Digitalization of Innovation Networks: Theoretical and Empirical Issues

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***Abstract* – The article is devoted to the analysis of digital aspects of innovation policy, in particular, based on the use of international ratings, the determination of the features of the construction of the digital component of innovation networks, and the deepening of scientific and methodological approaches to the digital support of innovation processes. Data from the Global Innovation Index and the ICT Development Index were used to assess the impact of digitalization on the development of innovation processes. Based on the results of the calculations, significant positive correlation estimates were obtained with the key components of the innovation system and the level of cluster development. Marketing, communication, infrastructural, international dimensions of digitalization of innovative processes are defined. It has been proven that the growing availability of ICT makes it necessary to rethink many processes in the innovation field in a timely manner. On the basis of world experience, the role of universities is argued, which should assume a significant share of responsibility for the formation of a new technological order by improving the quality of research and implementing their results in the real economy within the framework of S2B-B2S (Science-to-Business – Business-to-Science).**

Keywords - innovation network, project, tech transfer, ICT

I. INTRODUCTION

The development of digital technologies, the formation of a digital economy and society is one of the main megatrends of today. According to Pricewaterhouse Coopers experts [1] by 2030 digitalization and smart automation will provide 14% of global GDP growth, which is equivalent to approximately US$15 trillion. at current prices. In the conditions of Industry 4.0, issues of digital transformation concern not only service services, but also a wide range of processes, including those based on the cooperation of various economic agents. Digitization significantly helps the participants of innovation networks to develop new products based on the results of scientific research, conduct the necessary testing or measurements, model and develop prototypes, improve existing technology, ensure communication on the implementation of scientific and technical solutions, technology transfer and innovation marketing.

Digital transformation as a result of the application of information and communication technologies (ICT) is expressed in the creation of unique business models, a qualitative change in the perception of a product or service by customers, a fundamental acceleration and simplification of the operational activities of the participants of the innovation network. It should be taken into account that in modern conditions, the company's success is determined not only by the use of unique technologies, but also by the digitalization strategy. Companies that apply ICT without a previously formed strategy solve only tactical tasks. It is important to remember that ICT is only a means, not an end. In the case of an innovation system, the goal is always a unique product (service) created using such technologies.

The report of Industrie 4.0 Working Group [2] notes that innovative development strategies in the context of Industry 4.0 should be based on a new approach to production as a conglomerate of large industrialists, experts, economists and scientists. With the inclusion of customers and contractors in a single open organizational structure, the boundaries between interacting enterprises become quite blurred and dynamic, and the success of some is a necessary condition for the success of others. At the same time, partners are increasingly taking an active part in the development of new products, services, and even business strategies.

Therefore, the question arises as to the design of appropriate innovative networks that will ensure the synergy of interaction, and the creation of their effective infrastructure support. Given the comprehensive impact and large-scale prospects of digitalization processes, the task of working out the conceptual issues of managing digital transformations in the context of innovative trends becomes especially relevant, in particular for developing countries. Both the macro level of digitization of innovative processes and the specifics of using ICT innovations for the transformation of business models based on a network mechanism require attention.

The article is devoted to the analysis of digital aspects of innovation policy, in particular, based on the use of international ratings, the determination of the features of the construction of the digital component of innovation networks, and the deepening of scientific and methodological approaches to the digital support of

innovation processes.

II. Review of Recent Studies

Transformations of business models become a critical factor of innovation, but are poorly studied from a theoretical and practical point of view. Scientists note the lack of tools that allow studying business models in combination with the complex relationship between their change and market results. The study introduces a comprehensive framework for these issues, recognizing the relevance of tools for the practical implementation of value integrated management of critical components of the business model. The changes caused by Industry 4.0, in particular its digital capabilities, lead to the transformation of production, economic and social systems [3; 4; 5]. One of the main trends in the development of companies is information and network interaction, through which they learn to manage information, exchange knowledge, form and develop the necessary competencies.

The report of UNCTAD [6] notes that digitalization has given rise to a new wave of innovation that will have profound consequences for humanity, changing the relationship between society, the state and business, and will also lead to the transformation of the structure of society and the economy. The pace of economic growth, labor productivity and the development of human potential will be increasingly determined by the level of integration into the digital economy. Indeed, digitalization not only creates new business opportunities, but also create a number of problems and risks.

The study [7] examines the case of the Chinese software and services industry. It is shown that it has become a driving factor of economic growth and leading innovations. The study of the structure of an intercity network based on patent cooperation between cities helped to understand the positioning of cities from the point of view of innovations related to service software (software service-related innovation).

