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Digitalización del transporte en la macrorregión del sur de Rusia y sus consecuencias ambientales

Digitalization of transport in the South Russia macro-region and its environmental consequences

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Resumen: Este documento evalúa la madurez digital de la industria del transporte y el almacenamiento en el sur de Rusia y los cambios relacionados en el fondo electromagnético de esta macrorregión. Se realizó el análisis de los puntos clave del proceso de digitalización de la economía en general y de la industria del transporte y almacenamiento en particular. Se identificaron los principales problemas relacionados con este proceso. Se presentan los resultados de la evaluación estadística de la relación entre los componentes individuales del índice de digitalización. Los resultados muestran que el acceso a Internet de banda ancha inalámbrica es el principal mecanismo de digitalización, y los suscriptores de la macrorregión Sur acceden principalmente a través de teléfonos inteligentes y tabletas.
Palabras clave: Macrorregión del sur de Rusia, digitalización de la industria, transporte, brecha digital, redes de acceso a Internet de banda ancha, impacto ambiental, fondo electromagnético del territorio

Abstract: This paper evaluates the digital maturity of the transport and storage industry in Southern Russia and the related changes in the electromagnetic background of this macro-region. The analysis of the key points of the process of digitalization of the economy in general and the transport and storage industry in particular was carried out. The main problems connected with this process were identified. The results of the statistical evaluation of the relationship between the individual components of the digitalization index are presented. The results show that wireless broadband Internet access is the main mechanism of digitization, and subscribers in the Southern macro-region access it primarily through smartphones and tablet computers.
Keywords: South Russian macro-region, digitization of industry, transport, digital divide, broadband Internet access networks, environmental impact, electromagnetic background of the territory

1. INTRODUCTION

The qualitative shifts in the global economy that began in the 1990s and were associated with the development of the Internet (Bukht & Heeks, 2018; Schvab, 2017) eventually led to the intensive use of information and communication technologies (ICTs) in various areas of life. It should be noted that the composition of ICT used in the economy has changed over time. At the beginning of the XXI century, four technologies were distinguished (big data, digitalization, virtualization and generativity) (Bukht & Heeks, 2018). After 2010, Huawei experts, based on the analysis of the development directions of countries with developed economies, identify 5 technologies used (Salahov, 2020), according to which statistical collections are compiled: broadband wireless networks; data processing centers (data centers); cloud technologies; Big Data and the Internet of Things (IoT). It should be noted that the list of information and communication technologies used may vary for different industries. In this regard, the concepts of "digital transformation" and "digitalization" have been introduced in modern literature (Abdrakhmanova et al., 2021).

From the analysis of the modern classification, it follows that networks of broadband wireless access to the Internet are moving to the first place among infocommunication technologies, since it is on their basis that the digital economy is being formed. As it is known (Salahov, 2020), the main difference between the digital economy and the traditional economy is that its product is not a specific material product, but information, and it is focused on the provision of services. The value of the contribution to the gross domestic product (GDP) from its use is less than from the development of the industry as a whole, however, it requires less investment in a shorter time interval. As a result, the development of ICT provides an increase in labor and capital productivity, increased access to world markets, as well as a reduction in transaction costs (Ndungu, Morales & Ndirngu, 2016; Radelet, 2016; Bukht & Heeks, 2018; Arkhipova & Sirotin, 2019; Safiullin & Moiseeva, 2019; Abdrakhmanova et al., 2021; Mirolubova & Radionova, 2021; Zvezdina et al., 2022). The latter consequence makes the development of the digital economy an attractive direction for less developed and developing countries in which there is virtually no industry. A good example is the African countries, which experienced rapid GDP growth in 1994-2016. During this period, in the twenty fastest growing countries (excluding oil exporting countries), GDP growth averaged 5.8 % annually, and real per capita incomes more than doubled (Radelet, 2016). One of the reasons for this jump was a significant reduction in transaction costs due to the use of mobile telephony-based financial services technology (M-Pesa), which allowed expanding financial services to organizations and individuals, including those with low income. Thus, during this period, the percentage of the population covered by financial services in Kenya increased by 25 % (from 59 % to 83 %), in Tanzania and Uganda by 28 % and 15 %, respectively (Ndungu, Morales & Ndirngu, 2016). This made it possible to create new jobs in the banking sector through the expansion of financial services.

The economic attractiveness of digital transformation has led to a sharp increase in the number of countries with wireless broadband networks on which it is based. Thus, during the period 2005-2013, the number of countries increased from 17 to 134, i.e. almost 8 times (Pastukh, Devyatkina & Sukhodolskata, 2014). In the Russian Federation, the development of digital transformation is planned by the state starting in 2017. Over the past period, strategic planning documents have been adopted, in particular, the "Forecast of scientific and technological development of the Russian Federation until 2030", the Decree of the President of the Russian Federation "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024", "Strategy of digital transformation of the transport industry of the Russian Federation" and a number of others.

One of the difficulties of developing a country's digital transformation is its dependence on economic development. In this regard, the development of a roadmap for the development of the digital economy for each specific country requires a preliminary assessment of the readiness of the economy for the process of integrating ICT into its structure (Schvab, 2017; Abdrakhmanova et al., 2021), indicating the directions, timing and pace of its development, as well as possible negative consequences. The assessment of the timing and pace of ICT development, as well as their positive impact on the economy, can be qualitatively carried out on the basis of an analysis of the relationship between the value of GDP (or the value of gross regional product, GRP) per capita and the value of the IDI indicator (Mirolubova & Radionova, 2021; Arkhipova & Sirotin, 2019; Pastukh, Devyatkina & Sukhodolskata, 2014; Kuzuvkova, Gencur & Kuzovkov, 2016; Kasimova, Magomedova & Rabadanova, 2021).

