Nexo Revista Científica
Vol. 34, No. 04, pp. 1343-1354/Septiembre 2021

ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v34i04.12669

Assessment and analysis of innovative activities of high-tech industries in the digital economy based on the cluster approach

Evaluación y analisis de actividades innovadoras de industrias de alta tecnología en la economía digital con base en el enfoque cluster

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(recibido/received: 02-mayo-2021; aceptado/accepted: 25-julio-2021)

ABSTRACT

The purpose of the study is to analyze the level of digitalization of the economies of various countries of the world by dividing them into groups according to the level of digitalization of the economy through cluster analysis methods using a model for the development of high-tech industries. The following analysis methods were used during the analysis: a comparative approach in the analysis of approaches to the concept of "digital economy" by Russian and foreign authors, statistical analysis of indicators of the development of the digital economy of Russia and the countries of the world, cluster analysis in dividing the countries of the world into separate groups according to the level of development of the digital economy, morphological analysis and synthesis in the formation of the optimal structure of high-tech industries to increase the level of digitalization of the Russian economy, tabular and graphical methods to illustrate the results obtained. The result of the study is the formation of clusters of countries in the world according to the level of development of the digital economy and the application of a model for the development of high-tech industries in the country to increase the level of digitalization.

Keywords: Digitalization; Digital economy; High-tech enterprises; Model; Development.

RESUMEN

El propósito del estudio es analizar el nivel de digitalización de las economías de varios países del mundo dividiéndolas en grupos según el nivel de digitalización de la economía a través de métodos de análisis de clústeres utilizando un modelo para el desarrollo de industrias de alta tecnología. . Se utilizaron los siguientes métodos de análisis durante el análisis: un enfoque comparativo en el análisis de enfoques al concepto de "economía digital" por autores rusos y extranjeros, análisis estadístico de indicadores del desarrollo de la economía digital de Rusia y los países del mundo, análisis de clústeres en la división de los países del mundo en grupos separados según el nivel de desarrollo de la economía digital, análisis morfológico y síntesis en la formación de la estructura óptima de las industrias de alta tecnología para aumentar el nivel de digitalización de Rusia economía, métodos tabulares y gráficos para ilustrar los resultados obtenidos. El resultado del estudio es la formación de clusters de países en el mundo de acuerdo

al nivel de desarrollo de la economía digital y la aplicación de un modelo para el desarrollo de industrias de alta tecnología en el país para incrementar el nivel de digitalización.

Palabras claves: Digitalización; Economía digital; Empresas de alta tecnología; Modelo; Desarrollo.

1. INTRODUCTION

Many high-tech enterprises in Russia operate in the conditions of crises of the external and internal environment, which make it difficult to achieve strategic goals. However, the innovative activity of high-tech enterprises determines the development of the entire domestic economy, which ultimately should contribute to achieving the goal of Strategy-2030 to change the paradigm of the functioning of industry, shifting the focus towards innovative digital, import-substituting with the subsequent integration of Russia as an equal partner in the global economy.

The concept of the digital economy is relatively new and relevant since it has been the driving force of economic development in recent decades (Batkovskii, Kravchuk and Styazhkin, 2019; Vorontsovskii, 2020; Bukh and Heeks, 2017).

The fundamental formulation of the term "digital economy" is the interpretation given at the World Bank Group seminar (2016), which considers the digital economy as a paradigm of accelerated economic development based on digital technologies (The World Bank, 2016).

Special attention is paid to the functioning of enterprises within the digital economy and the implementation of the industrial policy of high-tech industries. The study Industrial Policy: Peculiarities of Understanding and Dependence on the Level of Implementation (Trofimov, Kostyrev, Strelkova, Makusheva and Trofimova, 2020) emphasizes the multiplicity of approaches to understanding this term both within the country and abroad, which leads to different goals and implementation tools.

According to M. Knickrehm, B. Berthon, and P. Daugherty (2016), the digital economy is a part of total production created by digital resources (including digital skills, digital equipment, and intermediate digital goods and services used in production).

As M. Rouse (2016) notes, the digital economy is a worldwide network of economic activities based on the use of digital technologies.

Digital technologies, in turn, create new opportunities in the digital environment and organizations can apply the digital system in production activities (Frolov, Klimova and Trofimov, 2020; Pavlinov *et al*., 2019; Heeks, 2016, 2017). The degree of impact of any technology is considered as a result of its spread and depth of implementation.

