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Digital Transformation in Agricultural Cluster Management: Interrelated Factors and Model Applicability

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The digital revolution is forcing a fundamental transformation of agricultural cluster management, challenging traditional structures and demanding new approaches for efficiency and competitiveness. The purpose of the study was to examine how digital technologies are reshaping cluster management and identified the dominant management forms under these conditions. The adoption of digital technologies requires a fundamental rethinking of the principles governing coordination and interactions among agro-cluster participants. Unlike previous studies, our analysis highlights the prevalence of hybrid transitional models in Russian agricultural clusters, demonstrating their unique adaptation path in the digital economy. Data collection involved expert surveys with cluster managers and focus groups, including representatives from various links in the production and distribution chains of 28 enterprises across five different clusters within the Agriculture and Fisheries sector. The data were processed using statistical methods to analyze performance indicators. Results show that digital platforms foster hybrid structures combining vertical integration and horizontal cooperation, with transitional hybrid models (42.3%) and traditional hierarchical models (37.4%) prevailing, while platform-based (15.8%) and ecosystem-based (4.5%) remain limited. Key barriers to digital transformation were identified: high implementation costs and a shortage of digital competencies. Therefore, the development of human capital and institutional transformation is essential to maximize the benefits of digitalization in agricultural clusters.

Keywords: Digitalization, business model, deterrence factors, success factors, human capital, agribusiness, ecosystem.

INTRODUCTION

The cluster-based approach, which relies on the territorial concentration of interrelated enterprises, serves as an organizational model for the development of the agro-industrial complex. It facilitates the establishment of stable production and technological linkages and the optimization of resource flows among participants in the agri-food value chain. The development of effective management models for agricultural clusters (Muhlinina, 2024) has gained particular relevance due to the need to enhance the competitiveness of the agro-industrial sector (Plotnikov *et al.*, 2024), ensure food security (Tleshpayeva *et al.*, 2025), and respond to the challenges posed by the digital transformation of the economy. The use of digital technologies in agriculture represents not only a process of technological modernization. Recent studies emphasize the role of digital tools such as GIS, IoT, and internet penetration in advancing precision farming, land management, and overall sectoral modernization (Tulyeyeva et al., 2024; Ilham *et al.*, 2025). At the same time, digitalization introduces new managerial, economic, and organizational methods that enhance production efficiency and sustainability, for example through improved monitoring and the application of composite indicators such as the Genuine Savings Index. Digital tools enable the real-time management of material and technical resources, as well as production processes, laying the groundwork for the advancement of precision farming and automated livestock management systems (Abdullayev *et al.*, 2024 ; Mukhametov *et al.*, 2024). The emergence of a new management paradigm for agricultural clusters under the influence of digital technologies is marked by a shift from traditional hierarchical structures to network-based models of interaction, grounded in the principles of the platform economy (Muyang *et al.*, 2023). Traditional management models of agricultural clusters reveal certain limitations in the context of the digital

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economy, including information asymmetry, elevated transaction costs, and insufficient integration among participants (Stelmashonok and Stelmashonok, 2021; Shamin *et al.*, 2022). Digital technologies directly address these weaknesses: digital platforms combat information asymmetry by providing real-time data and transparency across the value chain, while integrated information systems reduce transaction costs through automated coordination and streamlined logistics. Ecosystem-based solutions further strengthen integration by enabling continuous data exchange and collaborative decision-making among stakeholders. As a result, digital platforms and ecosystems play a transformative role in reshaping the organizational structures and operational models of the agro-industrial complex (Stelmashonok and Stelmashonok, 2021; Kotov *et al.*, 2022). While prior studies have described digitalization in agriculture broadly, they have not systematically examined how management models evolve within Russian agricultural clusters under these conditions. There is a lack of empirical evidence on which models dominate, how hybrid transitional forms emerge, and what barriers or success factors drive their adoption. This research directly addresses that gap by combining expert surveys and focus groups to analyze the applicability of different management models in the Russian context. In Russia, the development of the cluster-based approach in agriculture has remained one of the most pressing issues for over a decade. Several government documents and strategic development programs emphasize the creation of clusters as key drivers in shaping an innovative economy at the national level (Gasanov, 2024) and within individual regions (Abirov *et al.*, 2022). Special attention is also given to the implementation of platform-based solutions fostering technological advancement in the agricultural sector (Shogentsukova and Shogentsukov, 2020; Akhmetshin *et al.*, 2024).