For the Russian Federation, the main points of the roadmap are formulated in the national project "Industry 4+" (Devyatkin & Ivankovich, 2021). As a negative factor of digitalization, it notes a change in the electromagnetic background in places where wireless networks of mobile broadband access to the Internet are deployed. This is legitimate, since broadband wireless communication technologies are at the heart of digitalization (Abdrakhmanova et al., 2021). Ways and methods for assessing the electromagnetic environment (EME) near emitting antennas of base stations of various technologies (3G / 4G) or changes in the electromagnetic background of the territory as a whole are given in many publications of Russian and foreign scientists, for example, in (Markov, 2013; Suleiman et al. , 2014; Mordachev, 2016; Zvezdina et al., 2018; Mordachev, 2019; Zvezdina et al., 2021). However, a significant expansion of the used frequency range with 5G and higher technology requires additional studies to assess its negative consequences (Devyatkin & Ivankovich, 2021).

It should be noted another feature of the development of a roadmap for the development of the digital economy for countries with different levels of economic development by region, leading to the formation of limited opportunities for part of the population to access modern means of communication, i.e. to the emergence of digital inequality (Arkhipova & Sirotin, 2019; Kaneva & Untura, 2019; Safiullin & Moiseeva, 2019; Mirolubova & Radionova, 2021; Grishchenko, 2020; Kramin & Imasheva, 2020; Litvintseva & Karelin, 2020). In relatively small states, digital inequality is observed mainly between urban and rural populations (Zvezdina et al., 2022). In the Russian Federation, which unites 85 regions at the time of 2022, digital inequality is also observed between regions (Arkhipova & Sirotin, 2019; Safiullin & Moiseeva, 2019; Kasimova, Magomedova & Rabadanova, 2021). This fact makes the assessment of the country's readiness for the development of the digital economy quite a difficult and voluminous task. In this regard, an attempt has been made in this article to localize the consideration of issues related to digitalization at the meso-level, i.e. limit the scope of research to the South Russian macro-region, which unites the Southern (SFD) and North Caucasian (NCFD) federal districts. To compare the results obtained, we will conduct an assessment with the leaders in the field of digitalization in the Russian Federation – the cities of Moscow (Central Federal District, CFD) and St. Petersburg (Northwestern Federal District, NFD). In addition to the restriction on the territory, we will introduce another restriction on the field of research due to the heterogeneity of economic development. In the analysis, we will not consider all branches of the economy, but only one "Transportation and Storage".

The choice made is due, firstly, to the presence of this branch of the economy in the infrastructure of the region's economy (Grishaeva et al., 2018; Krasyul, Kolgan & Medvedeva, 2021; Marchenko et al., 2021; Popov et al., 2022), as well as the high level of broadband Internet usage (more than 70%). Secondly, the inclusion for all regions of this industry in the "Industry 4.0+" project (Rappaport et al., 2017; Alsweity et al., 2021; Devyatkin & Ivankovich, 2021) for the modernization of the road structure, including by providing basic conditions for the introduction and use of digital solutions for the operation of unmanned or highly automated vehicles, as well as training in the field of digital technologies for transport.

Thus, the purpose of the article was to assess the level of digital maturity of the Transportation and Storage industry in the Southern Russian macro-region and the associated change in the electromagnetic background of the territory.

It is necessary to solve the following tasks to achieve this goal:

- analysis of the development of the digital transformation of the Russian economy against the background of global development, as well as the selected macro-region relative to Russia as a whole;
- assessment of the digital divide in the "Transport and storage" industry between the subjects of the macro-region and identification of ways to eliminate it;
- assessment of the environmental consequences of digitalization of the industry "Transportation and storage" in the South Russian macro-region.

2. MATERIALS AND METHODS

2.1. Statistical data for the analysis of ICT development in Russia in general and in the selected region in particular

When conducting research on the development and use of ICT in Russia and the selected macro-region, in particular, we use methods of abstraction, analysis and synthesis, comparative and correlation analysis.

A number of indices were used as a quantitative measure to assess the level of development of ICT infrastructure and their demand by the population. Currently, a truncated composite indicator is used to assess the digital transformation of economic sectors - the digitalization index (Devyatkina & Sukhodolskata, 2014; Kuzuvkova, Gencur & Kuzovkov, 2016; Arkhipova & Sirotin, 2019; Salakhov, 2020; shepherd, Kasimova, Magomedova & Rabadanova, 2021; Zvezdina et al., 2022), which includes four indicators: the level of "digital maturity" of key sectors of the economy and social sphere (transport, education, healthcare, public administration, urban economy and construction); comparison of the share of mass socially significant services available electronically with the required level of 95%; comparison of the share of households with broadband Internet access with the required value of 97%; investments in domestic solutions in the field of information technology.

The article uses statistical data provided by the state bodies of the Russian Federation regarding the world ranking as of 2021, and for the Russian regions for 2018 (the closest to the date under study) to analyze the assessment of the development and use of ICT. When analyzing the digitalization of the macro-region, statistical data provided by the State Bodies of the Russian Federation for the state of 2019 (the closest to the study period) were used. The analysis of the pace of digitalization of organizations in the “Transportation and Storage industry” was carried out using statistical data provided by State Statistical Organizations as of 2018 (the latest available). As initial data, statistical data on the ranking of countries, as well as subjects of the studied macro-region in terms of the digitalization index, as well as the intensity of the use of digital technologies in transport organizations were used.