Globally, the digital economy is a systemically organized structure of interaction between economic entities in the information environment and involves the transition from the third industrial revolution (that is, the transition from analog electronic and mechanical devices to digital technologies) to the fourth industrial revolution.

V.V. Ivanov, G.G. Malinetskii (2017) defined the digital economy as a virtual reality (complementing the traditional one), the actions of which relate to production, distribution, or exchange.

R.V. Meshcheryakov interprets the concept of "digital economy" from two different positions: the first is "classical", based on the use of digital technologies in various fields, and the second is the production with the use of digital technologies (Urmantseva, 2017).

D. Tapscott (1995) was one of the first to use the term "digital economy" in his book "Digital Economy: Promise and Danger in the Age of Network Intelligence" and J. Negroponte (1995), who emphasized the special importance of information and digital technologies in society and the economy. Until now, within the framework of the digital economy, the main attention has been paid to the technical aspects of its manifestation, economic problems are considered by a few authors. Special attention should be paid to the functioning of high-tech industries in the digital economy.

It is considered in the world economy that high-tech industries include those industries where the high-tech index is more than 4.5-5.0%. The share of financial expenditures on research and development in high-tech industries is from 2.5 to 5%, in medium-tech industries – 1-2.5%, and in low-tech industries less than 1%.
The high-tech sector of the economy is characterized primarily by the use of high-tech technologies implemented based on the achievements of science and technology in the field of creating new technologies and products, in the process of organizing production at the enterprise in the provision of services of production and non-production nature. Recent trends in the development of the economy indicate that there are more high-tech services on the world markets. They are considered as the basis for the innovative development of the economy.

Currently, high-tech enterprises determine the quality of development of the national economy and stimulate innovative activity in the industry in countries with a developed digital economy.

2. METHODS

The following analysis methods were used during the analysis: a comparative approach in the analysis of approaches to the concept of "digital economy" by Russian and foreign authors, statistical analysis of indicators of the development of the digital economy of Russia and the countries of the world, cluster analysis in dividing the countries of the world into separate groups according to the level of development of the digital economy, morphological analysis and synthesis in the formation of the optimal structure of high-tech industries to increase the level of digitalization of the Russian economy, tabular and graphical methods to illustrate the results obtained.

3. RESULTS

By the level of development of information and computer technologies (ICT), Russia is confidently rated as a representative of the group of developed countries that lag behind the group of leaders. The estimate of the level of the gross value of the ICT sector in the GDP of the Russian Federation for 2020 is 2.6%, which is 1 percentage point less than the data for 2019, which are in the debt of the group of leaders.

We will analyze the gross domestic research and advanced development expenditures in various countries of the world, according to PPP in US dollars. This data is presented in Table 1.

The table shows that the largest domestic research and advanced development expenditures are carried out in the United States in the amount of 657.4 billion US dollars, while in all the countries represented, the corresponding expenditures are increasing, for example, in the United States for the period 2015-2019, they increased by 132.6%, in China by 143.6%. In Russia, research and advanced development expenditures amounted to 44.5 US Dollars Billion in 2019 and increased by 114.6% in 2015-2019. Therewith, spending in the USA is 14.77 times more than spending in Russia, and it is 11.8 times higher in China.

Table 1. Gross domestic research and advanced development expenditure by PPP, US dollars, million

Country	2015	2016	2017	2018	2019	Change for the period, %
USA	495,893	522,652	556,343	607,474	657,459	132.6%
China	366,080.9	393,015.5	420,815.6	465,501	525,693.4	143.6%
EU	341,613.9	360,092.7	386,984.9	413,001.8	437,083	127.9%
Japan	168,514	160,269.3	166,621.7	172,785.9	173,267.1	102.8%
Germany	114,097.6	122,472.2	133,668	142,080.3	147,502.1	129.3%
Great Britain	45,665.95	48,111.34	50,845.1	54,234.3	56,935.75	124.7%
Russia	38,818.63	39,012.98	42,246.09	41,693.19	44,500.51	114.6%
Mexico	9,577.037	9,241.683	8,079.106	7,851.176	7,407.707	77.3%
Latvia	305.8871	227.8475	284.6014	379.2418	392.8017	128.4%

Let us consider the indicators of digitalization of the economy of various countries of the world for several indicators:

- gross domestic research and advanced development expenditure, % of GDP (P1),
- government-funded research and advanced development expenditures, % of GDP (P2),
- basic research expenditures, % of GDP (P3),
- mobile broadband subscribers per 100 residents (P4),
- enterprises receiving orders via the Internet, % (P5),
- enterprises with a website or home page, (P6).