Based on the research focus, we formulated two questions:

1. How do digital technologies reshape management models of agricultural clusters?
2. What factors act as barriers or enablers in the digital transformation of agricultural cluster management?

This study aims to identify the interrelation of factors influencing the applicability of modern management models in the practice of managing Russian agricultural clusters in the context of a digitalized economy.

***Concept of agricultural clusters and performance indicators in digital transformation*:** An agricultural cluster is defined as a geographically localized group of interconnected enterprises, including agricultural producers, processing facilities (Abdullayev *et al.*, 2023), suppliers of material and technical resources, logistics companies, and support institutions (Shamin *et al.*, 2022). This organizational form is characterized by the establishment of stable production and technological linkages and the creation of added value through the synergistic interaction of its participants.The effectiveness of agricultural cluster operations is measured through a system of key economic indicators, which have been systematized in studies on the digital transformation of the agro-industrial complex (World Bank, 2020; Shamin *et al.*, 2022; Patil *et al.*, 2023). In the context of evaluating the performance of agricultural clusters, the following indicators are emphasized: labor productivity of cluster participants, production profitability, optimization of operational costs, product quality and compliance with international standards, investment in research and development, export potential, speed of bringing innovative products to market, and energy efficiency of production processes (Degtyarev *et al.*, 2024).

Studies have documented the significant impact of digitalization processes on the development of agricultural clusters and the improvement of key performance indicators of their functioning (Stelmashonok and Stelmashonok, 2021; Chutcheva, 2024). Digital technologies offer opportunities for optimizing production processes, enhancing monitoring systems, and increasing the accuracy of planning and forecasting (Akhmetshin *et al.*, 2025). From a socio-technical systems perspective, these technologies do not simply automate processes but restructure the interaction between people, technologies, and organizations, requiring complementary changes in skills, workflows, and governance. They also enable the creation of integrated information systems that contribute to faster managerial decision-making. Studies show that digital solutions improve the efficiency of decision-making processes by streamlining data flows and strengthening the analytical capacity of managers in agricultural enterprises (Shogentsukova and Shogentsukov, 2020; Goncharov, 2024). In addition, integrated systems help reduce information asymmetry among cluster participants, optimize logistics, and improve coordination across the value chain, which is particularly important for enhancing competitiveness and sustainability in the agro-industrial sector (Vaganova *et al.*, 2020). The implementation of digital technologies enables cluster managers to comprehend the perspective of transaction cost economics. Electronic infrastructures curtail transactional expenditures since they diminish informational disparities and strengthen collaborative frameworks therefore additional dispersed and allied types of administration exist versus customary ordered systems. Uneven institutional backing plus regional discrepancies within digital infrastructure engender limitations. These limitations impact upon the rate and extent of cluster conversion inside the Russian environment. Based on an analysis of research on the digital transformation of the agro-industrial complex (Stelmashonok and Stelmashonok, 2021; Kurnosova *et al.*, 2021; Kotov *et al.*, 2022), we identified the following main types of management models (Table 1).

