

ANNOTATION

**to the dissertation work of Kulzhambekova Barno Shakirovna on the topic:
«Formation and development of digital ecosystems of industrial enterprises of
Kazakhstan», presented for the Doctor of Philosophy degree (PhD)
on the educational program «8D04101 – Economics»**

Relevance of the research topic. The vector of global economic development demonstrates a rapid shift towards Industry 4.0 formats, whereby digital transformation ceases to be an optional tool of modernization and becomes a key determinant of the industrial sector's efficiency. In this context, digital ecosystems are not merely the result of technological progress but a complex organizational and technological construct that ensures the integration of business processes with the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), cloud solutions, and integrated information platforms.

The simultaneous development of end-to-end digital technologies generates a qualitatively new range of opportunities for industrial enterprises: the automation and robotization of production circuits are complemented by the implementation of intelligent systems for monitoring equipment operation, predictive analysis of product demand, as well as algorithm-based management of logistics and supply chains using artificial intelligence mechanisms.

At the current stage of forming digital ecosystems – digital spaces built around one or several platforms and integrating a wide range of services as well as diverse physical and legal participants – the role of professional competencies and technological preparedness in their effective management is increasing. Such ecosystems meet various participant needs within a single integrated process, which makes the issues of managing them particularly relevant. The key characteristics of this stage include the virtualization of processes and systems, digitalization, and the enhancement of cybersecurity frameworks.

In connection with the consistent implementation of key state documents – the “Kazakhstan-2050 Strategy: A New Political Course of an Established State” and the Concept for the Development of the Manufacturing Industry of the Republic of Kazakhstan for 2023-2029 – the issues of formation and evolution of digital ecosystems in industrial enterprises acquire particular research significance. For Kazakhstan, which is focused on deep technological modernization and the long-term strengthening of industrial potential, the development of such ecosystems is not merely an element of digital transformation but a fundamental condition for enhancing the resilience, innovative productivity, and global competitiveness of the national industrial sector. It is especially important for Kazakhstan's enterprises to continue the targeted improvement of digital ecosystems and to increase the efficiency of interaction between their actors and various external information and communication systems.

Effective functioning of digital ecosystems is possible only with a well-developed digital infrastructure, professionally trained personnel, and integration with external platforms. However, successful implementation of these tasks requires a comprehensive analysis of the current level of digitalization in industrial enterprises, an assessment of their readiness for transformation, and the development of

methodological approaches to the formation of digital ecosystems.

Leading global companies such as Siemens, General Electric, and Bosch are actively implementing and utilizing digital ecosystems to optimize their operations. Despite the global relevance of the topic, the issue of digital ecosystems remains insufficiently studied in the Kazakhstani scientific and practical context. Industrial enterprises in Kazakhstan need to explore and adapt international best practices in forming digital ecosystems, taking into account national specifics, which will accelerate their digital transformation processes.

Therefore, the relevance of this research is determined by the need for theoretical and practical understanding of the formation and development of digital ecosystems for Kazakhstan's industrial sector. This will not only help identify and eliminate existing barriers but also create conditions for sustainable economic growth, enhanced competitiveness, and deeper integration of Kazakhstan into global digital economy value chains.

Degree of scientific development of the research problem. The issues of forming and developing digital ecosystems are actively explored in global academic literature through the works of foreign scholars such as A. Tansley, M. G. Jacobides, J. Moore, M. Iansiti, R. Levien, and others, who examine the concepts of the ecosystem approach, strategies for developing digital platforms, and the impact of digitalization on enterprise productivity and sustainable development.

Digital platforms in industrial production, which have become the foundation for the creation of industrial digital ecosystems and have transformed traditional modes of production, are covered in the works of researchers such as Yu.V. Orlovskaya, T. Ignatova, C. Cennamo, Z. Mi, D. Koffman, H. Lin, Yu. H. Akbar, and E.D. Platonova. The formation and development of ecosystems across various industrial sectors have been studied by a large group of scholars, including M. Darking, E. Whitley, B.K. Che, M. Subramaniam, P.K. Senyo, S.Suuronen, A.V. Babkin, L.V. Tashenova, N. Bakhtadze, and A. Suleykin.