When conducting cluster analysis, we use the k-means method, which makes it possible to divide countries into clusters (groups) according to the presented indicators (features).

The sample includes 44 countries that are members of the Organization for Economic Cooperation and Development (n.d.). The individual values of the indicators for the presented indicators are presented in Table 2.

Table 2. Digitalization indicators for selected countries in 2019

Country	Gross domestic research and advanced development expenditure, % of GDP	Government-funded research and advanced development expenditures, % of GDP	Fund costs research, % of GDP	Mobile broadband subscribers per 100 residents	enterprises receiving orders via the Internet, %	Enterprises with a website or home page, %
Indicator designation	P1	P2	P3	P4	P5	P6
Israel	4.93	0.51	0.49	129.3	23.2	75.2
Korea	4.64	0.96	0.68	103.6	14.65	67.1

Chinese Taipei	3.50	0.64	0.24	88.3	36.3	62.1
Sweden	3.40	0.84	0.35	110.6	26.3	89.65
Japan	3.24	0.58	0.44	98.2	24.2	91.5
Austria	3.19	0.96	0.54	66.7	25.15	89.45
Germany	3.18	0.87	0.75	82.9	16.44	88.21
USA	3.07	0.66	0.49	149.8	16.2	74.3
Denmark	2.96	0.82	0.56	116.9	32.3	93.92
Belgium	2.89	0.53	0.29	83.9	20.8	86.72
Finland	2.79	0.78	0.56	117	18.2	59.3
Iceland	2.35	0.7	0.44	98.6	33.29	65.3
China	2.23	0.46	0.13	98.3	14.5	85.3
France	2.19	0.69	0.5	88.7	13.39	71.54
Netherlands	2.16	0.63	0.52	116.3	21.47	91.89
Norway	2.15	0.98	0.38	95.9	18	78.22
EU (27 countries)	2.10	0.62	0.64	95.1	32.2	77.62

In this case, the task of conducting a cluster analysis of the countries of the world by the level of digitalization is, based on the data on the indicators of digitalization (P1-P6), which are in the data set X, to divide the set of countries into m clusters Q1, Q2 ... ..Qm, so that each country is included in only one division set (cluster). Countries belonging to the same cluster are similar to each other in terms of the values of the parameters P1-P6, and countries belonging to different clusters are heterogeneous.

The algorithm for using the k-means method of the STATISTICA package to divide 44 countries of the world into clusters, depending on the level of digitalization (the values of the signs P1-P6) is as follows.

1. There are n observations, each of which is characterized by m signs of digitalization of the economy of individual countries of the world P1-P6, presented in Table 2. These observations shall be divided into k clusters. In this case, each region (country) will belong to the cluster that is closest to the center. The Euclidean distance is used as a measure of proximity.

2. Rationing of attributes. We will cluster the countries according to the selected six indicators, for this we use the STATISTICA package. According to the source table, we can say that the presented indicators differ significantly in the magnitude of the indicators. For example, spending on basic research ranges from 0.13 % of GDP (China) to 0.75% of GDP (Germany).

Mobile broadband subscribers per 100 residents range from 66.7 people per 100 residents in Austria to 149.8 people in the United States. Thus, the signs P1, P2, and P3 are in the intervals from 0–5, and the boundaries of the signs P4, P5 and P6 are larger. That is, if clustering is carried out according to the current values, then the signs P1-P3 are excluded from the analysis due to small values, and in fact, the division into groups of countries will be carried out according to the signs P4-P6.

Therefore, for a correct analysis, it is necessary to normalize the features using the formula:

$$z = \frac{x - \bar{x}}{\sigma} \quad (1)$$

$\bar{x}$ – the average value of the attribute,

σ – standard deviation.

3. Splitting the data array into clusters and interpreting the results. In a particular case, the number of clusters is 3, and the average graph for them is shown in Figure 1.