***Barriers and enablers of digitalization in agriculture*:** To systematize the barriers identified across prior studies, we classify them into four categories. Economic barriers primarily include the high implementation costs of digital

technologies and budgetary constraints that limit investment capacity (Kurnosova *et al.,* 2021; Kotov *et al.,* 2023). Technological barriers arise from underdeveloped digital infrastructure, interoperability issues between information systems, and insufficient availability of advanced platforms (Dutta *et al.,* 2023). Human capital barriers relate to low levels of digital literacy, shortages of skilled personnel, and organizational resistance to change (Shafazhinskaya *et al.,* 2024). Finally, institutional barriers stem from gaps in the regulatory framework, inconsistent policy support, and regional disparities in governance mechanisms (Trendov *et al.,* 2019; Vaganova *et al.,* 2020; Chutcheva, 2024). This taxonomy provides a structured lens for analyzing the restraining factors that shape the digital transformation of agricultural clusters in Russia (Shogentsukova and Shogentsukov, 2020).

The russian context: The digital transformation of agricultural clusters is marked by specific features arising from regional disparities in technological development, differences in investment capacity (Gayduk *et al.,* 2025), and uneven levels of digital infrastructure development (Shamin *et al.,* 2022; Shogentsukova and Shogentsukov, 2020). These disparities result in an uneven pace of cluster modernization: less developed areas often remain dependent upon basic automation tools, whereas more developed regions possessing strong investment flows can adopt cloud services, advanced monitoring systems, as well as platform-based solutions. Aggregations throughout Russia manifest varied levels of digital development. This disparity confounds the manner modern management models permeate throughout the nation.Government initiatives aimed at supporting the digitalization of the agro-industrial complex (Gayduk *et al.,* 2023a) provide an institutional framework for advancing modern cluster management models (Gayduk *et al.,* 2023b). However, the effectiveness of these programs varies considerably depending on regional governance quality, local infrastructure readiness, and the ability of enterprises to access financial and human resources. In many cases, policy measures remain declarative and are not matched with sufficient funding or practical mechanisms for implementation, which limits their real impact. Therefore, the successful digital transformation of agricultural clusters in Russia depends not only on state-level strategies but also on reducing regional disparities, ensuring equal access to infrastructure, and strengthening institutional mechanisms that support innovation adoption (Shogentsukova and Shogentsukov, 2020; Vaganova *et al.,* 2020).

The focus of this study is to determine the most promising models for managing agricultural clusters under Russian conditions and to identify the key factors influencing their development in the context of the digital transformation of the economy.

MATERIALS AND METHODS

***Design*:** To achieve the objective, we employed mixed-methods design, combining qualitative and quantitative approaches to capture both measurable patterns and deeper contextual insights, followed by statistical analysis methods.

The empirical research was conducted from March to November 2024 and consisted of two stages.

Stage 1. The identification of cluster management models, which were typologized based on the theoretical foundations outlined in the literature review. The models were classified into four categories: traditional hierarchical, transitional hybrid, platform-based, and ecosystem-based.

***Sampling*:** The selection of enterprises for the study was based on the official register of clusters in Russia (https://map.cluster.hse.ru/list), which includes five clusters specializing in Agriculture and Fisheries (general population). The sample consisted of 28 enterprises selected from among 117 member organizations of the identified clusters according to established inclusion criteria. The sample covered different types of enterprises along the agri-food value chain, including producers, processors, and logistics providers.

Inclusion criteria for the study are as follows:

- Primary business activity in agricultural production,
- Cluster membership for at least two years,

Table 1. Main types of management models.

Management model	Characteristics	Advantages	Challenges/Limitations
Traditional hierarchical	Centralized decision making, vertical communications	Clarity of management procedures, controllability	High transaction costs, information asymmetry, low adaptability to digital tools
Transitional hybrid	Partial decentralization, mixed communications	Flexible adaptability, combination of stability and innovativeness	Complex coordination, risk of institutional inertia, uneven digital uptake
Platform-based	Distributed decision making, horizontal integration	Responsiveness, reduced transaction costs	Dependence on digital infrastructure, interoperability issues, limited diffusion in Russian clusters
Ecosystem-based	Network coordination, algorithmic management	Maximum adaptability, innovative potential	High implementation costs, lack of digital competencies, regulatory uncertainty

- A minimum of 15 employees,
- Willingness to participate in the study.

Table 2. Characteristics of the study sample.