The issue of the development of innovation platforms is very relevant in the framework of the ever-increasing cooperation in the creation of innovation value (co-creation), which makes it possible to introduce new products (services), increasing the efficiency of business processes and creating new value for customers [8]. Article [9] illustrates the fact that increasing economic attention to knowledge concerns the development of knowledge-intensive business services (KIBS).

The work [10] emphasizes the importance of the level of self-sufficiency and recognition of the status of research structures. In addition, the study demonstrates that the mass of necessary knowledge is constantly increasing due to constant technological progress, due to which opening through cooperation (open up through cooperation) is necessary for the company. In these conditions, digital transformation is considered as a factor of access to information and new opportunities that can improve the technological potential of the firm. The articles [11] investigated the essence of the ICT category, its relationship with such concepts as the Internet of Things, the Industrial Internet of Things, cyber-physical systems, identified and analyzed the factors that determine the implementation of information and digital technologies within the framework of the concept smart manufacturing. Digitization enables the creation of administrative solutions, data protection systems, storage of research data and educational resources, as well as opportunities for better collaboration [12; 13].

The study [14] analyzed the impact of digitalization on the formation of advantages of new technologies and access to them, as well as determined their impact on organizational transformations in terms of cooperation and competitive advantages. In this context, for a better understanding of "agent-agent" interactions (actor-to-actor interactions), elements of systems thinking, determining the degree of openness of systems and the concept of managing communication flows are used.

Research results [15] empirically support the hypothesis that ICT acts as a catalyst for innovation. However, the impact of digitalization on innovation activity depends on the type of ICT innovations, as well as the scale of their application. In particular, a strong positive relationship was found between ICT integrating administrative and industry software and innovative productivity. The identified pattern does not apply to market-oriented ICT, such as e-commerce or customer relationship management software.

One of the options for ICT innovations from the point of view of machine-to-machine and human-to-machine interaction problems in the innovation space is presented in the research [16]. Among the main issues covered are problems of agents, their interaction with each other.

Another direction is considered in the works [17], which refers to Big Data as a new paradigm that provides a lot of data and opportunities for improving or expanding application networks research and decision support for digital applications including business, science and technology. For the purposes of our research, the following conclusions are quite useful:

- cloud computing and big data make it possible to make scientific discoveries and applications;
- cloud computing provides solutions for Big Data;
- big data, spatio-temporal thinking and various fields of applications contribute to the advancement of cloud computing and related technologies with new requirements;
- the internal spatio-temporal principles of Big Data and geospatial sciences serve as a source of finding technical and theoretical solutions for optimizing big data processing;
- the open availability of Big Data and processing capabilities create social problems of geospatial significance;
- there is a transformation of innovation waves.

Therefore, it can be concluded that digitalization promotes the exchange of accumulated knowledge and experience, which provides opportunities for various stakeholders to make more informed decisions in the framework of innovation management and marketing. ICT support for the vide range participation tasks of agents in innovation networks [18; 19; 20; 21; 22], is an important factor in the formation of modern innovation systems on

at different levels.

III. Empirical Estimations

Data from the Global Innovation Index and the ICT Development Index were used to assess the impact of digitalization on the development of innovation processes. In the table 1 analyzed the impact of digitalization on the relevant components of the innovation system and provided a quantitative assessment of such impact based on the data of 2019. Based on the results of the calculations, significant positive correlation estimates were obtained with the key components of the innovation system and the level of cluster development (column 4 of Table 1). Also the dependence of the Global Competitiveness Index and the ICT Development Index (the correlation coefficient between them is 0.92) confirms the significant impact of digitization on the global competitive positions of countries. The dependence of the innovation capability indicator of the economy (Innovation capability) and the ICT development index (the correlation coefficient between them is 0.772) confirms the positive impact of digitalization on the innovation potential of countries.

IV. Trends Analytics and Policy Recomendations

In the conditions of a change in the paradigm of innovative development and increased competition for ideas, it is difficult for developers and owners of new technologies to organize the marketing of their developments and find partners to create joint productions. From the point of view of developing countries, this aspect is a challenge, since the problems of technology transfer, in particular international, are largely due to the lack of a modern technology transfer infrastructure, which would include specialized centers and information systems for the exchange of technological requests and proposals.

Another aspect of the need for accelerated digitization is related to the creation of conditions for overcoming technological dependence on other countries and the development of one's own innovation ecosystem. In other words, we are talking about the formation and satisfaction of the domestic technology transfer market.

