Integral Assessment of the State and Development Potential of Info-Communication Infrastructure for Ensuring Sustainable Digital Development*

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Abstract. In the context of high digital transformation rates of the economy and society, complex assessments, necessary for monitoring ongoing processes and developing constructive management tools to ensure sustainable development, are relevant. The paper reveals the essence, parameters, and procedures of an integral method for assessing the state and potential of the development of info-communication infrastructure, which plays a critical role in developing the digital economy. The integral approach to assessing the development of info-communication infrastructure is based on the following principles: (1) building a hierarchical system of indicators and (2) integrating private parameters. The following measurements are made: (1) the state and potential of development, (2) quantitative assessment of reserves and potential opportunities, (3) the possibility of comparative analysis in time and space for each object. These actions are done in two planes: in a horizontal and vertical section, according to the system of private, generalized, and integral indicators, as well as the evolution of indicators by stages of digital development. The results obtained allow us to conduct a deep comparative analysis with a clear definition of reserves and potential in quantitative terms, that is, to specify management decisions in developing the info-communication infrastructure of the digital economy. The discussion regarding the existing methods reveals many advantages of the proposed method in integrating complex multi-factor developing network and infrastructure systems.

Keywords: Infocommunication infrastructure · State · Development potential · Integral method · Monitoring digital development

1. Introduction

The high rates of digitalization of the economy and society in the country, the interests of ensuring national security, public administration, and socio-economic

development dictate the need for the progressive development of the information and communication infrastructure [ICI]. Effective methodological support of managing the sustainable development of the national economy, taking into account catalytic and strategic role, is based on a comprehensive measurement and monitoring of the ICI state and potential development. In this context, these measures become an effective mechanism for developing regulations to create a single national (global) information space by identifying and eliminating regional imbalances, adjusting national or international policies for the digital development of the economy and society.

Existing international and national approaches to measuring digital development are primarily based on the rating method for assessing the position of countries (regions) in the world by composite indexes, which allows for determining the current rating of the research object, and in dynamics – to estimate the success or lag of countries in the expansion of info-communication technologies [ICT] and the development of info-communication. However, these methods cover only fragments of multifaceted and multi-factor digitalization; they do not provide a unified, general, and comprehensive description of the effectiveness of the ongoing digitalization, nor do they quantitatively disclose the available reserves.

The documents of the national program *Digital Economy of The Russian Federation* aim to "create a stable and secure information and telecommunications infrastructure for high-speed transmission, processing, and storage of large amounts of data accessible to all organizations and households." Communication networks of the new generation must meet the requirements of digitalization of the economy and society in terms of technical and technological parameters. With the development of the digital economy, the burden on the ICI increases many times. Therefore, users need the power, flexibility, and availability of modern digital networks for various platforms and services in electronic form. At the same time, the concept of *the user* is changing dramatically since in the context of digital transformation, not only people fall into this category but also connected technical devices of the industrial Internet of Things, the number of which is many times greater than the number of people (Schwab, 2016).

During the period of digital development, the ICI is subject to significant requirements to ensure the sustainable development of the economy and society, such as multiple traffic growth, growth of speed, channel capacity, high quality, minimal data transmission delays, as well as providing virtual network functions, unlimited scalability of cloud resources, operational big data analytics, security, integration of info-communication business with other related activities (Kuzovkova, Kukharenko & Salutina, 2019, pp. 38).

Thus, a comprehensive system for assessing the ICI development should consider both quantitative parameters of accessibility, network security, technology progressiveness, and the intensity of use in the economy and social life of the population along spatio-temporal trajectories, and the development potential, taking into account the requirements of the digital economy and its development stages.

