THE EFFECT OF CROSS-BORDER FIBRE-OPTIC TRANSITIONS ON THE INFORMATION AND COMMUNICATION CONNECTIVITY OF THE RUSSIAN CITIES

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The Russian cities are connected by many telecommunication lines. The information flow between any two cities can be sent via multiple routes, including those running through the networks of other countries. Cross-border transitions are created to connect the Russian lines with the international networks. The effect of these transitions on the connectivity of the cities has not been analysed earlier, either for Russia or for any other country. Using my own database on the Russian telecommunication lines, the Rosstat data on the cities' population, and the results of the scanning of the Internet topology, I attempt to assess the effect of these transitions on the connectivity of the Russian cities. The assessment is carried out at the physical, economic, and digital levels of connectivity. For each level, I calculate the proportion of cities and their residents interacting directly with international telecommunication networks. Of the three categories of physical connectivity, the system of the Russian cities is associated with the worst option — the exogenous connectivity. This is explained by the impossibility of connecting the Kaliningrad region with mainland Russia without using international networks. An analysis of the traffic redistribution between the core cities of the autonomous systems shows that closed flows and internal economic connectivity are predominant in Russia. The calculation of information flow delays between all the Russian cities and the cores of the national and international digital agglomerations makes it possible to establish what cities are affected by the international cores. I conclude that the cross-border transitions have little effect on the information and communication connectivity of the Russian cities.

Keywords: information and communication connectivity, cross-border transition, telecommunications line, autonomous system, digital urban agglomeration, Russian Federation

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Introduction

For any state, the connectivity of the socioeconomic objects operating on its territory is a major priority. This connectivity is obtained by creating transport and information and communications infrastructure equipped with transfer systems and control units. In a broad sense, socio-economic connectivity is the possibility for a rapid movement of energy, raw materials, goods, people, and information between each pair of spatially distributed objects. The disruption of connectivity may be viewed as a precursor of the disintegration and collapse of a state. In this article, we focus solely on the information and communications connectivity, namely, the possibility to link two objects for the transmission of information (data, sound, images) along telecommunications lines. In this case, the object may be a person, a robot (the Internet of Things), an organisation, a city, a region, or a country. Below, we analyse only the connectivity of the Russian cities, which numbered 1112 as of January 1, 2017, according to Rosstat.[1]

The connectivity of the cities within one country can be supported by both domestic and international telecommunications lines. Each large state strives to control its connectivity, particularly, in order to minimise the number of domestic information flows that use the international lines. However, the geographic position, the settlement systems, and the telecommunications network configurations affect the ratio between the domestic and international lines. To understand this ratio, it is important to know the location of the junctions between these lines, the so-called transboundary links. Today, most information is transmitted via fibre optic communications lines (FOCL). Thus, in this article, we will consider only fibre optic links. Their effect on the information and communications connectivity of the Russian cities has not been studied before. This gap in the knowledge complicates the preparation of a new strategy for the information security of the Russian Federation, as well as the drawing up of the concepts of the spatial development of cities and agglomerations aimed at the technological breakthrough towards a digital economy.

The impact of international networks on the internal situation is often exaggerated due to political considerations (for a qualitative analysis of such concerns about the Internet, see [1]). Therefore, it is crucial to obtain a highly accurate quantitative assessment of the influence of transboundary links on city connectivity. Alongside the direct objective of this study, which is to assess the contribution of international resources into

[1] The population of the Russian Federation by municipalities. URL: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/afc8ea004d56a39ab251f2bafc3a6fce (accessed 15.09.2017).

the connectivity of the Russian cities, we set a reverse objective of establishing whether it is possible to impose an international information and communications blockade by closing the transboundary links. Our primary focus will be on the direct research objective.

In this study, we rely on the 'Communications lines of the Russian Federation' database which we compiled based on the reports of the national communications service providers; the official websites of the communications service providers from the neighbouring countries; the Rosstat urban population data; the results of the international scanning of the Russian Internet topology from the *Expert Svyazi* (Communications Expert) website.[2] All the benchmark data are from January 1, 2017. The findings of the study are presented in the following order — the levels of city connectivity, the effect of transboundary links on different levels of connectivity, and the discussion of the findings with major conclusions.

City connectivity

Earlier studies have established the physical, economic, and social levels of information and communications connectivity [2]. Further studies have revealed the fourth level — the digital connectivity [3]. Below, we will analyse all these levels except the social connectivity. The lack of benchmark information relating to the interactions between the Russian citizens and their interactions with international users (this relates to the data exchange and the voice and video calls) precludes aggregation by city. Probably, such a study will become possible when the providers of all types of communications services disclose the 'big data' [4].