2.2. Methods and materials for assessing the electromagnetic environment in the locations of broadband wireless Internet access networks

Of all the possible options for providing broadband Internet access, the simplest and cheapest for mobile subscribers is access via cellular networks. The assessment of the environmental impact of these networks on human health in the work is carried out using the approach proposed by V.I. Mordachev to assess the electromagnetic background on the territory of the cell as a whole (Mordachev, 2016; Mordachev, 2019). The choice of this technique is due to the fact that it allows you to take into account the totality of emitters operating at different frequencies. To this end, the methodology (Mordachev, 2016) uses indicators of the electromagnetic load on the territory and on the population as an integral system characteristic of the electromagnetic safety of the radio-electronic environment and the electromagnetic ecology of the urban development area with broadband networks. Indicators are defined as the total equivalent isotropically radiated power of a user or cellular base stations per unit of territory. The basic methodology (Mordachev, 2016), as well as its modification for 4G/5G technologies (Mordachev, 2019), allow us to take into account both the change in traffic in the network and the density of radiating units for each frequency range. The indicator of the electromagnetic load on the population is determined by the total intensity of the electromagnetic field from the base stations or the subscriber near the Earth's surface. The value of the total intensity of the electromagnetic background created by the antennas of the base stations and the subscriber at the observation point at a height of 1 m or 2 m, depending on whether the subscriber is sitting or standing for the values of confidence probability $p \leq 0.1$. The maximum permissible level of radiated power (MPL) per 1 cm^2 of human skin is used as an irradiation criterion. This value is regulated in the Sanitary Regulations and Norms (SanPiN) 2.1.8/2.2.4.1190-03 "Hygienic requirements for the placement and operation of land mobile radio communication facilities" in the frequency range of cellular networks (1-30 GHz). The value of the MPL according to these documents is 10 mW/cm^2 for base station antennas, 100 mW/cm for smartphone antennas.

The correctness of the methodology proposed by V.I. Mordachev was proved by the author by comparison with the results calculated by the method of computational forecasting (Markov, 2013; Zvezdina et al., 2018a; Zvezdina et al., 2018b; Skrynnikov, Paltsyn & Devyatkin, 2019; Spodobaev, 2019; Zvezdina et al., 2020; Maslov & Spodobaev, 2021a; Maslov & Spodobaev, 2021b; Spodobaev, 2021 Examples of visualization of the energy flux density distribution for various types of mobile communication antennas are given in (Zvezdina et al., 2018a; Zvezdina et al., 2018b; Zvezdina et al., 2020; Zvezdina et al., 2021). The emergence of life-threatening situations, as shown in (Maslov & Spodobaev, 2021b), is observed either at the stage of compaction of existing buildings, since at the initial stage the installation of base station antennas is accompanied by an examination, or when deploying new networks over old ones.

3. Results

3.1. Assessment of ICT development in Russia and the macro-region under study in the world ranking

Based on a sample of statistical data on the development of ICT in the countries of the world, we will build the dependence of the IDI index value on GRP per capita as of 2021. To assess the relationship between the indicator of economic growth and well-being and the indicator of the development of ICT technologies, we use exponential functions for full regression, as recommended in (Litvintseva & Karelin, 2020). As a result , the model of the influence of the GRP value on the IDI index by country has the form:

$$y_i = 1.848 \ln(GN_i) - 12.342, \quad (1)$$

where GNI_i – GDP (or GRP for regions) per capita in the equivalent of US dollars in the *i-th* region (country); *y* – the value of the IDI index in the i-th region (country) according to ITU data.

The calculated coefficient of determination R2 according to the selected statistical data was 0.869, which indicates that the accuracy of the selection of the regression equation is high. Figure 1 shows the obtained dependencies. It should be noted that for the convenience of analyzing the position of the Russian Federation in the rating in the figure, restrictions were imposed on the size of GRP (less than $60,000). As a result, a number of countries (Denmark, Norway, USA, Brunei, Switzerland, Qatar, Ireland, Singapore and Luxembourg) with GRP exceeding 60 thousand US dollars and an IDI value from 8.48 to 8.98 were excluded from the analysis. For comparison with the data of individual regions in Fig. 1, the values of the IDI index for the Southern Federal District, the North Caucasus Federal District, as well as Moscow and St. Petersburg are shown by triangles.

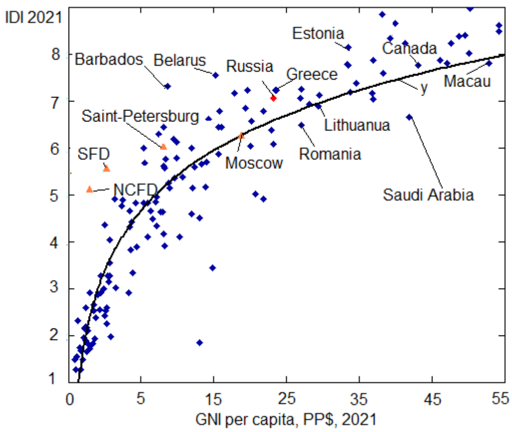

Fig. 1. Dependence of the ICT development index on the value of GRP per capita in the region for 2021: diamonds – actual values for the countries of the world according to statistics for 2021; triangles – actual values for the macro-region under study according to statistics for 2018; solid line - regression dependence for the countries of the world. *Source:* Compiled by the authors.

To analyze the ranking of federal districts by the level of ICT development relative to the world ranking, as before, we use exponential functions for full regression. The model of the influence of the GRP value on the IDI index for the studied federal districts of the macro-region has the form:

$$y_i=0.546\ \ln(GN_i)+0.834. \quad (2)$$

The coefficient of determination R^2 according to the selected statistical data was 0.985, which indicates that the accuracy of the selection of the regression equation is high.

As it was previously revealed for countries, there is a relationship between the GRP value and indicators of the development and use of ICT. The calculated correlation coefficients between the GRP value and indicators of the development and use of ICT in the subjects of the macro-region are given in Table. 1. In the course of the correlation analysis, the Republic of Crimea and the city of Sevastopol were excluded, in which significant differences between the indicated administrative units are mainly due to Western sanctions imposed against them to ban the use of communication equipment.

Table 1. Correlation between GRP per capita and indicators of ICT development and use.

GRP per capita, thousand US dollars 2019	Internet users, %	Traffic of mobile BBA in the Internet, Gb	Households with a computer, %	Households with Internet access, %
1	0.51	-0.531	0.785	0.092

Source: Compiled by the authors.