The structure, characteristics, and prerequisites for the formation of digital ecosystems in industrial enterprises, as well as various ecosystem strategies and the roles of companies within these ecosystems, represent a key research direction in recent works by V. Parida, R.D. Serdyukov, O.E. Kalenov, A. Kamalaldin, and others. Within the platform-based approach, scholars such as M.G. Jacobides, H. Dong, L.M. Camarinha-Matos, H. Afsarmanesh, A. Cozzolino, M.A. Komissarova, and I.N. Storozhuk highlight the role of ecosystems in shaping organizational activity.

Despite the broad range of research dedicated to the conceptual content, typology, and models of digital ecosystems, the practical component of this topic remains insufficiently developed, especially in the context of emerging economies, including Kazakhstan. The scientific field is still characterized by inadequate attention to the issues of transferring foreign practices to domestic conditions, adapting existing digital platforms and technological solutions to the country's industrial specifics, as well as developing effective organizational and technological mechanisms for interaction among actors within digital ecosystems. In this context, the dissertation research aims to fill this gap by providing a comprehensive analysis of the processes of formation of digital ecosystems in Kazakhstan's industrial enterprises and integrating the theoretical

framework with applied solutions necessary for addressing practical tasks of digital transformation.

The purpose of the scientific research is to develop theoretical and methodological foundations and applied tools for the formation and development of digital ecosystems of industrial enterprises in Kazakhstan, as well as to assess their impact on industrial production efficiency and the competitiveness of the national economy.

To achieve this purpose, the following **research objectives** are set:

- to reveal the essence and specific features of digital ecosystems of industrial enterprises;
- to conduct a scientometric analysis of research in this field and identify the key directions of the scientific discourse;
- to study international experience in forming digital ecosystems and identify best practices for adaptation in Kazakhstan;
- to develop a methodological approach to assessing the digital readiness of industrial enterprises and an algorithm for calculating an integral indicator;
- to examine the current state of digitalization in Kazakhstan’s industrial sector and identify regional disparities;
- to perform a cluster analysis of regions by level of digital maturity;
- to test the proposed methodology using the example of selected enterprises;
- to introduce the indicator of “digital output” and apply methods of economic and mathematical analysis (including SFA) to assess digital productivity;
- to propose an organizational and technological mechanism for interaction between digital ecosystems and external ICT resources;
- to identify promising directions for the development of digital ecosystems and formulate practical recommendations.

The object of the dissertation research is the digital ecosystems functioning within industrial enterprises.

The subject of the dissertation research comprises the conceptual and methodological principles and the organizational-economic mechanisms that ensure the formation and development of digital ecosystems of industrial enterprises. Within its scope, the study examines tools for assessing the level of digital readiness, approaches to determining operational efficiency, and directions for implementing and integrating digital technologies into production and managerial processes.

Theoretical and methodological significance of the research lies in enriching the scientific categorical apparatus through the introduction of the author’s interpretation of the term “digital ecosystem of an industrial enterprise”. A significant outcome is also the developed methodology for diagnosing the level of digital readiness of Kazakhstan’s industrial enterprises for the implementation and adaptation of digital ecosystems. The study proposes a conceptual scheme of a digital ecosystem, interpreted as an interconnected set of technologies, processes, and forms of interaction aimed at ensuring innovative and efficient management of an industrial organization in a digital environment. In addition, an organizational and technological mechanism has been developed that defines the principles and tools for interaction between the actors and objects of digital ecosystems of industrial enterprises with external services

and information and communication resources.

A comprehensive set of general scientific methods was employed in the study. Methods of analysis and synthesis were used to clarify definitions and reveal the essence of the category “digital ecosystem”. The structural-functional approach and the method of generalization allowed for identifying the key characteristics of digital ecosystems and developing a conceptual understanding of a “digital ecosystem of an industrial enterprise.” Additionally, the use of the case study method provided an opportunity to examine practical examples of implementing digital solutions in industrial enterprises and to identify the features of their adaptation. In addition, specialized methods were employed, including the content analysis of scientific publications, the scientometric analysis method (using the Web of Science database), and the graphical frame-building method in VOSviewer, which allowed for identifying research trends and directions in the development of digital ecosystems. The following methods were also applied: the expert assessment method, used to determine the weighting of criteria and subcriteria in the development of the methodology for assessing the digital readiness of industrial enterprises; cluster analysis, which allowed for grouping regions of Kazakhstan based on the level of digital maturity of industrial enterprises and identifying the heterogeneity of their digital development; the stochastic frontier analysis (SFA) method, which provided an assessment of technical efficiency and identified unrealized digital potential of regions; and graphical modeling and data visualization methods, applied in constructing dendrograms, heat maps, as well as in developing schemes of the organizational and technological mechanism for interaction between subjects and objects of digital ecosystems.

