Comparative analysis of the level of digital infrastructure development: case of two Russian urban agglomerations

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Abstract. The purpose of the study is to develop a method for assessing the level of digital infrastructure development for doing business in a region and a comparative analysis on the example of the two largest urban agglomerations of the Russian Federation - Moscow and St. Petersburg. The relevance of the research topic is confirmed, on the one hand, by the special role of the Moscow and St. Petersburg in the Russian economy, on the other hand, by the current processes of digitalization going on in the Russian economy. The authors propose a refined concept of "digital infrastructure of the region", and justify the choice of indicators characterizing its level. The article presents the integral indicator for assessing the level of development of the region's digital infrastructure, based on separate indicators of two types, characterizing, on the one hand, the material basis and on the another hand, the access to digital infrastructure. The study used a formula for calculation of the integral indicator. The presented formula is the convolution of the indicators of two types taking into account the relative significance of every indicator. The comparative analysis has been carried out, and recommendations have been developed for increasing the level of digital infrastructure development in the largest urban agglomerations of the Russian Federation - Moscow and St. Petersburg.

1. Introduction
The most important task of the upcoming years is the transition of enterprises and organizations of the Russian economy to digital technologies of design, production and management. However, the business operates in a certain infrastructure environment, which can create conditions favorable or, conversely, unfavorable for the implementation of digitalization processes. That is why the governmental program “Digital Economy of the Russian Federation”, among its goals, is also “creating the necessary institutional and infrastructural conditions” [1] for the development of the digital economy. However, the concept of “digital infrastructure” applied to the region, as well as the issue of determining the level of development of digital infrastructure were not adequately reflected in the scientific literature, and, as a result, a unified and generally accepted approach was not formed. The solution to this scientific problem will allow us to determine the level of readiness of the regions for digitalization of the economy, to identify the regions that are leaders in this field and to disseminate their experience, as well as to carry out the process of managing the development of
digital infrastructure of the regions, monitoring the dynamics of the process over time. A particularly important issue of managing the development of digitalization seems to be for the two largest urban agglomerations of Russian Federation - Moscow and St. Petersburg (12507 thousand people and 5316.8 thousand people in 2017) [2], since these regions are leaders in the production of gross regional product among subjects of Russian Federation and need in intensive development, taking into account their role in the economy of the country.

In the context of a growing level of digitalization of society, the role of digital infrastructure in the innovative development of the region is noticeably increasing, which is convincingly proved by studies of the functioning and development of regional innovation systems [3-7]. Note that in these studies, the authors focus on the problem of the development of the innovation system of the region as a whole. The implementation of a regional innovation policy, which includes a policy for the development of digital infrastructure, has clear administrative boundaries, while urbanization processes lead to an increase in urban agglomerations that act as supra-regional entities. The development of urban agglomerations generates interest in the effects arising in such a multicomponent dynamic system [8-11].

Considering the role of mega policies in the modern world economy, T. Kharlamova [12] shows their role in ensuring sustainable development and the importance of developing their information infrastructure. In continuation of this approach, the authors of [13] emphasize the need for careful goal setting and analysis of the process and results of innovation in a metropolis to ensure its sustainable development.

The digitalization of business and social processes led to the emergence of the concept of “smart city”, which at some point came into conflict with the concept of sustainable development [14]. However, we agree with the authors that the development of “smart sustainable cities” becomes most relevant, and in the first place for city-centers of agglomerations, large cities, megalopolises.

Gil-Garcia, JR, Pardo, TA, DeTuya, M. [15] found specific characteristics of modern large cities and megalopolis in terms of their impact on the benefits and problems of information exchange in context of Smart City concept. Considering them in the relation to the possibilities of using smart city projects, the authors identified such specific characteristics of the large cities and megalopolis as a high level of financial resources and technical skills. For small cities and municipalities, the lack of financial resources and technical skills in urban structures is one of the most important problem for innovative development, including digital one.

One of the most comprehensive studies of the innovation policy for the development of megalopolises is the work of CaragliuA., DelBoC.F [16], which analyzed data on 309 European megalopolis in terms of the impact of the Smart City policy on urban innovation and revealed that joint participation in urban projects of the large multinational corporations along with local government bodies, as well as local small and medium-sized business companies, are accelerating the innovative development of the metropolis. Similar results were obtained in [17], where the experience of designing information hubs for the implementation of the large Russian project “Smart City. Successful region” in the Samara agglomeration. The paper [18] is also investigating the Smart city concept in context of IT services providing.