Physical connectivity is the possibility to send information from one city to any other, using telecommunications lines. If one city in the country is not connected by telecommunications lines with other cities, there is no connectivity. However, transboundary links to international networks can restore it. Of course, this requires at least two links. The affected city should be connected to one of them and the other should ensure a connection to the national network. Here, there are three categories of connectivity: self-sufficient, almost self-sufficient, and externally dependent (Fig. 1). The first category of connectivity (see Fig. 1, A) describes a situation when each city of the state has at least two communications lines linking it to the neighbouring cities. This ensures connectivity supported by domestic lines. Transboundary links contribute to connectivity (the number of routes among all the cities). In the second case (see Fig. 1, B), one line connects a city to the other cities of the state and the other line connects it with a city across the border. Although connectivity

[2] *Autonomous systems* (Russia). URL: http://www.expertsvyazi.ru/index.php?id=bgpcity (accessed 02.01.2017).

persists, it is impaired because there is always a chance that the only internal line may be damaged. If this happens, externally dependent connectivity will emerge (see Fig. 1, C). However, the above classification excludes the situation when a city is not connected to other cities by either a domestic or an international line, since this situation has nothing to do with either transboundary links or universal connectivity. A quantitative assessment of the social significance of the second or third categories can rest on the ratio between the affected cities to the total number thereof or the ratio between the population of the affected cities and the total population of all the cities. For instance, if one Russian city with a population of 10,000 people is affected, the significance of this case for the whole system of the Russian cities is 0.09 % (1: 1112 = 0.000899) or 0.01 % (10000: 101854049 = 0.000098).

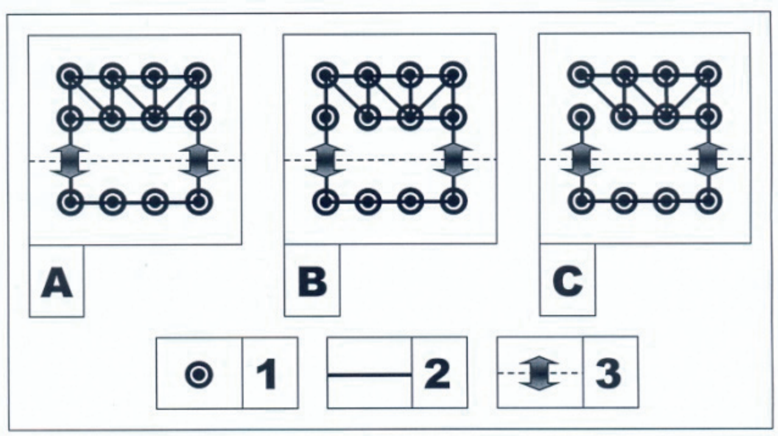

Fig. 1. The information and communications connectivity of the cities, international lines included: self-sufficient connectivity (A), almost self-sufficient connectivity (B), and externally dependent connectivity (C)
1 — city, *2* — communications line, *3* — national border with a transboundary link

Source: prepared by the author.

Relations between communications service providers emerging when Internet traffic is purchased, sold, or exchanged determine economic connectivity. Any operator can connect to a number of national or international providers, based on economic considerations. Thus, the physical connectivity of cities does not translate immediately into economic connectivity. A state may have self-sufficient physical connectivity (see Fig. 1, A) combined with externally dependent economic connectivity (see Fig. 1, C). This calls for a study into the second level of connectivity, at which a provider can have a local (servicing one city) or a regional (servicing several cities) network. In the latter case, all the data about the provider will apply to the city-core of a regional network. According to the international classification, the independent network of a single provider is called an autonomous system. Each is assigned an identification number (Autonomous System Number, ASN). For example, AS8506 is the network of the Irkutsk Research Centre of the Siberian Branch of the Russian Academy of Sciences located within one city. AS31214 is the regional network of OOO TIS-Dialog (Kaliningrad). The aggregated data on the connections of all the ASNs in one city make it possible to identify to what degree it is connected to other national and international cities. Four types of connectivity are possible here: (a) internal (the city receives 100 % of the Internet traffic from the local ASNs), (b) mostly internal (over 50 % from the national autonomous systems), (c) mostly external (over 50 % from the international systems), and (d) external (100 % from the international ASNs). These types can be translated to the level of the state by summing the data on the Internet traffic received by all the cities.

It is important to consider digital connectivity because there is a need to keep a record of the information and communications services relying on physical and economic connectivity. It is crucial to understand that the connection between two cities by a telecommunications line and the distribution of Internet traffic between them does not preclude the provision of services generated in one city to a different city. This relates to the breakthrough information and communications technologies and the associated future services: the Tactile Internet, the Internet of Nano-Things, virtual reality, augmented reality, holographic calls, interactive applications for 5G devices, e-health, and self-driving high-speed transport [5—10]. This list can be expanded with the need to manage digital agglomerations [3] comprised of 'smart' cities [11—15]. All these technologies are very sensitive to the connection quality (speed, data loss rate, delay, and delay variations [16]), particularly, to delay [17]. According to the recommendation of the International Telecommunications Unit [18], in the case of the breakthrough technologies such as the Tactile Internet, the delay should not exceed 1 ms (1 millisecond = 0.001 second). This delay has been called ultra-low [17]. It determines the maximum distances of the cities from the core where new services are generated. Thus, the cities located within the 1 ms isochrones have digital connectivity and those located beyond it do not. To calculate the delay, we used the formula from [17]. We described how it could be applied to identifying the connectivity of cities earlier in [3].