Cluster	Total number of cluster participants	Number of enterprises in the sample	Share of enterprises in the sample
Bryansk	18	4	22.2
Novgorod	27	6	22.2
Astrakhan	12	3	25.0
Rostov	20	5	25.0
Vologda	40	10	25.0

Stage 2 involved data collection through structured interviews with managers of 28 enterprises participating in five agricultural clusters and the organization of focus groups.

Primary data were obtained through structured interviews with enterprise managers, each lasting between 45 and 60 minutes. In addition, internal organizational documents were analyzed, and focus group sessions were conducted.

The digitalization of the enterprises was assessed using expert evaluations based on a five-point scale across the following parameters: the degree of automation in production processes, the use of management information systems, the application of digital technologies for monitoring and control (Protasova, 2024), and participation in electronic platforms for partner interaction. The final score was calculated as the arithmetic mean of the values across these parameters.

***Data collection instruments*:** A structured questionnaire was developed for the expert survey, comprising 18 questions grouped into two main thematic blocks: (1) characteristics of the cluster's management model; (2) the level of digital technology adoption. In addition, the questionnaire included items for the preliminary assessment of barriers and success factors related to digital transformation, using standardized rating scales.

Focus groups were conducted according to a semi-structured script that covered two primary thematic areas: (3) changes in organizational structure and decision-making processes; (4) an in-depth analysis of the barriers and success factors of digital transformation. The methodological design of the focus groups ensured a systematic discussion of transformational processes in inter-organizational interactions, information flows, and coordination mechanisms influenced by digitalization.

Differentiating the research tools by their functional purpose allowed for the optimization of empirical data collection procedures. Structured interviews provided standardized quantitative indicators, while focus groups enabled an in-depth qualitative analysis of organizational transformation processes and a more detailed exploration of the factors initially identified during the survey phase.

***Data analysis*:** A comprehensive set of statistical methods was applied to analyze the quantitative data. Factor analysis was conducted using the principal component method with varimax rotation to verify the theoretically grounded typology of management models and to identify the structure of key transformation factors. Descriptive statistics were used to characterize the distribution of variables and to differentiate digitalization indicators across the studied entities.

The qualitative data obtained from the focus groups were processed using thematic content analysis, employing a two-level coding system (open and axial coding). To ensure the validity of the results, data triangulation from multiple sources was applied. Data analysis was carried out using SPSS Statistics 28.0 for quantitative methods and NVivo 14 for qualitative analysis.

RESULTS

The application of principal component factor analysis to the structured interview data confirmed the theoretically grounded four-factor structure of management models.

The factor structure accounts for 79.2% of the total data variance, indicating a high level of validity for the theoretical typology of agricultural cluster management models (Table 3).

The analysis of expert evaluations regarding the level of digitalization in management processes showed significant variation among the studied clusters (Table 4).

The data analysis reveals a significant differentiation in the digitalization of management processes across the studied clusters. The technological capabilities of the clusters show a direct correlation with the degree of digital transformation achieved. Thematic analysis of focus group data enabled the systematization of the main directions of organizational transformation under the influence of digitalization (Table 5).

Table 3. Results of factor analysis and distribution of management models.

Factor/control model	Eigen value	Percentage of explained variance	Cumulative percentage	Share in sample (%)
Factor 1: Traditional hierarchical	3.42	28.5	28.5	37.4
Factor 2: Transitional hybrid	2.87	23.9	52.4	42.3
Factor 3: Platform-based	1.98	16.5	68.9	15.8
Factor 4: Ecosystem-based	1.23	10.3	79.2	4.5

Table 4. Characteristics of digitalization in management processes across the studied clusters.

Cluster	Average digitalization index	Standard deviation	Prevailing technologies
Bryansk	2.8	0.6	Basic accounting automation, local information systems
Novgorod	3.4	0.8	Cloud services, monitoring systems
Astrakhan	3.1	0.7	IoT elements, mobile applications
Rostov	4.2	0.9	Digital platforms, data analytics
Vologda	3.6	0.8	Monitoring systems, cloud technologies

Table 5. Characteristics of organizational changes by management model type.