The study [19] analyses the role of infrastructure-intensive companies and enterprise architecture designing in big cities. The modern IT, such big data and intelligent technologies in economic systems management are the research objects for the papers [20, 21]

Emphasizing the special role of large cities and megalopolises in the digitalization of the country's economy, the authors of scientific papers focus on identifying factors of various natures in the study of their digital infrastructure and essentially less attention is paid to the problem of quantitative assessment.

So Zemtsov, S., Barinova, V., Semenova, R. distinguish diversification, concentration of human capital, favorable conditions for entrepreneurship, the creative potential of residents and the development of ICT infrastructure as the key factors in the development of digital infrastructure [22].
The most profound methodology for assessing the development of digitalization of different objects has been developed in works on the development of digital ecosystems. The paper [23] proposed a detailed list of indicators for calculating the development index of the country's digital ecosystem, aggregated into four groups: ICT adoption, connectivity, absorption capacity, influenced by social capital. A slightly different list was compiled by Katz, R., Koutroumpis, P., Callorda, F.M. [24], who proposed assessing the level of digitalization of the country using a composite index, which includes six indicators: accessibility, investment in infrastructure, network access, capacity, use and human capital. However, we note that these works considered the digital ecosystem of the country not the country's region or city. Therefore, in our opinion, this approach needs to be adapted to be interpreted taking into account the specifics of large cities, including megacities and megalopolises.

A study carried out at the Center for Financial Innovations and Cashless Economics of the Moscow School of Management Skolkovo [25] offers a methodology for assessing the digital development of a region. The study highlights the section “Information Infrastructure”, but does not base its rating on digital development of regions on objective statistics, but on events covered in the media space, that means on the results of monitoring publications about facts, events related to the implementation of an information infrastructure element. Moreover, the methodology of calculating the index involves a rather complex mechanism for calculating indices and sub-indexes with an assessment of reliability.

In [26, 27], a set of indicators of regional innovative development was proposed, among which the indicator number of innovation infrastructure objects, which reflects to a certain extent the level of development of digital infrastructure, is presented. However, this list needs to be supplemented in the relation to the goals and objectives of this study.

Thus, an analysis of the scientific literature confirmed the relevance of solving the problem of determining the level of development of digital infrastructure for doing business in the region, which is especially important for the two largest Russian urban agglomerations. Therefore, the purpose of the article is to develop the method of calculating the level of development of digital infrastructure for doing business in the region, a comparative analysis of this indicator on the example of the two largest urban agglomerations of Russian Federation - Moscow and St. Petersburg.

To achieve the goal, the following tasks were solved:

− an analysis and clarification of the concept of “digital infrastructure of the region” in relation to the conditions of doing business in the region;
− two key components of the digital infrastructure for doing business have been identified: material and information and communication subsystems;
− the parameters available in the Rosstat database characterize the level of development of the digital infrastructure of the region according to the two components mentioned above;
− an integral indicator of the level of development of the digital infrastructure of the region and a methodology for its calculation, taking into account the significance of the two identified components, are proposed;
− a comparative analysis of the level of development of digital infrastructure for doing business in Moscow and St. Petersburg;
− the measures are proposed to increase the level of development of digital infrastructure for the two largest urban agglomeration of Russian Federation - Moscow and St. Petersburg.

2. Materials and methods
The concept of a digital infrastructure for running a megalopolis business, in our opinion, includes conditions that determine the opportunities and barriers to digitalizing a business. These conditions are associated, on the one hand, with the technical capabilities available in the city for digitalization, and on the other, with access to modern information and communication technologies. Therefore, in the digital infrastructure of the megalopolis, two key components can be distinguished: material and information and communication subsystems. The material subsystem characterizes the provision of the region with material resources that is technical means at the disposal of the region's economic entities
and the possibilities of their use in their activities. The information and communication subsystem characterizes the degree of use of modern information and computer networks and systems.