Physical connectivity

When analysing connectivity at the level of fibre optic communications lines (FOCL), it is necessary to take into account the fact that there are two types thereof: overland lines (FOCL proper) and submarine lines

(SFOCL). These lines cross the border of the Russian Federation and thus create transboundary links. The exact number of the transboundary links is unknown; one open source mentions 89 links [1]. Most links are of importance and they have little effect on the connectivity of the Russian cities. For example, these are the transboundary links created by the governmental communications (the FOCL of the Transneft company along the Uzen — Atyrau — Samara pipeline). Other minor links are associated with the 'deadend' lines (those that do not have junctions with the line of third countries connected to other Russian cities — the FOCL from Russia to Abkhazia or South Ossetia), the obsolete lines (those with a low bandwidth that does not meet today's requirements — the SFOCL of 1993 from Kingisepp to Copenhagen or the Novorossiysk — Istanbul — Palermo SFOCL of 1994 with a connection to Odessa), and the lines that are temporarily out of service. Therefore, there not many main links created by the major communications service providers (Table 1). Our list includes the non-transparent link to North Korea (it was created by the TransTelekom company), because it is highly probable that this link is connected to the junction between the North Korean and Chinese information and communications networks. Moreover, some of the links that connect the geographically proximate junctions of various Russian providers are considered as separate links when a different calculation technique is employed. For example, the Russian-Azerbaijani border is crossed by four parallel communications lines that run very close to each other: Frankfurt am Main — Berlin — Warsaw — Kiev — Makhachkala — Baku — Teheran — Muscat by the Europe-Persia Express Gateway cable system, Makhachkala — Baku by the TransTelekom company and Delta Telecom, Makhachkala — Baku by Rostelecom and Delta Telecom, and Derbent — Baku by Megafon and Delta Telecom.

Table 1

Major transboundary fibre optic links connecting Russia to the neighbouring countries (as of January 1, 2017)

No.	Link	Type	Neighbouring country	The nearest large (capital) city across the border
1	Lyttä — Vartius	1	Finland	Helsinki
2	Svetogorsk — Imatra	1	Finland	Helsinki
3	Perovo — Lappeenranta	1	Finland	Helsinki
4	Buslovskaya — Vainikkala	1	Finland	Helsinki
5	Logi — Kotka	2	Finland	Helsinki
6	Ivangorod — Narva	1	Estonia	Tallinn
7	Sovetsk — Pagėgiai	1	Lithuania	Riga

End of Table 1

No.	Link	Type	Neighbouring country	The nearest large (capital) city across the border
8	Nesterov — Kybartai	1	Lithuania	Riga
9	Mamonovo — Braniewo	1	Poland	Warsaw
10	Pechory-Pskovskie — Koidula	1	Estonia	Tallinn
11	Pytalovo — Rēzekne	1	Latvia	Riga
12	Velizh — Surazh	1	Belarus	Minsk
13	Gusino — Obukhovo	1	Belarus	Minsk
14	Ponytovka — Zvenchatka	1	Belarus	Minsk
15	Suzemka — Zernovo	1	Ukraine	Kiev
16	Glushkovo — Volfino	1	Ukraine	Kiev
17	Krasny Khutor — Kazachya Lopan	1	Ukraine	Kharkiv
18	Gukovo — Krasnaya Mogila	1	Ukraine	Donetsk
19	Sochi — Poti	2	Goergia	Tbilisi
20	Yarag-Kazmalyar — Samur	1	Azerbaijan	Baku
21	Aksarayskaya 2 — Ganyushkino	1	Kazakhstan	Astana
22	Elton — Saykyn	1	Kazakhstan	Astana
23	Ozinki — Semiglavy Mar	1	Kazakhstan	Astana
24	Iletsk-1 — Shyngyrlau	1	Kazakhstan	Astana
25	Sagarchin — Yaysan	1	Kazakhstan	Astana
26	Soyuznoe — Soyuznoe	1	Kazakhstan	Astana
27	Zolotaya Sopka — Selektsionnaya	1	Kazakhstan	Astana
28	Zauralye — Zernovaya	1	Kazakhstan	Astana
29	Kazanskoe — Sokolovka	1	Kazakhstan	Astana
30	Isilkul — Bulaevo	1	Kazakhstan	Astana
31	Kulunda — Sharbakty	1	Kazakhstan	Astana
32	Rubtsovsk — Semey	1	Kazakhstan	Astana
33	Naushki — Sükhbaatar	1	Mongolia	Ulaanbatar
34	Zabaykalsk — Manchuria	1	China	Qiqihar
35	Blagoveshchensk — Heihe	2	China	Heihe
36	Khabarovsk — Fuyuan	2	China	Jiamusi
37	Grodekovo — Suifenhe	1	China	Mudanjiang
38	Khasan — Tumangang	1	North Korea	Chongjin
39	Nakhodka — Jōetsu	2	Japan	Niigana
40	Nevelsk — Ishikari	2	Japan	Sapporo