The empirical basis of the research was formed using a combination of statistical materials, the results of the author's investigations, and information from official sources, which ensured the comprehensiveness, reliability, and representativeness of the analysis.

A significant role was played by the official data of the Committee on Statistics of the Ministry of National Economy of the Republic of Kazakhstan, as well as materials from open sources and corporate reports of industrial companies. These data made it possible to assess the dynamics of digital transformation across regions, track the scale of ICT investments, identify changes in workforce structure, analyze production indicators, and evaluate the degree of enterprises' involvement in innovation processes.

To compare national trends with global practices, international statistical indices were used, including the Global Innovation Index (GII), the Digital Economy and Society Index (DESI), and the Human Development Index (HDI). Their use allowed the identification of Kazakhstan's position in international rankings and the determination of priority areas requiring development.

Another important component of the empirical basis consisted of data from the Web of Science international publication database, which were subjected to scientometric analysis using the VOSviewer software package. This made it possible to identify key research trends and confirm the growing academic interest in the development of digital ecosystems in industry.

An essential addition was the set of practical examples (case studies) of the implementation of digital technologies at industrial enterprises in Kazakhstan, which

enabled the testing of the proposed methodology for assessing digital readiness. This material demonstrated the applicability of the developed algorithm in real-world practice and confirmed its relevance for managerial decision-making.

For conducting cluster analysis and stochastic frontier analysis (SFA), regional statistical data were used. This allowed the identification of heterogeneity in digital development and the determination of potential reserves for improving digital productivity in the industrial sector.

The scientific novelty of the results of the dissertation research is determined by the theoretical and applied results obtained, which expand existing knowledge about the essence, structure, and development prospects of digital ecosystems of industrial enterprises in the context of Kazakhstan's digital economic transformation. Within the framework of the conducted research, the novelty is reflected in the following provisions:

- the essence of the digital ecosystem of an industrial enterprise has been revealed as an integrative form of interaction among technologies, data, services, and actors, with the digital platform as its core element. An original interpretation of this concept has been formulated, reflecting the specific features of industrial production and emphasizing the adaptive nature of interactions within the ecosystem;

- the theoretical and methodological foundations for studying digital ecosystems have been systematized and structured, and their key components have been identified: infrastructure, technological, operational, human-resource, and customer institutional elements. A conceptual model has been proposed, illustrating the structure, interconnections, and functioning of these components;

- based on a scientometric analysis of international publications indexed in the Web of Science database, major research trends have been identified, and the dynamics of scholarly interest in the topic of digital ecosystems in industry have been documented. For the first time, attention is drawn to the fact that the industrial sector is increasingly recognized by the global scientific community as a priority domain of digitalization;

- a methodology for assessing the digital readiness of industrial enterprises for the implementation and adaptation of digital ecosystems has been developed, including an algorithm for calculating an integral indicator supported by a system of criteria and sub-criteria. The proposed methodology is notable for its reproducibility, universality, and ability to be adapted to various industrial sectors;

- a cluster analysis of Kazakhstan's regions based on the level of industrial digitalization has been conducted, revealing the heterogeneity of digital development and differentiating leading regions from lagging ones. This provides new insights into the territorial specifics of digital transformation;

- for the first time, an integral indicator called “digital output” has been introduced, enabling a quantitative assessment of the impact of digitalization on industrial production outcomes and allowing for the evaluation of digital productivity at both enterprise and regional levels;

- stochastic Frontier Analysis (SFA) has been applied to assess the technical efficiency of Kazakhstan's industrial sector, making it possible for the first time to

quantify the scale of unrealized digital potential;

– an organizational and technological mechanism has been developed for interaction between industrial digital ecosystems and external ICT resources. The mechanism focuses on process alignment, data integration, and enhancement of the reliability of digital system functioning;

– strategically significant vectors for the development of digital ecosystems have been identified, including the accelerated adoption of artificial intelligence, digital twins, blockchain, big data analytics, and cloud solutions, as well as their alignment with sustainable development principles and ESG practices.