It is proposed to look at the level of development of the digital infrastructure of a large metropolis as a numerical indicator that reflects, first of all, the ability of organizations to access the information resources and technologies used in the city on the one hand, and, on the other hand, the actual use of information and communication and digital technologies by enterprises and organizations of the city.

In accordance with the data presented in the materials of Rosstat, all indicators characterizing the level of development of the digital infrastructure of a large metropolis in the context discussed above can be divided into two groups.

The first group of material indicators includes:

- Costs of information and communication technologies in the total volume of GRP, %.
- Use of personal computers, % of organizations.
- Use of servers, % of organizations.
- Use of global networks, % of organizations.
- Use of the Internet, % of organizations.
- The broadband access of them, % of organizations.

The indicators of this group characterize the general material conditions and technical prerequisites for the formation of a digital economy.

The data for the first group of indicators for the two largest cities in Russia - Moscow and St. Petersburg are presented in Table 1.

Table 1. The values of the selected material indicators of the largest cities of Russia for 2010-2017. [2]

| Indicator for megalopolis organizations | St. Petersburg | Moscow |
|----------------------------------------|---------------|--------|
|                                        | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Costs of information and communication technologies in the total volume of GRP, % | 2,1  | 1,67 | 3,33 | 2,03 | 1,74 | 2,32 | 3,23 | 3,37 | 4,14 | 4,97 |
| Using personal computers, % of organizations | 98,0 | 98,2 | 95,8 | 96,5 | 98,2 | 100 | 100 | 100 | 100 | 100 |
| Using servers, % of organizations | 32,8 | 47,1 | 71,0 | 73,5 | 75,0 | 44,1 | 54,0 | 83,7 | 79,1 | 74,8 |
| Using global information networks, % of organizations | 96,9 | 97,5 | 95,3 | 96,0 | 97,7 | 98,8 | 99,2 | 99,6 | 99,2 | 99,0 |
| Using Internet, % of organizations | 96,8 | 97,4 | 94,9 | 95,9 | 97,4 | 98,7 | 99,1 | 99,4 | 99,1 | 98,9 |
| The broadband access of them, % of organizations | 93,3 | 93,1 | 90,5 | 91,2 | 93,5 | 97,4 | 96,8 | 95,0 | 95,5 | 94,9 |

The second subsystem of indicators characterizing the information and communication subsystem can include:

- Organizations using ICT, % of organizations
- Relative value of organization expenses on ICT, %
Organizations that had a Website, % of the total number of organizations surveyed.
Organizations using electronic document management systems, % of the total number of organizations surveyed.
Organizations that used special software, % of the total number of organizations surveyed.

The indicators of the second group form an idea of the level of development and use of information and communication technologies and software (Table 2).

Table 2. Indicators characterizing the ICT subsystem of cities [2]

| Indicator for organizations | St. Petersburg | Moscow |
|-----------------------------|----------------|--------|
|                             | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 |
| Organizations that had a website, % of the total organizations surveyed | 69,2 | 64,7 | 62,6 | 65,8 | 68,4 | 78,0 | 71,9 | 72,8 | 70,5 | 66,8 |
| Organizations using automatic exchange data between their external information systems, % | 30,8 | 67,9 | 72,4 | 76,1 | 76,2 | 30,3 | 69,3 | 78,7 | 79,4 | 78,3 |
| The relative value of organizations spending on ICT, % | 18,9 | 15,9 | 38,5 | 26,8 | 24,9 | 29,9 | 46,3 | 49,8 | 74,7 | 100,0 |
| Organizations using electronic document management systems, % | 63,2 | 63,1 | 65,8 | 69,6 | 69,9 | 62,9 | 66,9 | 71,3 | 71,1 | 70,5 |
| Use of special software, % of the total number of organizations surveyed | 93,9 | 94,2 | 91,3 | 90,9 | 92,4 | 96,9 | 96,0 | 95,4 | 93,9 | 93,1 |

The research methodology is based on general scientific methods, such as content, comparative analysis, analogy method, as well as special methods, in particular, proposed in [28] method for calculating the quantitative value of the level of development of the digital infrastructure of the region, which can be adapted to the study goals.