The regression equation for the dependence of the amount of mobile broadband traffic to the Internet after excluding the anomalous value corresponding to the Republic of Chechnya has the form:

$$y_i=90.519\ \exp(-0.267GN_i)+138.629. \quad (3)$$

The coefficient of determination R^2 according to the selected statistical data was 0.387, which indicates that the accuracy of the selection of the regression equation is relatively high.

3.2. Assessment of the digital divide in the “Transport and Storage” industry between the subjects of the macro-region

Transport, as you know, is a link between various sectors of the economy. In accordance with the passport of the project "Strategies for Digital Transformation of the transport industry of the Russian Federation" with a deadline of 2021-2030, the transport industry of the Russian Federation currently faces a number of challenges. Among them, we can note the high accident rate due to the human factor, the inefficiency of the transportation process by traditional modes of transport, low mobility of the population, the possibility of financial fraud when paying for travel in cash, low awareness and coordination of actions of federal, regional and local authorities, subjects of transport activities on issues of transport security (including transport security, cybersecurity) and a number of others. At the basis of the implementation of measures to respond to these challenges in the project "Strategies for Digital Transformation of the Transport Industry of the Russian Federation" (Grishaeva, 2018; Abdrakhmanova et al., 2021; Alsweity et al., 2021; Krasyul, Kolgan & Medvedeva, 2021; Marchenko et al., 2021; Popov et al., 2022) there are such infocommunication technologies as broadband Internet, cloud services, RFID technologies, ERP systems, electronic sales. The analysis of the relationship between infocommunication technologies used in the digitalization of the industry showed that Russia is not among the leading countries in terms of the digitalization of the "Transportation and Storage" industry, but actually closes the rating. The gap is 21 points with a maximum digitalization index of 48 points. The impact of digitalization of the "Information Technology" and "Telecommunications" industries on the digitalization of the "Transportation and Storage" industry is the greatest compared to other industries. This conclusion is confirmed both by the definition of the term digitalization given above and by the calculated correlation coefficients of 0.739 and 0.849, respectively. Comparison of these coefficients shows that the impact of digitalization of the "Information Technology" and "Telecommunications" industries on the digitalization of the "Transportation and Storage" industry is not the same. This is also confirmed by regression equations. Thus, the regression equation linking the indices of digitalization of the TT industry "Telecommunications" and "Transportation and Storage" has a linear character:

$$y_i=0.64\ TT_i. \quad (4)$$

The digitalization indices of the IT industry "Information technology" and "Transportation and Storage" are interconnected by an exponential regression equation:

$$y_i=2.34\ \exp(0.04IT_i)+13.816. \quad (5)$$

The coefficient of determination is equal for equation (4) R^2=0.717, for equation (5) – 0.57, which indicates a high accuracy of the selection of the regression equation.

Let's perform an assessment of digitalization in the subjects of the South Russian macro-region. To assess the digital inequality of subjects, we use the data in Table 2, which shows the values of the digitalization index and its components provided by state statistics bodies.

Table 2. The index of digitalization of the industry and its components by objects of the studied macro-region for 2019.

Subject	**PPP Index**	**Digitalization Index / Rating Group**	**BBA, %**	**Cloud technologies, %**	**RFID-technologies, %**	**ERP-systems, %**
Russian Federation	-	31/-	86	27.1	6.8	21.8
Moscow	-	28/1	90.1	29.7	4.8	15.1
Saint-Petersburg	-	26/1	87.8	26.4	4.5	11
SFD	-	30/-	94.2	30.8	8	19.5
Republic of Adygea	14.5 %	26/3	86	24.9	5.6	11.4

Republic of Kalmykia	9.0 %	26/3	89.1	27.6	4.6	9.3
Republic of Crimea	25.2 %	21/3	77.5	17.8	2.1	7.7
Krasnodarskiy Krai	37.0 %	25/2	87.8	25.6	4.7	6.2
Astrakhan Region	51.6 %	26/2	87.8	25.1	6	13.1
Volgograd Region	50.3 %	26/2	88.5	25.5	5.7	11.2
Rostov Region	50.4 %	24/2	78.8	22.7	6.2	11.2
Sevastopol	20.2 %	26/2	88.5	26.2	4.7	6.2
NCFD	-	27/-	90.1	28	8.2	6.5
Republic of Dagestan	23.9 %	22/3	79.2	21.3	3.3	6.2
Republic of Ingushetia	10.2 %	16/3	62	13.1	2	2.2
Kabardino-Balkarian Republic	29.7 %	27/3	93	30.7	2.6	7.4
Karachay-Cherkess Republic	12.4 %	24/2	79.6	33	2.7	5.8
Republic of North Ossetia-Alania	9.6 %	24/3	84.7	24.9	3.4	7.2
Chechen Republic	11.3 %	24/3	83.6	23.9	4	8.3
Stavropol Krai	48.0 %	21/3	85.1	14.8	2.6	2.8
The highest index value	51.6 %	27	93	30.7	8.2	13.1
The smallest index value	9.0 %	16	62	13.1	2	2.2
The ratio of the largest index value to the smallest	5.73	1.69	1.5	2.34	4.1	5.96
Coefficient of variation	61.5 %	12.58 %	9.99 %	19.34 %	36.12 %	35.71 %

Source: Compiled by the authors.

The main difficulty of digitalization in the Southern Russian macro-region is the small number of 4G networks necessary for the full-scale use of the advantages of digital technologies. According to statistics, only a third of cellular base stations support it. The introduction of the 5G standard even before the introduction of Western sanctions was postponed until 2022, and currently for an even longer period – until 2025. When choosing a communication standard, we use the Recommendation of ITU-R M.2083-0 "The concept of IMT – The basics and general objectives of the future development of IMT for the period up to 2020 and beyond". In accordance with it, the communication standard is calculated by the size of the territorial density of consumers. Table 3 shows the results obtained for the regional centers and capitals of the republics of the macro-region under study.