– applied recommendations have been formulated to enhance the digital maturity of industrial enterprises in Kazakhstan, develop human capital, and scale platform-based solutions across the national industrial landscape.

The main provisions of the dissertation research submitted for defense.

1. The theoretical and methodological justification of the essence of digital ecosystems of industrial enterprises, which presents the author's interpretation of this phenomenon as the integration of technologies, data, services, and actors within a unified interaction space. The key features distinguishing the ecosystem approach from traditional forms of business organization are identified.

2. A conceptual model of the digital ecosystem of an industrial enterprise, defining its structural components (infrastructure, technological, operational, human-resource, and client's blocks) and revealing the mechanisms of their interconnection, as well as their influence on the stability and performance of the ecosystem.

3. A methodological approach to assessing the level of digital readiness of industrial enterprises, which includes an algorithm for calculating an integral indicator based on a system of criteria and sub-criteria. This approach ensures comparability, reproducibility, and practical applicability of diagnostic results.

4. The results of the empirical analysis of the digitalization level of Kazakhstan's industrial sector, confirming the heterogeneity of regional development and identifying differences in the levels of digital maturity of industrial enterprises through cluster analysis.

5. The "digital output" indicator, introduced into scientific circulation as a tool for quantitatively assessing the contribution of digitalization to industrial production outcomes, as well as the results of the stochastic frontier analysis (SFA), which revealed a significant reserve for growth in the digital productivity of Kazakhstan's regions.

6. An organizational and technological mechanism for interaction between industrial digital ecosystems and external information and communication resources, ensuring integration and standardization of data flows, strengthening the resilience of digital infrastructure, and enabling the scaling of ecosystem solutions.

7. Promising directions for the development of digital ecosystems of industrial enterprises in Kazakhstan, including the adoption of artificial intelligence, digital twins, blockchain technologies, big data analytics, and cloud solutions, as well as the integration of sustainability principles and ESG practices.

8. Practical recommendations aimed at increasing the digital maturity of industrial enterprises, developing human capital, and creating conditions for large-scale

implementation of platform-based solutions focused on building competitive digital ecosystems in the national industrial sector.

Practical significance of the dissertation research lies in the fact that its results can be directly applied by industrial enterprises as well as by public authorities in addressing the challenges of digital transformation. The developed methodological approach to assessing digital readiness provides the possibility for a comprehensive diagnosis of enterprise conditions and enables the identification of key directions for their modernization. The use of the integral digital maturity indicator allows companies to formulate more substantiated strategic decisions and facilitates comparative analysis across regions and sectors for determining priorities for government support. An important practical outcome is the introduction of the “digital output” indicator, which makes it possible to quantitatively assess the contribution of digitalization to industrial production results. Its application expands the toolkit available both for corporate management and for national statistical systems, forming a basis for monitoring the effectiveness of digital transformation. The developed organizational and technological mechanism for interaction between digital ecosystems and external ICT resources can be applied in building corporate digital platforms and integration solutions, ensuring the stability and coherence of ecosystem processes.

The practical value of the research is also reflected in the recommendations aimed at increasing digital maturity and developing human capital, which are particularly relevant for enterprises experiencing a shortage of digital competencies. The findings can be used in educational settings for developing academic courses on digital economics, innovation management, and strategic management, contributing to the training of a new generation of specialists. Thus, the dissertation forms an applied foundation that enables not only the evaluation of the current state of digitalization but also the identification of strategic development priorities for industrial enterprises in the context of emerging digital ecosystems.

Reliability and validity of the research results are ensured by the integrity of the chosen methodological framework, the comprehensive use of theoretical and empirical sources, and the application of proven analytical tools. The robustness of the conclusions is supported by the combination of qualitative and quantitative methods, which made it possible to examine the research problem from multiple perspectives and ensure the representativeness of the obtained data. The study is grounded in official statistical data from the Committee on Statistics of the Ministry of National Economy of the Republic of Kazakhstan, international databases such as Web of Science, and global indices (HDI, GII, DESI). The use of diverse data sources minimized the risks of systematic error and ensured the accuracy of the analysis.