It should be noted that the growing availability of ICT makes it necessary to rethink many processes in the innovation field in a timely manner. A wave of disruptive innovation is not only sweeping through technology markets, but also disrupting a number of established and forecasted industries. In particular, in this situation, the role of universities is important, as they must take on a significant share of responsibility for the formation of a new technological order. It is advisable to simultaneously pay attention to both improving the quality of research and the issue of implementing their results in real economy.

Analysis of the experience of leading foreign universities shows that each university has its own innovation ecosystem. We can mention Stanford, LU Innovation System, Cambridge Enterprise, KU Leuven Research & Development, Polytechnic School of Lausanne (EPFL) IV-VP TTO. Each of these university innovation ecosystems has an important ICT component, which has an individual character depending on the types of projects, industry specifics, type of partnerships, etc.

TABLE I. Correlations between ICN and Innovation Indicators

Indicators of the Global Innovation Index	Components of the indicator	Impact of ICT	Correlation with the ICT Development Index
Knowledge creation	Patenting (national and international), publications, citations	Access to international patent and scientometric databases, scientific networks, research and forecasts, reports and overviews of trends in industries and technological areas. Informational support for the marketing of ideas, covering all activities aimed at forming a network that will further implement the relevant innovative project(s).	0,667
Knowledge impact	GDP growth, new business creation, software acquisition, high-tech business, ISO 9001 certification	Informational support for the marketing of innovations as an activity of enterprises for the creation of innovative products that allow ensuring the high-quality satisfaction of needs or the formation of a new market.	0,564
Knowledge diffusion	Fees for intellectual property rights, high-tech export, export of ICT services, foreign direct investment	Technology services and databases, information systems for the exchange of technological requests and proposals, venture project databases, news archives and company databases. Informational support for market activities of organizations aimed at achieving the key goals of technology transfer.	0,603
State of cluster development	Geographical concentration of firms, suppliers, manufacturers related products and services, as well as specialized institutions	The use of digital infrastructure for the formation of interregional and international clusters, in particular virtual clusters, as well as the management of innovative interaction processes.	0,630

Noting this successful experience, it is necessary to especially emphasize the educational function of science within the framework of S2B-B2S (Science-to-Business – Business-to-Science) networks, which is important not only for education, but also for science itself, since in the process of teaching knowledge their development and approval often takes place. Thus, a comprehensive approach to the creation of digital innovation ecosystems requires the study of both institutions and participants, networks of their interaction, the specifics of environment, resources, technologies, etc.

Innovation networks in modern conditions are considered as an effective mechanism of mutually beneficial interaction between research organizations, startups and innovative businesses interested in the practical implementation of scientific and technical developments and projects both on the territory of their state and at the international level. One of the leading

international tools for assessing the spread of the network approach with the use of ICT is the Network Readiness Index (NRI). The inset presents the positioning of Ukraine according to the results of a recently updated global study of network readiness [23].

We propose to consider the role of ICT in the development of innovation networks based on a combination of the following modern approaches to the development of innovations:

1) multidisciplinary engineering analysis (PLM Ural, 2019), which involves parametric optimization and statistical analysis, sensitivity analysis, topological optimization through high-performance computing.

2) system design methodology, which consists in the formation of an interdependent balanced system "goals – projects – measures – resources – result", which is determined on the basis of an iterative procedure. It combines the results of analysis and modeling of the targeted application of complex technical systems and their components with the use of simulation models - design models of means and functioning of the system as a whole and its components (their external and internal relationships), innovation models based on targeted complex programs with taking into account limitations on resources (levels and rates of financing, production and experimental capacities, etc.).

3) the methodology of parallel engineering (concurrent engineering or C-engineering), which provides information interaction of remote participants of the innovation network during the design of complex technical systems. At the same time, the exchange of information takes place at all stages of design, which makes it possible to organize reduction of deadlines due to the parallel solution of project tasks. The methodology of parallel engineering involves the implementation of development and design processes simultaneously with the modeling of manufacturing and operation processes.

It is assumed that the C-engineering project team must solve various design tasks in parallel to ensure the achievement of project goals. Each such task is associated with the implementation of certain important requirements, which in turn affect a number of other requirements. It is these relationships that are often not taken into account in the traditional (sequential) approach to the development of new products.

The basis of the application of C-engineering for the development of innovative networks is based on conceptual provisions about the possibility of a hierarchical representation of object systems, as well as the possibility of a hierarchical representation of the goals and tasks of the designed complex system.