Since for the purposes of comparative analysis it is important to have a generalizing, integral indicator characterizing the level of development of the digital infrastructure of the regions, it is necessary to propose a method for its calculation. As presented above, among the indicators characterizing the level of development of the digital infrastructure, two groups can be distinguished: indicators characterizing the general material conditions and technical prerequisites for the formation of the digital economy, indicators that give a certain idea of the level of development and use of information and communication technologies and software. The indicators of the second group, as shown by a survey of experts, have more significance for business since they determine the real use of ICT, while material indicators reflect the conditions for the use of ICT.

Then the integral indicator can be calculated as the sum of two weighted generalized indicators for the above groups calculated on the basis of normalized particular indicators of each group. Moreover,
the indicators of the first group are included in the integral indicator with the weight coefficient \( k_m \), and the indicators of the second group with the weight coefficient \( k_{ik} \).

The formula for calculating the integral indicator:

\[
I_{di} = k_m \sum_{i=1}^{Nm} \frac{P_{mi}}{N_m} + k_{ik} \sum_{i=1}^{Q_{ik}} \frac{P_{ikl}}{Q_{ik}}
\]

- Where \( I_{di} \) - is a calculated value, an integral index of the level of development of the digital infrastructure of the region;
- \( P_{mi} \) - the \( i \)-th normalized indicator of the group of material indicators characterizing the level of development of the digital infrastructure of the region;
- \( N_m \) – the number of indicators of the first group characterizing the level of development of the digital infrastructure of the region;
- \( k_m \) – coefficient of significance of the indicators of the first group, the group of material indicators characterizing the level of development of the digital infrastructure of the region;
- \( P_{ik} \) – the \( i \)-th normalized indicator of the second group of indicators characterizing the level of development of the digital infrastructure of the region;
- \( Q_{ik} \) – the number of indicators of the first group characterizing the level of development of the digital infrastructure of the region;
- \( k_{ik} \) – the coefficient of significance of the indicators of the second group of indicators characterizing the level of development of the digital infrastructure of the region.

Then the sequence of calculation of the integral indicator will include the following steps.
1. Definition of a list of indicators characterizing the level of development of the digital infrastructure of selected regions for the two groups presented above.
2. The choice of period for analysis and the determination of numerical values of indicators for the selected period.
3. Rationing the values of selected indicators.
4. Calculation of an integral indicator of the level of development of digital infrastructure of selected urban agglomerations for the selected time period.
5. Analysis of the results and conclusions.

3. Results
The results of calculating the total indicator for the first subsystem of indicators characterizing the material conditions and technical prerequisites for the formation of the digital economy by years are given in Table 3.

Table 3. Subsystem of indicators characterizing the material conditions and technical prerequisites for the formation of the digital economy

| Integral indicator                                 | St. Petersburg | Moscow       |
|---------------------------------------------------|----------------|--------------|
| Subsystem characterizing the material conditions and technical prerequisites for | 69,98 72,50 75,14 75,86 77,26 | 73,55 75,39 80,18 79,51 78,76 |
| 2013 2014 2015 2016 2017 | 2013 2014 2015 2016 2017 | 2013 2014 2015 2016 2017 |
The formation of a digital economy

The results of the calculation of the integral indicator for the second information and communication subsystem are presented in Table 4.

Table 4. Information and communication subsystem

| Integral indicator                      | St. Petersburg | Moscow |
|----------------------------------------|----------------|--------|
| 2013 2014 2015 2016 2017              | 2013 2014 2015 2016 2017 |
| Information and communication subsystem | 55,20 61,17 66,12 65,84 66,36 | 59,60 70,08 73,60 77,92 81,74 |

The weighting coefficients of the two groups of indicators in accordance with the opinion of the experts surveyed are 0.4 ($k_1$) and 0.6 ($k_2$) respectively.

The calculation of the final integral index of the level of development of the digital infrastructure of the metropolis, taking into account weights, is presented in Table 5.

Table 5. The final integrated index of the level of development of the digital infrastructure of the metropolis

| Indicator                                                             | St. Petersburg | Moscow  |
|----------------------------------------------------------------------|----------------|---------|
| 2013 2014 2015 2016 2017                                            | 2013 2014 2015 2016 2017 |
| Integral megalopolis digital infrastructure development index        | 61,11 65,70 69,73 69,85 70,72 | 65,18 72,20 76,23 78,55 80,55 |

The dynamics of the index of the level of development of the digital infrastructure of the metropolis is presented in Fig. 1.
Fig. 1 Dynamics of the digital infrastructure development level index of St. Petersburg and Moscow

We note the steady growth of the index in Moscow and St. Petersburg, although the growth rate in St. Petersburg is somewhat lower. Moreover, since 2015, the gap in the level of development of digital infrastructure is widening.