2. Materials and methods

Assessment of the state and potential of ICI development in the context of economic sectors and regions and the comparison of achieved indicators with potential levels should serve as a quantitative basis for managing the sustainable development of the digital economy, determining measures to accelerate the progressive development of info-communication, and intensify the use of digital technologies in the ecosystem of the national economy and society (Bukht, & Hicks, 2019). Thus, a comprehensive analysis of the ICI development should use an integral approach that focuses on building a hierarchical system of private, generalized, and integral indicators of the state (achieved level) and development potential, as well as applying the method of integrating actual (growth rate) private indicators.

The method of integral assessment of info-communication development, used in the countries of the Regional Commonwealth in the Field of Communications (Zorya, & Kuzovkova, 2012, pp. 115), as well as the method of integral assessment of digital development developed by the authors (Kuzovkova, Kukharenko & Salutina, 2019, pp. 94-95), can serve as an example of an effective methodological tool for managing the ICI development based on the integral approach.

The methodological basis of the integral approach to the complex assessment of informatization can be found in the work of V. Vasiliev and T. Salutina (2005). According to N. Zorya and T. Kuzovkova, the theoretical basis reveals the system essence of the ICI development:

It is a multi-parameter and multi-factor process of changing social production and society based on the purposeful use of ICT, networks, and means in various socio-economic areas. These measures contribute to the transition to an advanced ICI state and the formation of an information society. The effect of ICI development is determined by the joint synergetic result of the evolutionary change of specific parameters of ICI development in terms of infrastructure availability, its progressiveness, and intensity of use, supported by the effectiveness of the implementation of the informatization strategy (Zorya, & Kuzovkova, 2012, pp. 216).

Fig. 1 shows the hierarchical system of ICI development indicators at the first stage of digital development of the Russian Federation.

High dynamics characterize the ICI development due to scientific and technological progress, digitalization, and business model transformation. Consequently, when forming the system of indicators of the state and potential of ICI development, one should take into account the evolution of target criteria by the stages of digital development and the impact of digital transformation on industry and results at the national level (Salutina, Kuzovkova & Kukharenko, 2019, pp. 92-93).

The methodology for integral assessment of the ICI development is based on the principles of goal setting, the correlation of parameters and scales of measurement of particular indicators with the main properties of the process under study by (1) stages of their evolution, (2) reduction of variation of indicators through normalization, (3) methods of hierarchical system construction and integration of a set of indicators, (4) ranking and determining the potential for growth rate parameters.

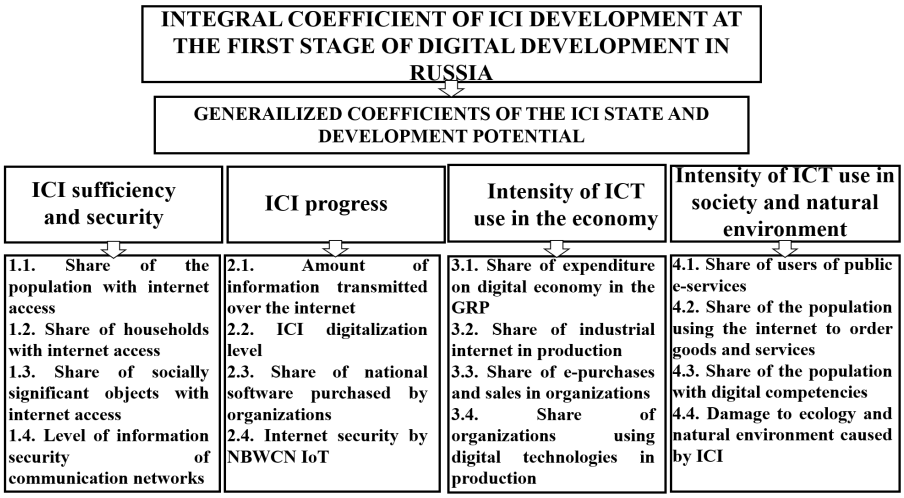

Fig. 1. The hierarchical system of indicators for assessing the state and potential of ICI development. *Source*: Compiled by the authors.