The hierarchical basis of these methods is based on the concept of distributed access to product information. It includes a set of data that is created and used during its life cycle and includes information about its configuration, characteristics and properties, organizational information (a description of the processes associated with changing product data, necessary resources, etc.), information about testing and all product data from the moment of design to sales and subsequent service.

An important element of the digitalization of innovation processes is the infrastructural provision of information exchange between various network participants (customers, researchers, developers, manufacturers, operators, etc.). When transferring project data from one ICT component to another, universal formats and appropriate organizational efforts are required. Under the conditions of a low information culture, these processes are accompanied by a large expenditure of labor and time, in particular, for repeated coding, which leads to numerous errors and loss of time.

The tasks of creating a new product, especially in high-tech areas, are characterized by high requirements for reliability and are complex in nature. Therefore, the cost of making changes to the project increases exponentially until the final stages of the project. In the case of using parallel engineering, many problems that may arise at later stages of the life cycle are detected and solved already at the appropriate design stage.

Studies of the development of high-tech areas and technology support networks have shown that the main trend in the development of the modern innovation system is a new type of infrastructure – virtual, which functions in the virtual world of the Internet, complements the existing ecosystem, overcoming its limitations and providing radically new opportunities. A number of projects were developed for informational support of such entrepreneurship. As part of the National Industrial Information Infrastructure Protocol (NIIIP) project in the USA, the development of open software protocols for industry was carried out, which allowed manufacturers and suppliers to interact effectively. In EU, a number of ESPRET (ESTimation and PRediction of Execution Time) projects have been developed to create an appropriate infrastructure for virtual entrepreneurship, in particular for small and medium-sized firms.

In the work [24], the system of joint design and production for virtual organizations CDMS (Collaborative design and manufacturing system) was investigated, the architecture of the agent for the implementation of such virtual organizations in CDMS was revealed, and an example of joint planning of several enterprises was presented. A vivid example of a virtual scientific organization is the program Partnerships for Advanced Computational Infrastructure (RASI), founded by the US National Science Foundation, which includes more than 50 institutes and thousands of scientists. This association is aimed at the development of technologies in the field of informatics for the general use of resources in the process of scientific research. On the basis of the above, a virtual innovation structure can be defined as an association of organizations participating in the innovation process, the key competencies of which form the innovation cycle, and the interaction is carried out in the virtual space on the basis of technical and semantic compatibility, and whose activities go beyond geographical boundaries and cover stages of development and promotion of innovative ideas. Virtual integration is aimed at openness and active exchange with the external environment within the paradigm of "open" innovations.

Virtual integration assumes a relationship of complete

information transparency between partners, maximum flexible interaction, which allows to optimize material flows and reduce costs. The functional environment is formed as necessary – the same entity can simultaneously be a participant in international innovation projects or their parts, through participation in active networks.

V. CONCLUSIONS

The practical value of the presented proposals should be considered in the context of the practical implementation of the recommendations of the analytical report of OECD [25], dedicated, in particular, to the development of DSIP (Digital science and innovation policy) initiatives in many countries. The report notes that digital platforms and solutions in the field of science and innovation policy increasingly connect different sources of information and use new technologies and applications for innovation analytics. For example, government structures can use DSIP systems for policy design, implementation, monitoring and evaluation, and financial and credit institutions for planning, coordination, monitoring and evaluation of their activities. As the volume of research and innovation data increases, DSIP systems will help determine ways to transform science and technology policy and provide public services.

The results of the study show that DSIP-systems can be presented in different versions in the context of national policies. Thus, the creation of DSIP-systems taking into account the specific nature of digital management in the field of scientific and innovation policy is an urgent task for the development of competitive national innovation systems.

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REFERENCES

[1] R. Geissbauer, E. Lubben, S. Schrauf, and S. Pillsbury, "Digital Champions. How industry leaders build integrated operations ecosystems to deliver end-to-end customer solutions," PricewaterhouseCoopers, 2018.

[2] Industrie 4.0 Working Group, "Recommendations for implementing the strategic initiative Industrie 4.0," 2013.

[3] R. Morrar, H. Arman, and S. Mousa, "The Fourth Industrial Revolution (Industry 4.0): a social innovation perspective," Technology Innovation Management Review, № 7 (11), pp. 12-20, 2017.

[4] L. Melnyk, O. Kubatko, I. Dehtyarova, O. Matsenko, and O. Rozhko, "The effect of industrial revolutions on the transformation of social and economic systems," Problems and Perspectives in Management, Vol. 17 (4), pp. 381-391, 2019.