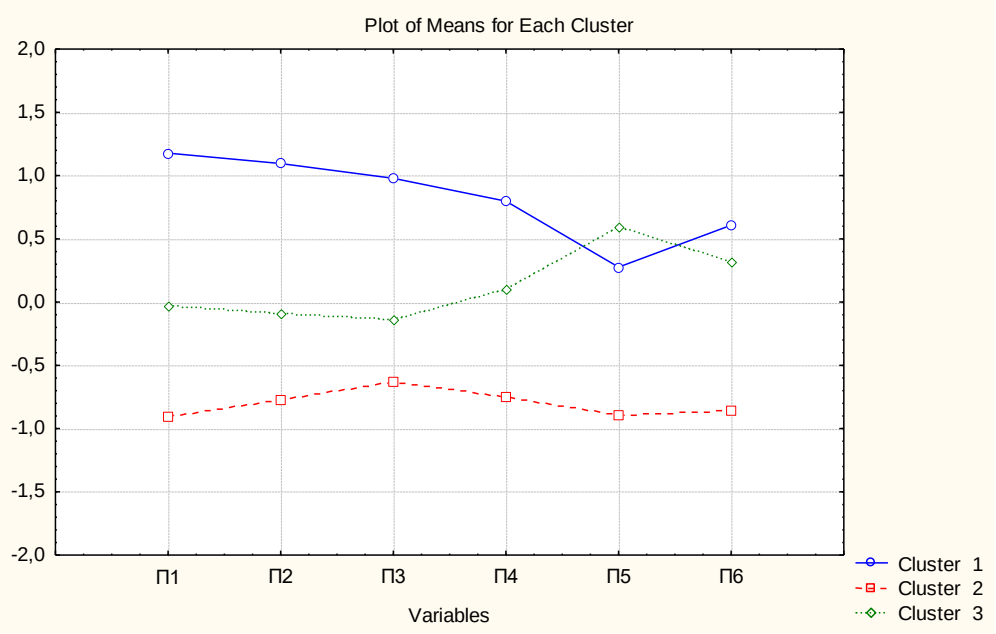

Figure 1. Graph of the average values for each cluster

Table 3. Group countries into clusters depending on the values of the parameters

Cluster No.	Number of countries	Name of countries	Cluster characteristics
1	12	Israel, Korea, Sweden, Japan, Austria, Germany, USA, Denmark, Finland, Netherlands, Norway, Switzerland	Indicators P1-P4 are at the highest level The value of P5 (Enterprises receiving orders via the Internet, %) and P6 (Enterprises with a website or home page, %) is significantly higher than in cluster 2, the same as in cluster 3
2	15	Canada, Hungary, Italy, Portugal, Poland, Greece, Turkey, Russia, Slovakia, Latvia, Romania, Mexico, Colombia, Argentina, Chile	This cluster includes countries with low values of all the studied indicators
3	17	Chinese Taipei, Belgium, Iceland, China, France, EU, Slovenia, Crete, Great Britain, Lithuania, Australia, Singapore, Spain, Ireland, Luxembourg, New Zealand	Indicators P1-P4 are higher than in cluster 2 and lower than in cluster 1. The value of P5 (Enterprises receiving orders via the Internet, %) and P6 (Enterprises with a website or home page, %) is significantly higher than in cluster 2, the same as in cluster 1

Table 4. Average values of the features for the original, non-normalized features.

	Cluster=1 Descriptive Statistics (Spreadsheet1)				
Variable	Valid N	Mean	Minimum	Maximum	Std. Dev.
P1	12	3,2417	2,15304	4,9344	0,82677
P2	12	0,7858	0,51000	0,9800	0,15699
P3	12	0,5933	0,35000	1,3600	0,26626
P4	12	106,8250	66,70000	149,8000	21,73105
P5	12	21,1750	14,65000	32,3000	5,20482
P6	12	81,9950	59,30000	93,9200	11,07863
	Cluster=2 Descriptive Statistics (Spreadsheet1)				
Variable	Valid N	Mean	Minimum	Maximum	Std. Dev.
P1	15	0,93215	0,28066	1,53810	0,46821
P2	15	0,37467	0,09000	0,68000	0,16703
P3	15	0,24000	0,09000	0,39000	0,10830
P4	15	80,39333	59,60000	96,60000	10,16095
P5	15	13,01333	8,82000	16,96000	2,20055
P6	15	65,60800	49,30000	81,80000	9,07889
	Cluster=3 Descriptive Statistics (Spreadsheet1)				
Variable	Valid N	Mean	Minimum	Maximum	Std. Dev.
P1	17	1,90192	0,99159	3,4987	0,643027
P2	17	0,52471	0,29000	0,7000	0,132388
P3	17	0,34941	0,13000	0,6400	0,129830
P4	17	94,86471	78,50000	110,2000	8,545828
P5	17	23,36765	11,58000	36,3000	7,179316
P6	17	78,81588	62,10000	86,7200	6,784222