The integral coefficient of the ICI state (*Kisici*) can be determined based on an additive model of equivalent (actual or normalized values) or by taking into account the significance of the weighted average value of the generalized indicators:

$$Kisici = \sum Kobsici\ j / 4; \quad Kisici = Kobsici\ j * dj,$$

where:
Kobsici j – j-th generalized coefficient included in the integral coefficient (Rel. units);
dj – the weight of the j-th generalized coefficient (Rel. units);
4 – the number of generalized coefficients included in the integral coefficient of the ICI state.

The calculation of the generalized coefficients of the ICI state is carried out in the same way using an arithmetic mean (simple or weighted) based on partial indicators-components of the generalized coefficients. Besides, the ratings of the federal districts on indices of potential have the opposite orientation relative to the ratings of the state of ICI development due to the economic substance of the

indicators of the state and development potential and the methods of their calculation.

To obtain an integral assessment of the ICI development, we consider the concept of *development potential* to achieve higher values of parameters that have already been achieved in other sectors of the economy or regions of the country (Kuzovkova et al., 2019). The main goal of fulfilling the potential of ICI development is to reduce the level of uneven development of networks across territories and the intensity of ICT use across sectors of the economy and society. In other words, it is necessary to ensure the harmony of the ICT use and the balance of communication networks in terms of bandwidth, information security, and speed of information transfer in the regional-subject perspective.

Therefore, a scientifically sound way to determine the ICI development potential is to identify the difference between the achieved parameters and the best ones in terms of the set of research objects and to calculate the indices of the potential capabilities of ICI development for each parameter $\Delta Inomj$ in the form of a growth rate. The integral potential index of ICI development is calculated based on the average arithmetic growth rate of potential opportunities:

$$\Delta Iipdici = \sum \Delta\ Iobpdici\ j\ /\ 4.$$

The proposed methodological apparatus comprises a set of methods and a sequence of the following analytical actions:

1. Calculation, statistical processing, and analysis of private, generalized, and integral indicators of the ICI development for the research objects: regions (districts, subjects) of the country;
2. Assessment of the state and potential of ICI development, ranking and establishing ratings of research objects in the regional context;
3. Identification of bottlenecks in the achieved state and reserves for increasing accessibility, security, the ICI progresS, and efficiency of ICT application in the economy and society;
4. Definition of directions and measures to ensure the regional balance of communication networks as the technological basis of the digital economy;
5. Evaluation of trends in the ICI development research objects given the potential opportunities, regional specifics, grouping research objects on socio-economic indicators;
6. Analysis of the distribution of the set of parameters of the state and development potential of the Russian ICI.

The integral system of indicators is designed for a comprehensive assessment of the state and potential of the development of ICI objects and subjects at the regional and sectoral (by type of economic activity) levels and for the development of management decisions at the national and regional levels to ensure the harmonious, balanced, and sustainable development of the national economy and the proportional development of the Russian regions to create a single digital space.

3. Results

To assess the state and potential of the ICI development in Russia at the first stages of the national digital development projects, we use (1) the targets and criteria of the socio-economic efficiency of the national project *Digital Economy;* (2) official Rosstat data (including the database *Indicators of the Digital Economy* of Rosstat together with the Higher School of Economics), and (3) the data of the Ministry of Digital Development, Communications, and Mass Communications of the Russian Federation. Considering the target indicators of the development of the Russian digital economy, we take into account the potential values of private indicators of ICI development of Russia for the federal districts and developed countries of the world, necessary for measuring the potential of ICI development.

Based on the developed methodology and the algorithm of the integral assessment of the state and potential of ICI development, we perform the calculations of generalized indicators, in accordance with the hierarchical system shown in Fig. 1: (1) sufficiency and security, (2) ICI progressiveness, the intensity of ICT use by organizations and the population, at the initial stage of digital development (2019). The results of generalized indicators and calculation of the integral coefficients of the state and potential of ICI development indices are presented in Table 1, 2.

Table 1. Integral indicators of the ICI state in the federal districts of Russia at the initial stage of digital development.