Management model	Nature of changes	Transformation directions	Degree of intensity of changes
Traditional hierarchical	Minimal adjustments	Automation of reporting, introduction of basic information systems	Low
Transitional hybrid	Partial restructuring	Creation of working groups, introduction of matrix elements	Moderate
Platform-based	Substantial transformation	Formation of horizontal links, creation of competence centers	High
Ecosystem-based	Radical reorganization	Transition to network structures, introduction of self-organizing teams	Very high

Table 6. Barriers and factors for successful digital transformation.

Category of factors	Main barriers	Average expert assessment of significance (1-10)	Key success factors	Frequency of mentioning in focus groups (%)
Technological	Infrastructural constraints	7.9	Quality of IT infrastructure	83.2
	Incompatibility of information systems	7.6	System integration	78.4
Economic	High implementation costs	8.7	Investment accessibility	87.3
	Budgetary constraints	7.1	Government support	76.5
Human	Lack of digital competencies	8.4	Human capital development	92.1
	Resistance to change	7.3	Retraining programs	84.2
Managerial	Lack of digital strategy	6.7	Strategic approach	76.8
	Organizational rigidity	6.4	Integrated approach	82.1

Organizational transformation processes are directly dependent on the level of digitalization within management practices and show an evolutionary transition from traditional to modern organizational forms (Katkov *et al.,* 2023).The systematization of expert survey results and thematic analysis of focus group discussions enabled the identification of key determinants of transformation processes (Table 6).

The identified structure of restraining factors (barriers) and success factors (drivers) highlights the dominant role of economic and human aspects in the digital transformation of management models within agricultural clusters.

DISCUSSION

The results provide a systematic understanding of the transformation processes occurring in the management models of agricultural clusters under the influence of digital technologies and allow for a comparison with the findings of previous research in this field.

***Typology of management models and their prevalence*:** The factor analysis confirmed the empirical validity of the theoretically grounded four-factor structure of management models, with a high level of explained variance (79.2%). The distribution of management models showed a predominance of traditional hierarchical structures (37.4%) and transitional hybrid models (42.3%), while the adoption of modern platform-based (15.8%) and ecosystem-based (4.5%) organizational forms remains limited. These findings are consistent with those of (Stelmashonok and Stelmashonok, 2021), which also highlight the emergence of new organizational models driven by digitalization but point to their limited diffusion within the Russian agro-industrial sector.

The identified inertia in transformation processes reflected by the fact that 79.7% of clusters continue to operate under traditional or transitional management models indicates a slower pace of digital transformation than projected in the forecasts presented in (Kotov *et al.,* 2022). This dynamic may