The application of modern economic and mathematical methods – cluster analysis and stochastic frontier analysis (SFA) – implemented in the RStudio and Python environments, contributed to a high degree of objectivity and reproducibility of the study. Practical testing of the proposed digital readiness assessment methodology on selected industrial enterprises confirmed its applicability and universality. Furthermore, the results of the research are aligned with international approaches to evaluating digital maturity and ecosystem development, which strengthens their validity and allows for the assertion of a high level of reliability of the conclusions.

Taken together, these factors ensure the scientific and practical feasibility of the obtained results and confirm their suitability for further research and managerial application.

Approbation of the research results. The results of the dissertation research have been widely presented in scientific publications: a total of 13 works have been published, including 4 articles in journals recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; 1 article in a journal included in the list of the Higher Attestation Commission of the Russian Federation; 3 articles in journals indexed in the Scopus database, including one article published in a first-quartile (Q1) journal with a 90th percentile; 4 articles in the proceedings of international conferences; and 1 article in conference proceedings also indexed in Scopus. In addition, a scientific monograph has been published in co-authorship, which underscores the integrity and completeness of the presented scientific results.

The findings obtained in the dissertation have been presented at international conferences, where they received high recognition from the academic community. Among these events are: the 7th International Scientific Conference on Innovations in the Digital Economy: SPBPU IDE-2025 (St. Petersburg, 2025); “Fundamental and Applied Research in Management, Economics and Trade” (St. Petersburg, 2023); “Advance Marketing Search” (Karaganda, 2022); “Challenges in Science of Nowadays” (USA, 2023); “Recent Scientific Investigation” (Norway, 2024); as well as other international scientific venues.

Approbation of the key results of the dissertation was carried out within the framework of the implementation of the grant-funded scientific research project of the Ministry of Science and Higher Education of the Republic of Kazakhstan, No. AR19680223, titled “Development of an organizational and managerial mechanism for adapting digital ecosystems into the business processes of industrial enterprises of Kazakhstan under conditions of customization and digital transformation of production.” Certain proposals of the author have been applied in the activities of the Institute for Digital Economy Research (Certificate dated September 21, 2025), as well as in the practical work of LLP “Bömer Armatura” (Certificate dated September 19, 2025), which confirms their applied value and their potential for adaptation to real industrial enterprise environments.

Structure and volume of the thesis. The structure of the thesis includes an introduction, three chapters, a conclusion and a list of references with 238 sources and three appendices. The total volume of the study is 257 pages, the text is illustrated with 68 figures and supplemented with 38 tables.

A description of the doctoral student’s contribution to the preparation of each publication.

1. Theoretical and practical approach to the essential characteristics and structure of digital ecosystems of industrial enterprises // *Economic Annals-XXI*. – 2023. – №205(9-10). – P. 14-33. Doctoral candidate’s contribution – 65%.

2. Organizational and technological mechanism of interaction of subjects and objects of digital ecosystems of industrial enterprises with third-party information and communication resources and services // *Economic Annals-XXI*. – 2024. – №209(5-

6). – P. 15-28. Doctoral candidate's contribution – 62%.

3. A Methodology for Assessing Digital Readiness of Industrial Enterprises for Ecosystem Adaptation: Evidence from Kazakhstan's Sustainable Industrial Transformation // Sustainability. – 2025. – №17(9763). – P. 1-53. Doctoral candidate's contribution – 60%.

4. Key aspects of digital transformation of logistics companies in Kazakhstan Bulletin of the Karaganda university. Economy series. – 2022. – №3(107). – P. 96-103. Doctoral candidate's contribution – 63%.

5. Characteristics of the use of digital twins by industrial enterprises: the experience of foreign countries and Kazakhstan // Bulletin of the Karaganda university. Economy series. – 2023. – №2(110). – P. 111-122. Doctoral candidate's contribution – 65%.

6. Study of the features of the implementation of digital ecosystems by foreign industrial enterprises: the experience of the Russian Federation // Herald of the Kazakh University of Economics, Finance and International Trade. – 2023. – №3(52). – P. 326-335. Doctoral candidate's contribution – 60%.

7. Digital transformation of economy: the experience of Estonia and Denmark // Herald of the Kazakh University of Economics, Finance and International Trade. – 2024. – №3(56). – P. 185-195. Doctoral candidate's contribution – 62%.

8. Применение цифровых двойников в производственных процессах // Advance Marketing Search: международная научно-практ. конференция, приуроченная к 50-летию кафедры маркетинга. – Караганда, 2022. – С. 94-98. Doctoral candidate's contribution – 65%.