Table 3. Recommended mobile communication standards in the regional centers of the subjects of the South Russian macro-region.

Subject	**Population density, people per km^2**	**Minimum acceptable standard**	**Subject**	**Population density, people per km^2**	**Minimum acceptable standard**
Nalchik	3876	3G	Nazran	1332	3G
Krasnodar	3753	3G	Makhachkala	1291	3G
Rostov-on-Don	3255	3G	Volgograd	1165	3G
Simferopol	3130	3G	Elista	1120	3G
Stavropol	2668	3G	Vladikavkaz	1024	3G
Astrakhan	2485	3G	Grozny	1007	3G
Maykop	1997	3G	Sevastopol	604	3G
Cherkessk	1756	3G	Moscow	15000	5G

Source: Compiled by the authors.

3.3. Assessment of the negative consequences of digitalization of the industry "Transportation and storage" in the South Russian macro-region

Using the methodology (Mordachev, 2016; Mordachev, 2019), an assessment was made of the change in the electromagnetic background on the territory during the deployment of a wireless broadband Internet access network. The possibility of its application is confirmed by the data of Table 3.

When conducting research, we will assume that the height of the base station antenna is 25 m, and the observation point is located at a height of 2 m above the ground level, which is the standard height when assessing the electromagnetic background. In addition, it was assumed that the population density varies from 0 to 10 thousand people per square kilometer, which makes it possible to cover almost all cities of the macro-region under study (with the exception of one of the cities used for comparison, Moscow). Figure 2 shows the dependence of the Z coefficient of the change in the intensity of the quasi-stationary electromagnetic background (EMB) generated by all subscriber stations with a transmitter power of 0.1 W near the observation point, relative to the standard EMB corresponding to the to the maximum permissible power level for a given territory, on the population density for various communication standards.

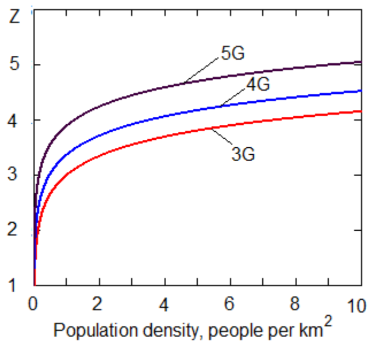

Fig. 2. Dependence of the coefficient Z of the change in the intensity of the quasi-stationary EMB on the population density for various communication technologies. *Source:* Compiled by the authors.

4. Discussion

4.1. Results of the assessment of ICT development in the South Russian macro-region

The assessment will be carried out consistently, starting with determining the level of ICT development in Russia in the world ranking. To do this, we will use Fig.1 and the data in the table.1. From the analysis of Figure 1, it is easy to see that Russia currently belongs to countries with a developing digital economy. It is not included in the group of leaders (USA, UK, South Korea, Sweden, etc.). In terms of its digital development, Russia correlates with the former Warsaw Pact countries, as well as the Baltic republics of Lithuania and Latvia. Therefore, we can say that investments in the development of the digital economy in Russia should lead to an increase in GRP per capita.

Analysis of the data in Fig. 1 shows that the IDI index for the federal districts of the macro-region is significantly higher than for countries with a similar level of GRP per capita. This is due to the fact that in Soviet times (before 1991), industrial and transport infrastructure was already created in these subjects, which is now partially preserved. The level of education of the population is high. In countries comparable in terms of GRP per capita, for example, in Africa, the construction of infrastructure must begin almost from scratch. Compared with other regions of Russia, the subjects of the macro-region lag far behind in the development and use of infocommunication technologies. In 2018, the federal districts of the macro-region under study occupied 7 (SFD) and 8 (NCFD) positions out of eight possible ones. In the ranking of regions by levels of digital maturity conducted by the Ministry of Statistics among 14 regions that fell into the low-level group, nine of them (Adygea, Dagestan, Ingushetia, Kabardino-Balkaria, Kalmykia, Crimea, North Ossetia, Stavropol Krai, Chechnya) belong to the South Russian macro-region.

From the analysis of Table 1, it also follows that the presence of a computer rather reflects the monetary income of the household. This relationship is also confirmed by the high correlation coefficient of 0.785, as well as the exclusion of this indicator when analyzing the degree of digital transformation of the region (Abdrakhmanova et al., 2021). To assess the level of digitalization, it is advisable to use an indicator reflecting the percentage of households with Internet access. Table 1 also shows one of the modern features of the population's access to the Internet: in regions with a low level of GRP per capita, access to the Internet is carried out through mobile wireless systems, i.e. smartphones and tablets. This conclusion is confirmed both by world experience on the example of African countries (Zvezdina et al., 2022), and by the dependence between the value of GRP per capita and the traffic of mobile broadband to the Internet on the example of the macro-region under study.

4.2. Analysis of the results of the assessment of the digital divide in the "Transportation and storage" industry between the subjects of the macro-region and identification of the direction of its elimination

The analysis will be carried out on the basis of the regression equations obtained in clause 3.2, linking the digitalization indices of the industries "Telecommunications" and "Transportation and storage", as well as "Information technology" and "Transportation and Storage". The form of these equations allows us to conclude that in the digitalization of the “Transportation and Storage” industry, the highest priority should be given to the development of specialized software (the Information Technology industry), and then the introduction of wireless communication technologies (the Telecommunications industry). The performed analysis confirmed a well-known pattern of ICT development (Kuzovkova, Gencur & Kuzovkov, 2016): the development of infrastructure of information and communication technology industries (in our case, digitalization of the "Information Technology" and "Telecommunications" industries) should outpace the digitalization of the industry in which they are used, i.e. the "Transportation and Storage" industry. Thus, we can say that the emergence of new opportunities in the “Transportation and Storage” industry is associated with the development of infocommunication technologies that allow implementing not only accounting functions, for example, tracking the position of a vehicle along the route, but also operations to optimize the flow of material resources based on logistics. The number of additional implemented functions and their quality directly depends on the degree of penetration of infocommunication technologies into the economy of the region (Grishaeva et al., 2018).