be attributed to the presence of significant barriers, as identified in this study. An analysis of the characteristics of digitalization within management processes has revealed substantial variation among the clusters studied, with scores ranging from 2.8 to 4.2 on a five-point scale. The established direct correlation between the level of digitalization and the technological capacity of the clusters supports the argument that the digital transformation of management processes follows a staged trajectory. These ideas are consistent with the conclusions of (Patil *et al.,* 2023), which demonstrate the positive impact of digital technologies on the operational efficiency of agricultural enterprises. The identified variation in technological capabilities, ranging from basic automation of accounting processes to integrated analytical systems, aligns with the concept of digital maturity presented in (Shogentsukova and Shogentsukov, 2020). However, the limited sample size does not allow for the establishment of cause-and-effect relationships between the level of digitalization and the economic performance of clusters. Addressing this limitation will require longitudinal studies supported by an expanded methodological framework. Thematic analysis of the focus group data revealed an evolutionary pattern of organizational transformation, ranging from minimal adjustments within traditional hierarchical models to radical restructuring within ecosystem-based frameworks. The established direct correlation between the degree of digitalization and the intensity of organizational change supports theoretical propositions about the transformative impact of digital technologies on organizational structures (Stelmashonok and Stelmashonok, 2021). The identified directions of transformation, including the development of horizontal linkages, the establishment of competence centers, and the implementation of self-organizing teams, align with the observations made in (Kurnosova *et al.,* 2021) regarding the shift toward network-based organizational forms driven by digitalization. An analysis of the factor structure influencing changes in management models has revealed the dominant role of economic and human resource determinants within the system of constraints to digital transformation. According to the expert evaluations, the highest significance scores among the barriers were recorded for financial costs associated with the implementation of digital technologies (8.7 out of 10) and the shortage of digital competencies among organizational staff (8.4 out of 10). These findings are consistent with the conclusions of (Chutcheva, 2024; Afanasev and Karpova, 2024), which identify financial constraints and a lack of digital competencies as critical barriers to the digital transformation of the agricultural sector. The technological barriers shown in this study, including infrastructural limitations (7.9 points) and incompatibility of information systems (7.6 points), align with the observations of (Dutta *et al.,* 2023) regarding interoperability issues in the context of agricultural digitalization. Among the success factors, the most frequently mentioned in focus groups were the development of human capital (92.1%), access to investment resources (87.3%), and workforce retraining programs (84.2%). This structure of success factors corresponds to the World Bank's recommendations (World Bank, 2020) on the critical importance of investing in human capital for the sustainable development of the agricultural sector (Karshalova *et al.,* 2025).

***Practical significance of the results*:** Our results have considerable practical relevance for various stakeholder groups. For managers of agricultural clusters, the proposed typology of management models can serve as a methodological foundation for developing digital transformation strategies that consider the identified success factors and barriers. For government authorities, the identified economic and technological barriers (Butakova, 2024) highlight the need to design targeted support programs for digitalization and establish an institutional environment conducive to the adoption of modern management models. This aligns with the recommendations of Shamin *et al.* (2022) regarding the critical role of government support in stimulating the development of rural areas.

***Limitations*:** It is important to acknowledge the methodological limitations of our study. While the selected sample of five clusters ensures representativeness in terms of specialization and geographical coverage, it may not fully capture the regional specifics of digital transformation across all constituent entities of the Russian Federation. The methodology based on expert evaluations and qualitative analysis provides a comprehensive understanding of the transformational processes. However, it does not allow for the verification of cause-and-effect relationships between digitalization and the economic performance of clusters. Establishing such relationships would require longitudinal studies utilizing structural modeling methods.

***Directions for future research*:** Promising directions for further research in this field include an in-depth examination of the mechanisms underlying the transition from traditional to platform-based and ecosystem-based management models; the development of differentiated digital transformation strategies tailored to various types of agricultural clusters; and the creation of methodological tools for assessing the digital maturity of agro-industrial clusters. Further investigation is also needed to analyze the long-term effects of implementing modern management models on the economic performance of agricultural clusters, using panel data and quasi-experimental analysis methods.

***Conclusion*:** The study revealed the multifaceted nature of the transformation of agricultural cluster management models under the influence of digital technologies. A clear differentiation of management models by degree of digitalization was established, along with a correlation between the level of digitalization and key economic

performance indicators. In addition, we systematized the main barriers and success factors associated with digital transformation.

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***Ethical statement*:** Permission was obtained from all participants prior to data collection. Participants were informed about the purpose of the study and were clearly advised that their responses would be used only in a generalized form, without reference to individual names or organizations.

***Availability of data*:** The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

***Consent to participate*:** All participants provided informed consent prior to inclusion in the study.

***Informed consent*:** Participants were informed about the purpose of the research, the voluntary nature of participation, and their right to withdraw at any time.

***Consent for publication*:** All authors approved the final version of the manuscript and consent to its publication.

***SDGs addressed*:** Zero Hunger; Decent Work and Economic Growth; Industry, Innovation and Infrastructure.

***Policy referred*:** The study refers to policy frameworks supporting digitalization of the agro-industrial complex in Russia, including national and regional programs for cluster development and digital transformation.

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