We will form some indicators explaining the presented conclusions (Table 6.)

Table 6. Indicators that hypothetically determined the dynamics of the index of the level of development of digital infrastructure in St. Petersburg and Moscow [2]

| Indicator for city organizations | St. Petersburg | Moscow |
|---------------------------------|----------------|--------|
|                                 | 2013 | 2014 | 2015 | 2016 | 2017 | 2013 | 2014 | 2015 | 2016 | 2017 |
| GRP of the region, trillion rub. | 2.49 | 2.66 | 3.39 | 3.67 | 3.87 | 11.81 | 12.78 | 13.52 | 14.24 | 15.72 |
| Share of ICT costs,% of the total number of ICT costs in the Russian Federation | 4.2  | 3.8  | 9.5  | 5.9  | 4.5  | 21.9  | 35.1  | 38.4  | 47.2  | 52.5 |
| ICT costs per organization, thousand rubles / org. | 14.75 | 12.44 | 30.04 | 20.92 | 19.45 | 23.33 | 36.14 | 38.85 | 58.28 | 78.54 |
| GRP growth rate | 1 | 1.07 | 1.27 | 1.08 | 1.05 | 1 | 1.08 | 1.06 | 1.05 | 1.10 |
| ICT Cost Rates | 1 | 0.85 | 2.54 | 0.66 | 0.9 | 1 | 2.51 | 1.1 | 1.3 | 1.32 |

It can be seen from Table 6 that the GRP of Moscow exceeds the GRP of St. Petersburg by 4 times, and the average expenses in Moscow exceed the average costs for ICT organizations in St. Petersburg. By 2017, the total amount of ICT spending in Moscow is more than 10 times higher than the absolute expenses of St. Petersburg, and makes up more than 50% of the total ICT spending in Russia, which largely explains the lag of St. Petersburg from Moscow in this area. We also note that the growth rate of GRP and ICT costs do not affect the growth rate of the integral indicator of the level of development of digital infrastructure.

4. Discussion

It is necessary to note that the application of the results of the study has several limitations. First, the study focuses on data analysis for only two regions of the Russian Federation - Moscow and St. Petersburg. Obviously, in the future, the study should cover a larger number of regions, ideally, all subjects of the Russian Federation, which will provide a more complete and objective picture. Moreover, over time it will be possible to build a longer time series of the desired indicator.

The following points can also be attributed to the ambiguous moments of the performed research.

If the selection of two groups of indicators, firstly, characterizing the general material conditions and technical prerequisites for the formation of a digital economy, and secondly, indicators that give a certain idea of the level of development and use of information and communication technologies and software, seems logical and reasonable, then the use of the same weighting coefficient of significance for all indicators of one group is very controversial. Moreover, the numerical values of weights should be further determined using more reasonable procedures, following the generally accepted methodology for conducting the examination.
However, all the discussion points listed above do not reduce the value of the research performed, but determine the ways and directions for further research.

5. Conclusion

The article proposes a method for calculating the integral indicator of the level of development of the digital infrastructure of the region. It is proposed to take into account the indicators presented in the Rosstat database and combined by the authors in two groups, firstly, indicators characterizing the general material conditions and technical prerequisites for the formation of a digital economy, and secondly, indicators that give a certain idea of the level of development and use information and communication technology and software.

According to the formula proposed by the authors, the calculation of the values of the integral indicator characterizing the level of development of digital infrastructure for the two important regions of the Russian Federation: Moscow and St. Petersburg, which can be attributed to urban agglomerations. The calculation results showed that St. Petersburg has lagged behind in the level of digital infrastructure development, which has been growing over time since 2015. Analysis of the results obtained using data on the relative values of ICT costs has shown that the lag is primarily due to the excess of the relative volume of ICT costs in comparable urban agglomerations. Thus, the authors calculated that in 2017 the volume of ICT expenses per organization in Moscow is more than 10 times higher than the same indicator in St. Petersburg.

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