of the Heaviside function or the function of the unit jump, which is defined as (1):

$$\delta(x) = \begin{cases} +\infty, & x = 0, \\ 0, & \forall x \neq 0, \end{cases}$$

with $$\int_{-\infty}^{+\infty} \delta(x) \, dx = 1$$. The value of $$x$$ in this case is an indicator of the factor effects of technologies and methods in the estimates of targets growing in time $$t$$. In this study this is the regulation of the impact of innovation indicators $$\{x = f(t)\}$$ on the investigated property of the efficiency ($$H$$) of the ACC. Therefore, in the theoretical model of the IBMM, a system account of the characteristics of the place, time, objects and factors of influence is required.

To elaborate on the ideas of the scientific work we proposed a theoretical model of the "WWW" space-time coordination, integration and balancing of the impacts of diversified resources and facilities to the imbalance between the opposite goals of HTID complex. Such a system of ACC is characterized by the inclusion of technical, technological and socio-economic subsystems and elements in the virtual complex. The initial letters of the English words "Where – W1, When – W2, What – W3, Why – W4" correspond to the direction of the effects and the content of cause-effect relationships (in the estimates of the target indicators of efficiency and innovation) of objects in the space and time of the formation and functioning of ACC.

However, the ideal mathematical representation of effects does not allow one to reveal the real-practical content of cause-and-effect relationships (Figure 1a). To determine the zones (surfaces or areas in the three-dimensional approach) of dynamic stability (Figure 1b) four types of stability are proposed to be taken into account in the balanced development methodology. The main type provides a return to the equilibrium state of the system under any environmental disturbances in the conditions of integration of resources and convergence of trajectories in the complex-plane 2. Unstable state in terms of resources and disintegration of divergence of the trajectories is 1. The stability in certain ranges of cycles of evolutionary development – 3; absolute stability of a closed system while reducing efficiency and innovation– 4.
Figure 1. The representation of the delta function (a) and its approximation (b) of development in cyclical processes in agriculture complex

The conditions of organizational and technological development of the system determine the choice of the method for assessing its stability: at an infinite time interval of zone 2; asymptotic stability as the convergence of the trajectories of progress to the compromise of goals in the evolutionary development in zone 3 or to reduce their imbalance in zone 1. Given the positive direction of time changes along the x-axis, we assume that planes 2 and 3 interpret the processes of functioning (W2 in the theoretical model). The negative direction of changes in planes 1 and 4 correspond to the processes of formation and divergence of cooperative relations of objects, respectively. Different orientation forms the difference of the evaluation methods of the following types of development processes on the quadrants: 1 – medium-tech (MTD), functional and evolutionary (FE); 2 – HTID, structural-revolutionary (SR); 3 – MTD, structural and evolutionary (SE); 4 – low-tech (LTD), the conservative self-organizing (CSO).

The following high-tech technologies recommended for use in ACC can be classified as target types of HTID processes: development of multilayer electronic maps of the economy based on the results of satellite geodetic measurements; fixing the state of crops by means of ground measurements, expert assessments of agronomists and data of remote sensing of the Earth using aerospace images; monitoring the state of the crop using unmanned aerial vehicles. This is also automation of the chain of processes in the technological chain - from sowing seeds, smart or precise processing of fields with pesticides and fertilizers to harvesting; development of the Internet of Things system, which allows remote monitoring of the health status of livestock on pig farms, and others [16].

The meaning of singular generalized functions can be understood based on their approximations, taking the generalized function as the limit of some approximating sequence of ordinary functions. For example, as noted, the delta function can be considered as the limit of a sequence of step functions. However, the use of a sequence of step functions does not allow for a proper representation of the derivatives of the delta function, which, in turn, are also generalized functions. The problem is that step functions have break points in which they are not differentiable mathematically. Therefore, to represent the derivatives of a delta function, we need to use an approximating sequence of analytic functions having derivatives of any order. It is proposed to approximate the Heaviside function by a sequence of functions of the form \( H_n(x) = 0.5(1 + f_n(x)) \), where the sequence of recursive functions \( f_n(x) \) is determined by the relation [5] (2):

\[
\{ f_n(x) \mid f_n(x) = \sin((\pi/2 \cdot f_{n-1}(x)), f_1(x) = \sin x; n \in N) \} \subset C^\infty [-\pi/2, \pi/2] 
\]

We consider the function \( f_0(x) = \text{sign}(\sin x) \). Similarly, one can prove that the sequence \( f_n(x) \) converges in the norm to a function \( f_0(x) \) in space \( L_2[0, \pi/2] \). The application of the toolkit made it possible to substantiate the effect of expanding the time interval of the mapping of the functions of realizing short-term technological and organizational solutions of a jump form.
5. Practical significance
To overcome the problem and realize the idea, we formulated the hypothesis of representing short-term processes of high-tech jump transitions and organizational-structural changes by a set of nested functions of their analytical approximation. In this case, the number of functions describing the transitions is proposed to be interpreted by the number of types of integrable resources and objects of the complex that regulate the convergence of trajectories of indicator-properties of the HTID. The possibility of such results is confirmed by studies of structures of human resources management and Internet of Things architecture for business model renewal [16,17]. Therefore, we consider the approximations of nested functions as a tool for improving the quality of management when applying additional functions for integrating resources and convergence of development paths in the Center for coordination of the objects of the complex. Similar approaches are implemented as responses to new challenges for industrial policy and in complex value chains and global innovation systems [18,19]. The functioning of the ACC in the form of an effective organizational structure is possible when solving tasks 2 and 3 in the Center using the Dat Science toolkit.