Federal district	Generalized state coefficients				***Integral state coefficient of the ICI development***	Rating of the integral coefficient of the state of ICI development
	Sufficiency and security of ICI	ICI progress	Intensity of ICT use by organizations	Intensity of ICT use by the population		
Central	0.96	0.99	1.00	0.92	**0.97**	1
North-western	0.93	0.81	0.63	0.41	**0.69**	2
Southern	0.52	0.10	0.23	0.71	**0.39**	4
North Caucasian	0.00	0.14	0.06	0.26	**0.11**	8
Privolzhsky	0.56	0.23	0.36	0.78	**0.48**	3
Ural	0.79	0.15	0.39	0.08	**0.35**	5
Siberian	0.42	0.35	0.22	0.42	**0.35**	6
Far Eastern	0.54	0.29	0.19	0.37	**0.35**	7
Russian Federation	***0.59***	***0.38***	***0.39***	***0.49***	***0.46***	**-**

Source: Compiled by the authors.

Table 2. Integral indicators of the development potential of info-communication infrastructure in the Federal districts of Russia at the initial stage of digital development.

Federal district	Generalized potential indices				***Integral index of the ICI development potential***	Rating of the integral index of potential
	ICI sufficiency and security	ICI Progress	Intensity of ICT use by organizations	Intensity of ICT use by the population		
Central	0.01	0.00	0.00	0.02	**0.01**	8
North-western	0.01	0.24	0.29	0.13	**0.17**	7
Southern	0.20	0.76	0.73	0.13	**0.45**	1
North Caucasian	0.00	0.00	0.84	0.24	**0.27**	6
Privolzhsky	0.08	0.53	0.47	0.32	**0.35**	5
Ural	0.03	0.57	0.56	0.33	**0.37**	3
Siberian	0.10	0.56	0.61	0.16	**0.36**	4
Far Eastern	0.08	0.74	0.53	0.17	**0.38**	2
Russian Federation	***0.06***	***0.42***	***0.50***	***0.19***	***0.29***	**-**

Source: Compiled by the authors

The results of the integral assessment of the current state of the ICI development in Russia indicate sufficient proximity to the generalized coefficients of the state of ICI development by adequacy, security, and progressiveness of ICI and use of ICT by organizations and population (from 0.38 to 0.59), that is, components of the integral characteristic. However, there is a significant variation in the generalized and integral coefficients of the state of ICI in federal districts from 0.11 to 0.97, caused by the disproportionality of info-communication and variability of the socio-economic development of regions. With a sufficiently high level of the integral coefficient of the state of the ICI in the Central District (0.97), the North Caucasian District has almost nine times lower level (0.11), especially in terms of the adequacy and safety of ICI, as well as the use of ICT by organizations.

The integral index of potential ICI development in Russia at the initial stage of digital development amounted to 0.29, which is determined by the significant potential in ICI progress (0.42) and the use of ICT by organizations (0.5). At the same time, the size of the potential of ICI development in the regional aspect does not exceed 50%, which indicates an increase in the degree of equilibrium of the ICI by regions in the past period (in 2018, the potential of ICI development amounted to 0.39) and a decrease in the degree of potential capabilities of the regions for the development of ICI and the use of ICT, which is within 38–45%. The most significant potential of digital development is observed in the Southern

and Far Eastern districts (45% and 38%, respectively), especially in terms of the ICI progress (0.76 and 0,74, respectively) and the intensity of ICT use by organizations (0.73 and 0.53).