The performed analysis of Table 2 shows that the subjects of the macro-region differ greatly in terms of the digitalization index. The difference between the maximum and minimum values is 1.69 times. With subjects for comparison, the difference is 1.95 (for Moscow) and 1.75 (for St. Petersburg). The variation in the values of the digitalization index within the region is 12.58%. In terms of the use of broadband Internet access, the subjects of the macro-region are developed approximately equally. The coefficient of variation is approximately 10%. The greatest differences among the subjects of the macro-region are observed in the use of RFID technologies and ERP systems. For these subindices, the coefficients of variation are 36.12% and 35.71%, respectively.

According to open sources, the main factors affecting the uneven development of digitalization in the regions are the following four: lack of qualified personnel; little funding; insufficient number of cellular base stations operating on 4G (LTE) technology; incompleteness of the formation of a new regulatory environment.

The obtained results of the analysis allow us to suggest possible ways to reduce the digital divide in the macro-region:

- The lack of qualified personnel in the regions can be eliminated by increasing the admission control figures for the relevant specialties. In the Southern Russian macro-region, the leading higher educational institution for training specialists in the digitalization of the "Transportation and Storage" industry (Transport and Logistics) is the Don State Technical University. Within the framework of this university, the departments of "Hardware and Software Complexes", "Radio Electronics" and "Operation of Transport systems and Logistics" of the Faculty of "Transport, Service, Operation" train bachelors and masters both in the field of vehicles and logistics, and wireless communication systems that provide, among other things, broadband Internet access. The modern approach to the educational system allows you to take into account any requirements of employers and adjust the educational program within the higher educational institutions.
- Small investments in the development of ICT within macro-regions are due to the development of ICT according to an inertial scenario (Nikitaeva, Maslyukova & Podgainov, 2019). For comparison: in the leading subjects, investments amount to $25,400,000 in Moscow and $2,020,000 in St. Petersburg, in the Southern Federal District they amount to $1,520,000, and in the NCFD – $0.250,000. In order to change the development scenario to an innovative scenario in (Nikitaeva, Maslyukova & Podgainov, 2019), it is proposed to pay attention in less developed subjects to the development of a public-private partnership (PPP) mechanism. The effectiveness of this mechanism has been confirmed in a number of African countries (Nigeria, Ghana, Kenya, Tanzania, etc.), in which this mechanism has been operating for about 20 years (Zvezdina et al., 2022). For the subjects of the South Russian macro-region in (Nikitaeva, Maslyukova & Podgainov, 2019), the relationship between the PPP index and the investment attractiveness index (correlation coefficient $R^2=-0.75$) was revealed: regions with a small PPP index are the most attractive from the point of view of investment.

- The problem of a small number of base stations in the regions can be solved by optimizing the communication standards used in regional centers and on the periphery. In regions with low population density, which mostly include regional and republican centers of the macro-region, the deployment of broadband access networks with 4G technology is due to the need for increased economic development, rather than a high territorial density of consumers, and requires a longer period of ICT infrastructure development. In regions with a high population density, for example, in Moscow, the deployment of 5G networks is due to the high territorial density of consumers.

The passports of the "Digital Transformation Strategy" projects approved in 2021 for each subject are the confirmations of the correctness of the formulated directions for reducing the digital divide in the macro-region. In them, directions for the development and use of information and communication technologies were formulated for each subject in key areas of the economy.

4.3. Results of the assessment of the negative consequences of digitalization of the “Transportation and Storage” industry in the South Russian macro-region

The results of the assessment of the negative consequences of digitalization of the industry showed that the change in the communication standard from 3G to 5G, i.e. the increase in the operating frequency, leads for the same locality to an increase in quasi-stationary EMB from 3.8 to 4.5 times the relative standard EMB corresponding to the maximum permissible power level for a given territory. It should be noted that only one frequency was taken into account in the calculations (1.8 GHz for 3G, 2.6 GHz for 4G and 4.4 GHz for 5G). When taking into account the entire frequency range used in 5G in macro cells for voice and data transmission, the total EMB will increase significantly. An additional increase in EMB in 5G in the low-frequency range is also due to an increase in the number of base stations due to a decrease in the size of the macro cell.

Summarizing the above, we can say that the current state of the digitalization level does not cause a significant electromagnetic load on the territory. A local change in the electromagnetic background associated with the radiation of base station antennas in 4G cellular communication systems can be compensated by the implementation of well-known organizational measures described, for example, in (Zvezdina et al., 2018a; Zvezdina et al., 2018b; Skrynnikov, Paltsyn & Devyatkin, 2019; Spodobaev, 2019; Zvezdina et al., 2020; Maslov & Spodobaev, 2021a; Maslov & Spodobaev, 2021b; Spodobaev, 2021; Zvezdina et al., 2021). The delay in the development of 5G networks, caused along with the reasons common to the whole country by the need to develop an appropriate ICT infrastructure in the macro-region, will allow the subjects of the South Russian macro-region to prepare more carefully for measures to eliminate the negative effects of the deployment of these networks.

4. CONCLUSION

The research and development results presented in the paper can be summarized in the following conclusions.