Analyzing the indicators of average values for each indicator, it can be confirmed that the countries included in cluster 1 are in the lead by all indicators, they have the highest gross domestic research and advanced development expenditure, government-funded research and advanced development expenditures, organizations that receive orders via the Internet, and others.

Cluster 3 occupies an intermediate position in the grouping. Cluster 2 is lagging in all parameters. Russia is included in the second cluster together with such countries as Canada, Turkey, Italy, Greece, Mexico, and others.

Thus, it becomes relevant for Russia to increase such indicators of the digital economy as gross domestic research and advanced development expenditures, the share of corresponding expenditures financed by the state, the ability to use the Internet by residents of the country, and for enterprises to use it as a platform for searching and fulfilling orders.

The generation of new digital technologies creates a new level of consumer value through a previously unattainable combination of accessibility and customization with the provision of analytically customized products and services immediately on demand and often at a much more attractive price compared to the traditional offer. High-tech organizations are becoming the leading organizations in the development of the digital economy, so their development becomes the main activity.

A system model of the organizational and economic mechanism for the development of priority high-tech industries of industrial production following the concept of Industry 4.0 was developed in the study of V.G. Frolov, O.V. Trofimov, E.Z. Klimova (2020).

This model is presented as a set of interrelated stages of selection of priority high-tech enterprises at the regional level, differentiation of the structure and elements of the model depending on the depth of penetration of digital technologies, and synthesis of the optimal structure of business processes, taking into account the use of digital technologies in a given system of restrictions (Figure 2).