[5] L. Melnyk, O. Kubatko, V. Piven, K. Klymenko, and L. Rybina, "Digital and economic transformations for sustainable development promotion: A case of OECD countries," Environmental Economics, 12(1), pp. 140–148, 2022.

[6] UNCTAD, "Information Economy Report 2017: Digitalization, Trade and Development," United Nations publication. Sales No. E.17.II.D.8. New York, Geneva, 2017.

[7] L. Zhang, Zh. Cao, G. Chen, and Zh. Wang, "A study of China's inter-city networks for innovation cooperation within software and service firms," Eurasian Geography and Economics, Vol. 60, Iss. 5, pp. 582-615, 2019.

[8] A. Aine, T. Björkroth, and A. Koponen, "Horizontal information exchange and innovation in the platform economy – a need to rethink?" European Competition Journal, Vol. 15. Iss. 2-3, pp. 347-371, 2019.

[9] R. Huggins, "The growth of knowledge-intensive business services: innovation, markets and networks," European Planning Studies, Vol. 19. Iss. 8, pp. 1459-1480, 2011.

[10] J.P. François, F. Favre, and S. Negassi, "Competence and organization: two drivers of innovation," Economics of Innovation and New Technology, Vol. 11. Iss. 3, pp. 249-270, 2002.

[11] M. Ghobakhloo, "Determinants of information and digital technology implementation for smart manufacturing," International Journal of Production Research, 2019.

[12] J. Khalid, B.R. Ram, M. Soliman, A.J. Ali, M. Khaleel, and M.S. Islam, "Promising digital university: a pivotal need for higher education transformation," International Journal of Management in Education, Vol. 12, № 3, pp. 264-275, 2018.

[13] V. Omelyanenko, O. Prokopenko, O. Kudrina, M. Biloshkurskyi, and O. Omelyanenko, "Digital Component of Innovation Landscapes: Con of Sustainable Development at the Local Level," 2021 44th International Convention on Information, Communication and Electronic Technology, MIPRO 2021 – Proceedings, pp. 1324–1328, 2021.

[14] B. Quattrociocchi, M. Calabrese, X. Hysa, and E. Wankowicz, "Technology and innovation for networks," Journal of Organisational Transformation & Social Change, Vol. 14, Iss. 1. pp. 4-20, 2017.

[15] P. Santoleri, "Diversity and intensity of information and communication technologies use and product innovation: evidence from Chilean micro-data," Economics of Innovation and New Technology, Vol. 24. Iss. 6, pp. 550-568, 2015.

[16] R. Kattel, V. Lember, and P. Tõnurist, "Collaborative innovation and human-machine networks," Public Management Review, 2019.

[17] Ch. Yang, Q. Huang, Zh. Li, K. Liu, and F. Hu, "Big Data and cloud computing: innovation opportunities and challenges," International Journal of Digital Earth, Vol 10. Iss. 1, pp. 13-53, 2017.

[18] T. Tirto, Y. Ossik, and V. Omelyanenko, "ICT support for Industry 4.0 innovation networks: education and technology transfer issues," Lecture Notes in Mechanical Engineering. Springer, Cham, 2020.

[19] V. Omelyanenko, and D. Volodin, "Nanoinformatics application framework for R&D and industrial analisys," 2017 IEEE 7th International Conference Nanomaterials: Application & Properties (NAP), Odessa, UKraine, pp. 01NNPT03-1-01NNPT03-4, 2017.

[20] Y. Robul, I. Lytovchenko, L. Tchon, O. Khanova, and O. Omelianenko, "Digital marketing tools in the value chain of an innovative product," International Journal of Scientific and Technology Research, 9(4), pp. 158–165, 2020.

[21] V. Omelyanenko, "Analysis of strategycal aspects of technology transfer in metallurgy," Metallurgical and Mining Industry, No.12, pp. 394–397, 2015.

[22] V. Omelyanenko, "Preconditions analysis of using of technological package concept for development strategy of space metallurgy," Metallurgical and Mining Industry, No. 8, pp. 508–511, 2015.

[23] Portulans Institute, "The Network Readiness Index 2019: Towards a Future-Ready Society," S. Dutta & B. Lanvin (Eds). Washington D.C., USA, 2019

[24] W. Shen, "Virtual organization in collaborative design and manufacturing system," Proceedings of the 4th International Workshop on CSCW in Design. Compiegne. pp. 177-184, 1999.

[25] OECD, "OECD Science, Technology and Innovation Outlook 2018: Adapting to Technological and Societal Disruption," OECD Publishing, Paris. 2018.