- The process of digital transformation of various sectors of the economy is currently a global trend in economic development. This is due to the fact that with relatively small investments and for a relatively short time interval, it provides a 0.5-3% increase in GDP, depending on the initial level of development of the country's economy, which, in turn, makes the latter more competitive. At the moment, the Russian Federation, in terms of the level of development and use of information and communication technologies, belongs to countries with developing economies (Greece, Croatia, Turkey, Malaysia).
- The process of increasing the digital maturity of the country's economy, and, consequently, its competitiveness, is associated with several aspects. Firstly, with the availability of broadband wireless Internet access networks (4G/LTE, 5G). It is on their basis that the advantages of digitalization can be used with less expensive Internet access via smartphones and tablets compared to a stationary computer. Secondly, in the absence of digital inequality between the regions that are part of the state. Thirdly, in the presence of highly qualified personnel in the field of ICT. Fourth, if there is a regulatory environment that provides a favorable legal regime for the emergence and development of digital technologies. At the same time, the modern approach to the digitalization process has allowed us to narrow the field of research and limit it to one branch of "Transportation and Storage" ("Transport and Logistics", depending on the statistical source) on the territory of the South Russian macro-region, which unites the Southern and North Caucasian Federal Districts. The choice of the industry is due to its inclusion in the five mandatory for digitalization, marked in the passport of the project "Digital Transformation Strategy".
- The analysis of the level of development and use of ICT in the South Russian macro-region showed that according to this indicator, the macro-region occupies the last two places in Russia. This is due to the fact that, firstly, the subjects of the macro-region are mainly subsidized, and, secondly, an inertial investment scenario was used during digitalization. Transition to an innovative scenario, as in the subjects for comparison (Moscow and St. Petersburg), is achieved by the development of a public-private partnership mechanism in subjects with low values of the digitalization index, which has proven itself well after 20 years of operation in African countries. This mechanism will eliminate digital inequality within the macro-region. It is possible to provide highly qualified personnel with the digitalization process of the “Transportation and Storage” industry by expanding the admission and adjusting the program of bachelors and masters studying at the Faculty of “Transport, Service and Operation” of the Don State Technical University.

The analysis of the economic development of the macro-region, as well as the distribution of population density across its territory, showed that the most optimal broadband Internet access technology for it is the 4G/LTE standard. The assessment of the environmental impact of these networks on the electromagnetic background of the territory showed that the current state of the digitalization level does not cause a significant electromagnetic load on the territory. A local change in the electromagnetic background associated with the radiation of base station antennas can be compensated by the implementation of well-known organizational measures. The delay in the development of 5G networks, caused along with the reasons common to the whole country by the need to develop an appropriate ICT infrastructure in the macro-region, will allow the subjects of the South Russian macro-region to prepare more carefully for measures to eliminate the negative effects of the deployment of these networks.

REFERENCES.

Abdrakhmanova, G. I., Bykhovsky, K. B., Veselitskaya, N. N., Vishnevsky, K. O., & Gohberg L. M. (2021). *Digital transformation of industries: starting conditions and priorities.* Moscow, Russia: Higher School of Economics Publ.

Alsweity, M. A., Muthanna, A. S., Borodin, A. S., & Koucheryavy, A. E. (2021). A system for detecting and recognizing moving biological objects for unmanned vehicles based on intelligent edge computing. *Electrocommunication*, 9, 35-41. DOI: 10.34832/ELSV.2021.22.9.004

Arkhipova, M. Yu., & Sirotin, V. P. (2019). Development of digital technologies in Russia: regional aspects. *Economy of region*, 15(3), 670-683. DOI 10.17059/2019-3-4

Bakulin, M. G., Varukina, L. A., & Krejndelin, V. B. MIMO technology: principles and algorithms. Moscow, Russia: Gorjachaja linija-Telekom Publ.

Bukht, R. & Heeks, R. (2018). Defining, Conceptualizing and measuring the Digital Economy. *International Organizations Research Journal*, 13 (2), 143-172. DOI:10.17323/1996-7845-2018-02-07

Devyatkin, E. E., & Ivankovich, M. V. (2021). 6G mobile networks. Action plan for Russia. *Electrocommunication*, 10, 14-22. DOI: 10.34832/ELSV.2021.23.10.002

Grishaeva, Yu. M., Matantseva, O. Yu., Spirin, I. V., Savosina, M. I., Tkacheva, Z. N., & Vasin, D.V. (2018). Sustainable development of transportation in the cities of Russia: experience and priorities. *South of Russia: ecology, development*, 13(4), 24-46. DOI:10.18470/1992-1098-2018-4-24-46

Grishchenko, N. (2020). The gap not only closes: Resistance and reverse shifts in the digital divide in Russia. *Telecommunications Policy*, 44(8), 102004. DOI:10.1016/j.telpol.2020.102004

Kaneva, M., & Untura, G. (2019). The impact of R&D and knowledge spillovers on the economic growth of Russian regions. *Growth and Change*, 50(1), 301-334. DOI: 10.1111/grow.12281

Kasimova, T. M., Magomedova, S. R., & Rabadanova, M. G. (2021). Assessment of the level of development of information and communication technologies and its impact on the region economy. *Fundamental research,* 5, 13-18. DOI: 10.17513/fr.43032

Kramin, T. V., & Imasheva, I. Yu. (2020). On the issue of benchmarking by the example of analyzing the efficiency of using the broadband Internet in the Russian regions. *Actual Problems of Economics and Law*, 14(1), 67-78. DOI:10.21202/1993-047X.14.2020.1.67-78

Krasyul, I., Kolgan, M., & Medvedeva, Y. (2021). Development of an Ecosystem Approach and Organization of Logistics Infrastructure. *Transport Research Procedia*, 54, 111-122. DOI:10.1016/j.trpro.2021.02.054

Kuzovkova, T. A., Gencur, M. A., & Kuzovkov, A.D. (2016). Methodological apparatus of the integrated forecasting of the development of infocommunications. *Systems of Control, Communication and Security*, 1, 146-190.