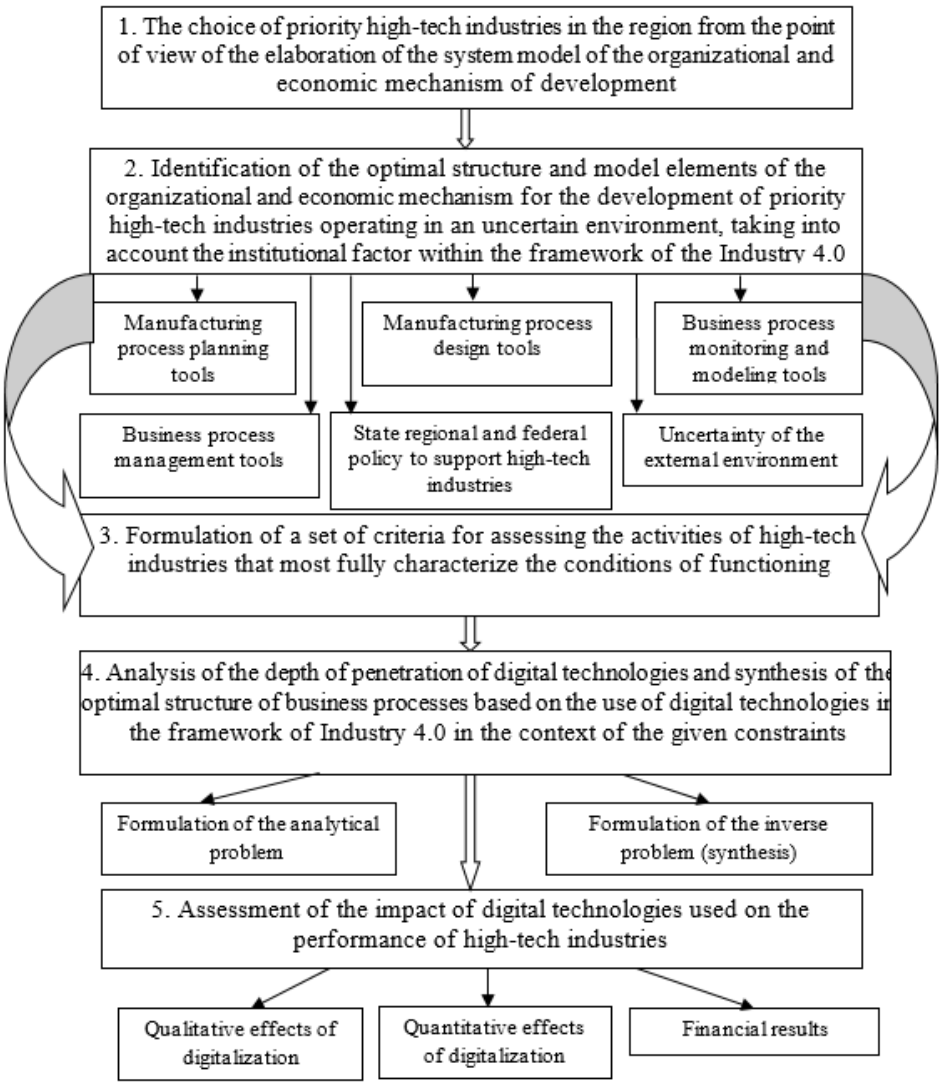

Figure 2. Organizational and economic model of the development of high-tech industries following the concept of Industry 4.0 (IOT Analytics, 2018; Industry 4.0 Market, 2019)

Based on the use of morphological analysis, the current structure of the advanced technologies used in high-tech enterprises is evaluated using expert approaches and its optimization using morphological synthesis (this model was tested in the Nizhny Novgorod region).

The morphological analysis and synthesis approach to Russian high-tech enterprises can be used in the following sequence:

1. The formal description of the object of high-tech production;

2. Formation of specific criteria $K\left(K_1, K_2, ..., K_m\right)$ that characterize the object of research and the design area (search) D;

3. Choosing a method for finding effective solutions, forming the goal function $F\left(x\right)$;

4. Formulation of an extreme mathematical programming problem (2) and its solution by numerical search methods (algorithms).

$$\overset{o}{F}\left(\overset{o}{x}\right) = \min_{x \in D} F\left(x\right) \tag{2}$$

The solution $\overset{\circ}{X}\left(\overset{\circ}{x}_1, \overset{\circ}{x}_2, ..., \overset{\circ}{x}_\nu\right)$ to the problem (4) is an efficient (Pareto) solution to the original vector optimization problem (2) (Mikheeva, 2008).

5. CONCLUSION

The use of morphological analysis and synthesis allows improving the quality of the technologies used, it is possible to quickly respond to changes and make adjustments to the system, replacing technological solutions.

Thus, in the context of digitalization, traditional approaches to business management need to be rethought. The digital economy is actively developing on a global scale. Based on the cluster analysis, it was revealed that several countries (for example, the United States, Germany, and Japan) are leading in digital development. Russia, being in the same group with such countries as Turkey, Canada, and Mexico, is significantly behind the world leaders. High-tech industries play a key role in the digital economy of any state, being the engine of development.

The formulated model of the development of high-tech industries and the application of morphological analysis and synthesis approaches makes it possible to increase the level of digitalization of these industries.

ACKNOWLEDGEMENTS

"The research was carried out with the financial support of RFBR and the Government of Nizhny Novgorod region within the scientific project No. 18-410-520009".

REFERENCES

Batkovskii, A. M., Kravchuk, P. V. and Styazhkin, A. N. (2019). Otsenka ekonomicheskoi effektivnosti proizvodstva vysokotekhnologichnoi produktsii innovatsionno-aktivnymi predpriyatiyami otrasli [Assessment of the economic efficiency of the production of high-tech products by innovatively active enterprises of the industry]. Kreativnaya ekonomika, 13 (1), 115-128.

Bukh, R. and Heeks, R. (2017). Defining, conceptualising and measuring the digital economy. Global Development Institute Working Papers. Paper No. 68. Retrieved from https://diodeweb.files.wordpress.com/2017/08/diwkppr68-diode.pdf (date of access: April 20, 2021).

Frolov, V. G., Klimova, E. Z. and Trofimov, O. V. (2020). Aprobatsiya sistemnoi modeli organizatsionno-ekonomicheskogo mekhanizma razvitiya prioritetnykh vysokotekhnologichnykh otraslei promyshlennogo proizvodstva Nizhegorodskoi oblasti [Approbation of the system model of the organizational and economic mechanism for the development of priority high-tech industries of industrial production in the Nizhny Novgorod region]. Voprosy innovatsionnoi ekonomiki, 10 (4), 2115-2128.