6. Conclusion
Thus, the following scientific and practical results were obtained and reflected in the paper:
1. The integrating and balancing management organizational and technological development is formulated, which the concretization of the theoretical model. The methods of modeling evolutionary and jump-like processes based on the approximation of generalized functions are mathematically grounded. Methods include assessment of static and dynamic characteristics [20], indices and criteria for zoning and typification of processes in agriculture that are distinguished by the innovative nature of technological and organizational processes.
2. The theoretical model of spatio-temporal integration of resources and inclusion of complex objects is specified, including methods for quantitative modeling of processes for improving the quality of management [21]. The new effect of space and time expansion for the organization of the effects of the application parameters of technologies and management methods corresponding to the zones and types of processes is mathematically substantiated and interpreted. The hypothesis of representation of jump-transitions of a high-tech type and innovative methods of management by a certain set of embedded approximation functions corresponding to the number of types of integrable resources and objects is formulated and confirmed.
3. The necessity of solving the problems of modeling and planning the processes of the formation and functioning of the ACC has been substantiated. It has been determined that this requires the integration of resources of objects that differ in the possibilities of using digital technologies, combining models and organizing interaction.

References
[1] 2019 Digital agriculture Depart. project, official publication (Moscow: FGBNU Rosinformagrotech)
[2] Nikitochkin M 2020 Digitalization of the agro-industrial complex. Fashion "hype" or a real business tool for the industry (Moscow: Agroinvestor)
[3] Barrow J D and Tipler F J 1986 The Anthropic Cosmological Principle (Oxford)
[4] Alyukov S V 2011 Approximation of step functions in problems of mathematical modeling Mathematical modeling, Journal of the Russian Academy of Sciences 23(4) 75–88
[5] Alyukov S V 2013 Approximation of generalized functions and their derivatives Questions of atomic science and technology. Ser. Mathematical modeling of physical processes 2 57–62
[6] Maine E 2014 Radical innovation from the confluence of technologies: Innovation management strategies for the emerging nanobiotechnology industry Journal of Engineering and Technology Management 32 1-25
[7] Wang Z 2016 Effects of standardization and innovation on mass customization: An empirical investigation Technovation 48(49) 79–86
[8] Chai S 2018 Multivariate rational response surface approximation of nodal displacements of truss structures *Chinese Journal of Mechanical Engineering* **1** 3–6

[9] Meimaris A T 2008 A closed form of approximation and error quantification for the response *Probabilistic Engineering Mechanics* **54** 87–94

[10] Newman J R 1953 *William Kingdom Clifford* (Sci. Amer.)

[11] Bessaih H 2018 Numerical approximation of stochastic evolution equations: convergence in scale of Hilbert spaces *Journal of Computational and Applied Mathematics* **343** 250–274

[12] Cao L 2018 An efficient evidence-based reliability analysis method via piecewise hyperplane approximation of limit state function *Structural and Multidisciplinary Optimization* **1** 201–213

[13] Alabugin A, Osintsev K and Aliukov S 2021 Combined approach to analysis and regulation of thermodynamic processes in the energy technology complex *J. Processes* **34** 1–32

[14] Helmberg G 1994 The Gibbs phenomenon for Fourier interpolation *J. Approx. Theory* **78** 41–63

[15] Wallace J C 2013 Change the referent? A meta-analytic investigation of direct and referent-shift consensus models for organizational climate *Journal of Management* **4** 838–861

[16] Bagis M and Karaguzel E S Longitudinal analysis on intellectual structure of human resources management *Theoretica foundations and research trends* **6** 796–814

[17] Rocha C and Narcizo C F 2019 Internet of management artifacts: internet of things architecture for business model renewal *International Journal of Innovation and Technology Management* **16** 8–9

[18] Bilbao-Ubillos and J Camino-Beldarrain V 2020 Industry 4.0, proximity constraints and new challenges for industrial policy *European Planning Studies* **1** 1–5

[19] Hipp A and Binz C 2019 Firm survival in complex value chains and global innovation systems: Evidence from solar photovoltaics *Research Policy* **49** 34–37

[20] Osintsev K V and Shishkov A N 2021 Increasing the energy efficiency of the industrial enterprise technological and mechanical equipment due to the use of converter steam *IOP Conference Series Materials Science and Engineering* **1064(1)** 012033

[21] Osintsev K V and Shishkov A N 2021 Using refrigeration machines and heat pumps in the cycle of oil preheating using electricity *IOP Conference Series Materials Science and Engineering* **1064(1)** 012031