9. Industry 4.0: digitalization and robotization of industrial enterprises of Kazakhstan // Challenges in science of nowadays: Proceedings of the 12th International Scientific and Practical Conference. – Washington, 2023. – P. 18-26. Doctoral candidate's contribution – 65%.

10. Digitalization trends: the use of digital twins by industrial enterprises in Kazakhstan // Recent Scientific Investigation: Proceedings of the 7th International Scientific and Practical Conference. – Oslo, 2024. – P. 8-17. Doctoral candidate's contribution – 65%.

11. Анализ бизнес-моделей промышленных предприятий Казахстана в разрезе основных видов деятельности в условиях современного экономического развития и цифровой трансформации // Вестник академии знаний. – 2023. – №5(58). – С. 515-525. Doctoral candidate's contribution – 62%.

12. International experience of adaptation and application of digital ecosystems by industrial enterprises and clusters // BIO Web of conferences. – 2024. – V.145, 04048. – P. 1-14. Doctoral candidate's contribution – 60%.

13. Особенности использования цифровых фабрик на промышленных предприятиях: опыт Казахстана // Фундаментальные и прикладные исследования в области управления, экономики и торговли: сборник трудов Всероссийской научно-практ. и учебно-методич. конференции. – Санкт-Петербург, 2023. – С. 136-145. Doctoral candidate's contribution – 65%.

14. Формирование и развитие цифровых экосистем промышленных предприятий Казахстана: организационно-управленческий аспект адаптации к

кастомизированной цифровой трансформации // - Караганда: изд-во НАО «Карагандинский университет им. академика Е.А. Букетова», 2025. – 297 с. Doctoral candidate's contribution – 35%.

The first chapter, “Theoretical and methodological foundations for the formation of digital ecosystems of industrial enterprises,” examines methodological approaches and conceptual frameworks related to the formation and development of digital ecosystems of industrial enterprises in the context of the transition to Industry 4.0 and the digital economy. The author systematizes approaches to defining the concepts of “digital platform” and “digital ecosystem,” identifies their distinctive features and interrelationships, and demonstrates the role of digital ecosystems in enhancing the efficiency and sustainability of the industrial sector.

An original definition of the digital ecosystem of an industrial enterprise is formulated as an integrated, self-organizing system that brings together digital technologies, platform solutions, intelligent devices, and interaction participants to optimize production processes, foster innovation, and create additional value.

Given the absence of unified approaches among researchers regarding the nature, structure, and characteristics of digital ecosystems in general and particularly with respect to their adaptation in industrial production the dissertation conducts a scientometric analysis of publications indexed in the Web of Science database using the VOSviewer software. The analysis identifies key research directions in the digitalization of industry, including the implementation of artificial intelligence, Big Data, blockchain technologies, and platform-based business models. The results confirm a shift in the scientific discourse from the study of digital platforms toward the examination of ecosystem-based models of industrial interaction.

The author further systematizes various classification approaches to digital ecosystems and provides a detailed description of the types, models, and structural components of digital business ecosystems of industrial enterprises. An overview of international experience in the formation of digital ecosystems in leading economies such as the United States, Germany, China, Japan, as well as Denmark, Estonia, France, and Russia allowed the identification of effective mechanisms for interaction between government, business, and academia in the context of industrial digital transformation.

A comparative analysis of foreign methodologies for assessing digital maturity (McKinsey, KPMG, PwC, Forrester, MIT Center for Digital Business, among others) was performed. It revealed that existing models typically focus on specific aspects of digitalization (either technological or managerial) and fail to capture the systemic nature of ecosystem interactions. As a result, the dissertation substantiates the need to transition to integrated systems for assessing and managing digital ecosystems. In this regard, the author develops a proprietary methodology for assessing the digital readiness of industrial enterprises for the implementation of digital ecosystems. This methodology encompasses strategic, technological, organizational, human-resource, and infrastructural parameters of digital development and enables comparable quantitative assessments. It includes a system of criteria and sub-criteria, an algorithm for calculating an integral indicator, and a scale for interpreting the obtained results, ensuring the possibility of conducting comparable quantitative assessments.

Thus, the first chapter establishes the theoretical and methodological foundation

for the subsequent parts of the study, creating a coherent link between theoretical principles, analytical tools, and practical mechanisms for the formation and development of digital ecosystems in Kazakhstan's industrial sector.