For each generalized indicator, horizontal and vertical analysis of the state and potential of the ICI development is also carried out, which allows for identifying the reserves and potential for each particular parameter of the ICI development. Thus, it helps to define the management decisions on improving the following factors:

1. Accessibility (by increasing the percentage of organizations and households with broadband internet access and the percentage of socially significant objects connected to the internet) and ICI information security;
2. ICI progress (due to the growth of the volume of information transmitted over the internet, the level of digitalization, the share of national software, and the availability of industrial internet with national narrow-band Internet of Things networks);
3. Intensity of ICT use by organizations (due to the growth of the share of expenditures for the development of the digital economy in GDP, the industrial internet in the volume of industrial production, e-procurement, sales, and the share of organizations using digital technologies in production);
4. Intensity of the ICT use by the population (due to the growth of the share of users of electronic public services, the share of the population with digital competence and literacy using the internet to order goods and services, reducing the damage to the ecology and the natural environment from ICI).

The revealed correlations of integral characteristics of ICI development in the regional context indicate the need to continue regional equalization of infrastructure development and digital transformation of socio-economic activities of the regions to ensure a unified national information space.

4. Discussion

The primary methodological approach of international organizations to measuring digital development and transition to the information society is the rating method for assessing the position of countries (regions) in the world by composite indices (Karyshev, 2011). A standard set of indicators recommended by various international organizations allows for determining the current rating of countries, judging the success or lag of countries in the ICT spread, and the development of info-communication. Comparison with the best rated (reference) countries at a particular time helps one to identify the appropriate strategy for further improvement and progressive ICT development (Vershinskaya, & Alekseeva, 2011).

Existing approaches, including rated ones, mainly give a quantitative characteristic of the informatization process (the number of phones, computers,

and internet users) for a minimal number of indicators; nevertheless, they do not show how well the processes of digitalization of the economy and social sector are proceeding in qualitative and temporal vectors (Vasiliev, & Salutina, 2005. pp. 68).

The approaches used in the practice of regional analysis of Russia differ in (1) the indicators of ICT development, (2) methods of normalization of significantly varying parameters of digitalization, (3) the goals of analysis, (4) formation of complex indexes and multiplicative indicators, and (5) types of regression models (Dubinina, 2019, pp. 375-377). Although these indicators help to study the regional distribution in many aspects of the development of the digital economy and ICI, they are not complex enough to assess the ICI development from the point of view of (1) the critical role of info-communication in the digital transformation of the economy and society, (2) the synergy of the results of the ICT use, and their impact on the quality and structure of production resources, (3) electronic form of services, (4) virtuality, and (5) integrity of business (Bukht & Hicks, 2019; Digital ecosystem of the economy of the future, 2019).

Essential advantages of the integral approach to measuring the state and potential of the ICI development are the evolutionary principle of forming indicators according to (1) the ongoing processes and stages of digital development, (2) objective ranking of research objects (regions) by the state and potential of ICI development in any period and regional or sectoral aspect, and (3) defining management decisions in terms of the potential for the ICI development.

The proposed method for assessing ICI state and development potential based on the integration of generalized and partial indicators reveals the reasons for the results achieved and the size of the ICI development potential for each research object. The integral approach allows one to quantitatively establish the available reserves and potential opportunities to ensure sustainable development of the digital economy based on the more progressive and balanced ICI development and effective ICT use through constructive activities to develop the economy and society in regional and sectoral perspectives.

5. Conclusion

The results of calculations of the integral coefficient of the state and the index of the potential of ICI development based on the generalized and partial indicators reveal the reasons for the results achieved for each research object and the potential of the regions to improve ICI.

The system of indicators of the state and development potential of ICI is crucial for monitoring the development of the digital economy, involving (1) collecting data, (2) analyzing and identifying bottlenecks and reserves (potential), and (3) developing regulations to ensure sustainable digital development. To provide the adequacy of the analysis results to the requirements of the development of the digital economy, when monitoring the ICI state and potential, one should use indicators corresponding to the stages of digital development and the target criteria of the national project *Digital Economy*.

The monitoring mechanism implies conducting analytical work on a special method for integrating private and generalized parameters of the state and the potential of the ICI development for infrastructure objects and subjects, allowing for coordinating and making management decisions on the sustainable development of the digital economy of Russia at the regional, national, and global levels.

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