Litvintseva, G. P., & Karelin, I. N. (2020). Effects of digital transformation of the economy and quality of life in Russia. *Terra Economicus*, 18(3), 53-71. DOI:10.18522/2073-6606-2020-18-3-53-71

Marchenko, Yu. V., Marchenko, E. V., Popov, S. I., Kuren, S. G., & Marchenko, I. V. (2021). Automated transport and storage systems for road transport companies. *IOP Conference Series: Materials Science and Engineering*, 1083. DOI:10.1088/1757-899X/1083/1/012063

Markov, M. S. (2013). Discussion of the article by Y. G. Grigoryev "Comparison of hazard assessment of ionizing and non-ionizing electromagnetic radiation" published in the journal "Radiobiology. Radiation Ecology" (2012, V. 52, N2, pp. 215-217). *Radiobiology. Radiation ecology*, 53(2), 105-107. DOI: 10.7868/S0869803113010086

Maslov, M. Yu., & Spodobaev, Yu. M. (2021a). Legal support status of electromagnetic safety. *Electrocommunication*, 9, 16-22. DOI: 10.34832/ELSV.2021.22.9.001

Maslov, M. Yu., & Spodobaev, Yu. M. (2021b). The convergence of biomedical and technical aspects of electromagnetic safety. *Electrocommunication*, 2, 14-21. DOI: 10.34832/ELSV.2021.15.2.001

Mirolubova, T. V., & Radionova, M. V. (2021). Assessing the impact of the factors in digital transformation on the regional economic growth. *Russian Journal of Regional Studies*, 29(3), 486-510. DOI: 10.15507/2413-1407.116.029.202103.486-510

Mordachev, V. I. (2016). Electromagnetic background created by base and mobile radio stations of cellular communications. *BGUIR Reports*, 95(1), 38-44.

Mordachev, V. I. (2019). Estimation of intensity of electromagnetic background, created by wireless systems of public information services, on the base of forecast of traffic terrestrial density. *BGUIR Reports*, 120(2), 39-49.

Ndungu, N., Morales A., & Ndirngu L (2016). The monetary fruits of the digital revolution. *Finance and development*, 6, 14-17.

Nikitaeva, A. Yu., Maslyukova, E. V., & Podgainov, D. V. (2019). Role of Public and Private Partnership in Implementing Development Strategies of the South of Russia. *Regional Economy. South of Russia,* 7(3), 94-106. DOI: 10.15688/re.volsu.2019.3.10

Pastukh, S. Y., Devyatkina, M. E., & Sukhodolskata, T. A. (2014). Development trends and the role of broadband in the global scale. *Electrocommunication*, 10, 8-11.

Popov, S., Galchenko, G., Marchenko, J., & Drozdov, D. (2022). Use of neural networks and autopilot for quick and accurate grain discharge on the elevator. *Smart Innovation, Systems and Technologies*, 247, 45-53. DOI:10.1007/978-981-16-3844-2_6

Radelet, S. (2016). Is the Rise of Africa Interrupted? *Finance and development*, 6, 6-11.

Rappaport, T., Xing Y., Maccartney, G., Molish, A., Mellios, E., & Zhang, J. (2017). Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless networks – With a Focus on Propagation Models. *IEEE Transactions on Antennas and Propagation*, 65(12), 6213-6230. DOI: 10.1109/TAP.2017.2734243

Safiullin, A. R., & Moiseeva, O. A. (2019). Digital Inequality: Russia and other countries in the Fourth industrial revolution. *St.-Petersburg State Polytechnical University Journal. Economics*, 12(6), 26-37. DOI: 10.18721/JE.12602

Salahov, A. Z. O. (2020). Assessment of human exposure to fifth-generation 5G mobile communications through experimental measurement and extrapolation of the maximum electromagnetic field strength. *Bulletin of the Russian New University. Series: Complex Systems: models, analysis and management,* 5, 29-39. DOI: 10.25586/RNU.V9187.20.05.P.029

Schvab, K. (2017). *The Four Industrial Revolutions*. New York, NY: Crown Business.

Skrynnikov, V. G., Paltsyn, D. A., & Devyatkin, E. E. (2019). Specifics of the assessment of EMC conditions for 5G networks. *Electrocommunication*, 5, 22-27.

Spodobaev, Yu. M. (2019). Updating approaches to the regulation of the electromagnetic fields created by 5G network technologies. *Electrocommunication*, 6, 14-18.

Spodobaev, Yu. M. (2021). Social Consequences of falsification of scientific materials in electromagnetic safety. *Electrocommunication*, 2, 21-25.

Suleiman, A., Gee, T. T., Krishnapillai, A. D., Khall, K. M, Hamid, M. W., & Muatapa M. (2014). Electromagnetic radiation health effects in exposed and non-exposed residents in Penang. *Journal of Geoscience and Environmental Protection*, 2, 77-83. DOI:10.4236/gep.2014.22012

Zvezdina, M. Yu., Shokova Yu. A., Al-Ali H. T., Al-Farhan G. H. (2018a). Electromagnetic background strengthening as a negative result of digital economy advance (Review). *International scientifical journal Theoretical & Applied Science*, 3(59), 29-42. OI:10.15863/TAS.2018.03.59.7

Zvezdina, M. Yu., Shokova, Y.A., Nazarova, O. Yu., Al-Ali, H. T. A., & Al-Farhan, G. H. A. (2018b). Visualization of electromagnetic exposure near LTE antennae. *IOP Conference Series: Earth and Environmental Science*, 115. DOI:10.1088/1755-1315/115/1/012037

Zvezdina, M. Yu., Shokova, Yu. A., Prygunov, A. G., Palyanitsa, A. A., & Sumin, D. L. (2020). The necessity to assess the electromagnetic environment near 5-G radio-emitting with instrumental procedure. *IOP Conference Series: Earth and Environmental Science*, 543. DOI:10.1088/1755-1315/543/1/012011

Zvezdina, M. Yu., & Shokova, Yu. A. (2021). Features of electromagnetic situation estimation near 5G base station antennas. *IOP Conference Series: Earth and Environmental Science*, 688. DOI:10.1088/1755-1315/688/1/012011

Zvezdina, M., Shokova, Yu., Lavrentyev, O., & Kaba, A. (2022). Choosing a broad internet access network deployment model in the Republic of Guinea. *International scientifical journal Theoretical & Applied Science*, 1(105), 701-712. DOI:10.15863/TAS.2022.01.105.47