The second chapter, "Analysis of the formation and functioning of digital ecosystems of industrial enterprises in Kazakhstan" provides a comprehensive assessment of the current state of digital transformation in the country's industrial sector, aimed at identifying trends, patterns, and structural characteristics of the formation of digital ecosystems within industrial enterprises.

Using statistical data and the author's calculations, the chapter characterizes the current state of industrial digitalization and identifies sectoral and regional differences in digital maturity. The analysis reveals that digital transformation is progressing unevenly: the greatest advances have been made by enterprises in the manufacturing sector and large corporations, whereas small and medium-sized enterprises show a low level of digital activity.

A regional analysis demonstrates significant asymmetry in digital development. The Kostanay, Karaganda, Aktobe, and Ulytau regions have emerged as leaders, while several territories continue to display low digitalization indicators. Through cluster analysis conducted in RStudio and Python based on a set of indicators reflecting digital transformation, innovation activity, investment levels, and digital infrastructure development the regions of Kazakhstan were grouped into three clusters representing different levels of digital maturity: cluster I – includes the cities of Astana and Almaty, which have the highest innovation and digital development indicators; cluster II – represents the Atyrau region, distinguished by high investment activity and a strong level of industrial digitalization; cluster III – unites the majority of regions, which are in the stage of gradual formation of digital ecosystems.

The results of the cluster analysis confirm structural heterogeneity in the country's digital development and provide the basis for a typology of regions according to the level of digital maturity in industry.

Based on a comparative analysis of business models of leading enterprises ("Kazakhmys Holding" LLP, "Qarmet" JSC, "NAC Kazatomprom" JSC, and others), key directions for the implementation of digital platforms and ecosystem-based solutions were identified.

To demonstrate the applicability of the methodology for assessing the digital readiness of industrial enterprises for the implementation and adaptation of digital ecosystems, pilot testing was carried out using the example of two enterprises: "Bömer Armatura" LLP and the "Kazakhmys" Group, which differ in scale and production characteristics. This approach confirms the potential of the proposed instrument both for medium-sized companies and large industrial structures. The calculated integral readiness indicators amounted to 0.8005 and 0.8026, respectively, which allows both enterprises to be classified as having a high potential for digital transformation. These results show that the key components of digitalization have already been integrated into their management and production systems. Despite differences in organizational structures and resource capacities, both enterprises demonstrate a strong commitment to strategic planning, infrastructure modernization, workforce development, and the implementation of digital tools in managerial practices. At the same time, differences

between certain blocks suggest that the “Kazakhmys” Group is characterized by the scale and systematic nature of digital initiatives, while “Bömer Armatura” LLP demonstrates flexibility and adaptability.

Particular attention is given to the “digital output” indicator, introduced into scientific circulation for the first time, which reflects the contribution of digitalization to production outcomes. Its use in combination with Stochastic Frontier Analysis (SFA) made it possible to identify, for the first time, the level of digital productivity and to determine reserves for improving the efficiency of Kazakhstan’s industrial sector.

It is important to note that “digital output” is not an official statistical indicator, but is introduced as an analytical instrument enabling an integral assessment of the impact of digitalization on industrial production. This is especially relevant given that digital transformation is increasingly viewed as a key factor in improving productivity and enhancing the competitiveness of the economy. The indicator is calculated using the following formula:

$$Y_i^{dig} = \text{manuf_output}_i \times \frac{\text{digital_tech_use_share}_i}{100},$$

where Y_i^{dig} – digital output in region i ;

manuf_output_i – the volume of the manufacturing industry (in billion tenge);

$\text{digital_tech_use_share}_i$ – the share of manufacturing enterprises using digital technologies in region i .

The results of the Stochastic Frontier Analysis (SFA) confirmed the presence of significant interregional heterogeneity in the level of digital technology adoption and the degree of realization of digital potential. The leading regions include the Kostanay, Almaty, Akmola, Karaganda, and Pavlodar regions, where the technical efficiency (TE) coefficient exceeds 70%, reaching its maximum value of 99.6% in the Kostanay region. These territories are characterized by a minimal “gap to the frontier” (from 0.4% to 29.7%), which indicates a high degree of realized digital output potential.