Frolov, V. G., Trofimov, O. V. and Klimova, E. Z. (2020). Razrabotka sistemnoi modeli organizatsionno-ekonomicheskogo mekhanizma razvitiya prioritetnykh vysokotekhnologichnykh otraslei promyshlennogo proizvodstva v sootvetstvii s kontseptsiei Industriya 4.0 [Development of a system model of the organizational and economic mechanism for the development of priority high-tech industries of industrial production following the concept of Industry 4.0]. Voprosy innovatsionnoi ekonomiki, 10 (1), 71-84.

Heeks, R. (2016). Examining "Digital development": the shape of things to come. Global Development Institute Working Papers. Working Paper No. 64. Retrieved from http://hummedia.manchester.ac.uk/institutes/gdi/publications/workingpapers/di/di_wp64.pdf (date of access: April 20, 2021).

Heeks, R. (2017). Information and communication technology for development. Abingdon, UK: Routledge.

Industry 4.0 Market. (2019). Industry 4.0 Market by technology and geography. Global Forecast to 2024. Market-Report, 2019. Retrieved from https://www.marketsandmarkets.com/Market-Reports/industry-4-market-102536746.html (date of access: April 20, 2021).

IOT Analytics. (2018). Industry 4.0 and smart manufacturing market report 2018-2023. Retrieved from https://iot-analytics.com/industry-4-0-and-smart-manufacturing/2018-2023 (date of access: April 20, 2021).

Ivanov, V. V. and Malinetskii, G. G. (2017). Tsifrovaya ekonomika: mify, realnost, perspektiva [Digital economy: myths, reality, perspective]. Moscow, Russia: Russian Academy of Sciences, p. 63.

Knickrehm, M., Berthon, B. and Daugherty, P. (2016). Digital disruption: the growth multiplier. Dublin, Ireland: Accenture.

Mikheeva, E. Z. (2008). Provedenie reinzhiniringa biznes-protsessov s ispolzovaniem metodov matematicheskogo modelirovaniya [Reengineering of business processes using mathematical modeling methods]. Rossiiskoe predprinimatelstvo, 4-1, 45-50.

Negroponte, N. (1995). Being digital. New York, NY, USA: New York Vintage Books, 255 p.

Organization for Economic Cooperation and Development (OECD). Official Website. (n.d.). Retrieved from https://oecdru.org/ (date of access: March 21, 2021).

Pavlinov, I. A., Skodorova, L. K., Pavlinova, E. I., Skaletsky, M. A., Cherniy, V. N., Lyakh, A. A., Popik, I. I., Terlyuga, I. M., Korlyuga, B. K., Popadyuk, K. N., Gres, O. V. and Vysochanskaya, E. S. (2019). Tsifrovaya ekonomika: kollektivnaya monografiya [Digital economy: collective monograph]. Rybnitsa, Pridnestrov'ye: PSU, Printing house "Tesline", 260 p.

Rouse, M. (2016). Digital economy. Newton, MA, USA: Techtarget.

Tapscott, D. (1995). The digital economy: promise and peril in the age of networked intelligence. New York, NY, USA: McGraw-Hill, 368 p.

Trofimov, O. V., Kostyrev, A. P., Strelkova, L. V., Makusheva, Y. A. and Trofimova, T. V. (2020). Industrial policy: peculiarities of understanding and dependence on the level of implementation. In: E. Popkova, B. Sergi (Eds.), The 21st century from the positions of modern science: intellectual, digital and innovative aspects. ISC 2019. Lecture notes in networks and systems, Vol. 91 (pp. 576-582). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-32015-7_65

Urmantseva, A. (2017). Digital economy: how experts understand this term. Retrieved from https://finance.rambler.ru/economics (date of access: May 5, 2021).

Vorontsovskii, A. V. (2020). Tsifrovizatsiya ekonomiki i ee vliyanie na ekonomicheskoe razvitie i obshchestvennoe blagosostoyanie [Digitalization of the economy and its impact on economic development and social welfare]. Vestnik Sankt-Peterburgskogo universiteta. Ekonomika, 36 (2), 189–216.

The World Bank. (2016). Development of the digital economy in Russia. Retrieved from https://www.vsemirnyjbank.org/ru/events/ (date of access: March 21, 2021).