In contrast, the regions at the lower end of the ranking include the Zhetysu, North Kazakhstan, Mangystau, Atyrau, and West Kazakhstan regions, where TE values do not exceed 15%. The minimum value was recorded in the Zhetysu region (4.9%), corresponding to an unrealized reserve exceeding 95%. This indicates that industrial performance in these regions is still driven predominantly by traditional technologies, while the opportunities of digitalization remain extremely underutilized.

The results of this asymmetry demonstrate that several regions require targeted measures aimed at overcoming organizational and human-resource constraints, as well as improving the quality and strategic orientation of digital investments. Taken together, the calculated technical efficiency (TE) coefficients form an empirical basis for identifying priority regions and designing targeted public policy instruments to accelerate the digital transformation of industry.

The results of chapter two formed the empirical foundation of the dissertation, providing justification for the necessity of transitioning Kazakhstan’s industrial sector to an ecosystem-based model of digital interaction and laying the groundwork for the

development of the conceptual model of the digital ecosystem and the organizational and technological mechanism for the functioning of digital ecosystems, presented in chapter three.

In chapter three, “Prospects for the development of digital ecosystems of industrial enterprises in Kazakhstan” the author proposes an original conceptual model of the digital ecosystem of an industrial enterprise, which includes five interconnected structural blocks: infrastructure block, providing the technological and communication foundation; technological block, comprising digital platforms, ICT tools, and data processing systems; operational block, reflecting the digitalization of production processes, the integration of equipment, the use of industrial IoT solutions, monitoring and management systems; human-resource block, aimed at developing digital competencies; client-side block, providing interaction with consumers, personalization of services, use of digital communication channels and involvement of end users in the enterprise ecosystem. The model reveals the internal logic of interaction among these structural components, thereby forming a theoretical basis for analyzing the sustainability, adaptability, and efficiency of digital management systems within industrial enterprises.

A particularly significant contribution is the author’s concept of the organizational and technological mechanism for the interaction of digital ecosystem actors with external ICT resources, defined as a system of interconnected components of a digital ecosystem, based on a set of applied tools, management principles and methods, as well as organizational and technological levers that regulate collaboration with external ICT resources and services, ensuring effective cooperation between the subjects and objects of the digital ecosystem of industrial enterprises.

The developed organizational and technological mechanism plays a key role in ensuring coordination and synergy among all participants and resources of the digital ecosystem. Based on the active introduction and adaptation of advanced ICT resources and services, it enables industrial enterprises to:

- optimize production and management processes through the use of advanced ICT solutions that automate data exchange and coordinate actions with partners;
- ensure sustainable development and scalability by integrating technologies that facilitate seamless adaptation of the ecosystem to new partners, markets, and changes in the business environment;
- reduce IT costs through the usage of cloud technologies and external services;
- enhance cybersecurity by implementing multi-level protection systems and integrating with external security services;
- increase customer satisfaction regarding products and services;
- achieve strategic development goals of the industrial enterprise.

Based on the results of chapter three, the author develops practical recommendations aimed at advancing digital ecosystems of industrial enterprises in Kazakhstan and ensuring successful adaptation to Industry 4.0 technologies. The necessity of establishing a system of continuous personnel training, developing digital competencies, and preparing the workforce for conditions of automation and robotization is substantiated. Particular attention is given to transforming organizational structures, introducing flexible forms of employment, and integrating

digital management tools.

The dissertation recommends the active adoption of Industrial Internet of Things (IIoT) technologies, big data analytics, digital twins, digital factories, and industrial robots to enhance productivity, precision, and stability of production processes.

The importance of developing a national technological infrastructure, including data centers and cybersecurity systems aligned with international standards, is emphasized.

Strengthening cooperation between industrial enterprises and universities, research institutions, and innovative startups in artificial intelligence, machine learning, blockchain, and robotics is proposed, as well as expanding international collaboration to exchange best digitalization practices.

In conclusion, it should be noted that the successful formation of digital ecosystems requires a strategic approach that includes ecosystem design, partnership strategies, and the integration of innovative Industry 4.0 technologies. In the Republic of Kazakhstan, the formation of such ecosystems must rely on international cooperation, the development of domestic science, increased investment in R&D, and the attraction of technological investments, which will ultimately enhance competitiveness and ensure sustainable growth of the national industrial sector.

Dissertation candidate



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