Comment: type 1 brings together overland lines and type 2 brings together submarine fibre optic lines. The link mentioned is the closest to the intersection of the state border and the telecommunications line.

Source: prepared by the author based on the data from the major communications services providers of Russia and the neighbouring countries.

All the main transboundary links (except those located in the Kaliningrad region) are connected by the major domestic FOCLs (Fig. 2). There are many variants of how information flows can be redirected in case of link damage. Thus, Russia's information and communications network is largely resistant to isolated external impacts. However, the physical connectivity of the Russian cities is externally dependent (see Fig. 1, C). The reason for this is the Kaliningrad region is connected to other Russian cities only by the international communications lines. The significance of the lacking direct connection between the Kaliningrad region and mainland Russia is estimated at 1.98 % with respect to the total number of the Russian cities and 0.74 % with respect to the population of the cities. In terms of the connection between each pair of the Russian cities, the 22 cities and towns of the Kaliningrad region account for 3.88 % of all the links (23980: 617716 = 0.038820). These figures (1.98; 0.74; 3.88) suggest that the effect of transboundary links on the physical connectivity of the Russian cities is very limited.

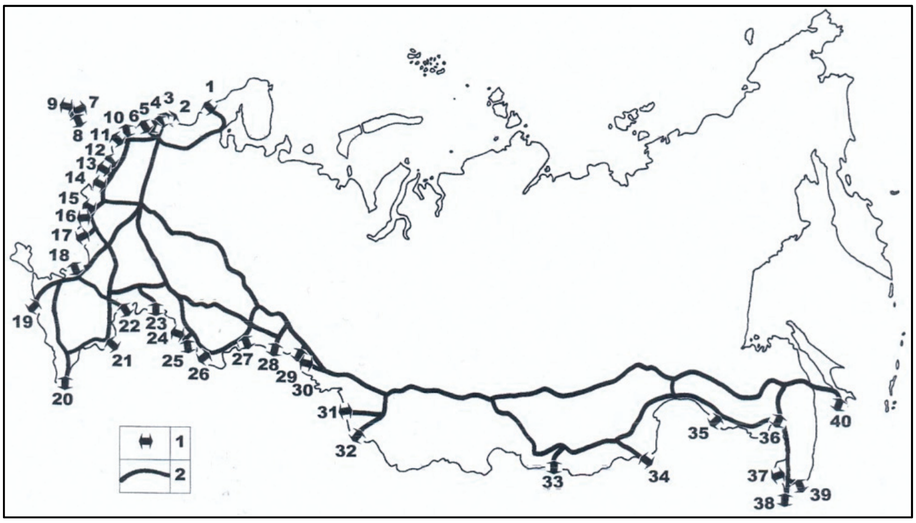

Fig. 2. Major transboundary links and the Russian fibre optic lines connecting them (as of January 1, 2017):
1 — transboundary link; *2* — communications line; the numbers of links are the same as used in Table 1

Source: prepared by the authors based on the reports of the major communications service providers of Russia and the neighbouring countries.

Economic connectivity

At this level, we study the economically feasible interactions (Internet traffic exchange) among the autonomous systems of communications service providers. Earlier, we analysed the spatial distribution of ASN to estimate the number of such systems and IP networks per area unit [19] or an agglomeration, to build a hierarchy of the cities [21], to model how the network developed [22], and to identify the index of regional telecommunications specialisation [23]. However, these works did not analyse the connectivity of spatially distributed ASNs in the context of the economic relations among the communications services providers. It is important to understand that the Internet functioning as a single network owes to the connectivity of the autonomous systems [24]. The only attempt to analyse the interactions among the ASNs from the perspective of connectivity was made in the framework of the feasibility study for Sibnet [2].

Since only 299 Russian cities or towns have the control centres of the autonomous systems (the other towns and cities are serviced from these centres), an analysis of the economic level of the information and communications connectivity focuses on the cities that are home to the control centres. Their distribution by the types of economic connectivity is as follows: 230 locations receive all the Internet traffic (100 %) from the national ASNs, which corresponds to type (a), 65 receive most of the Internet traffic from the Russian autonomous systems (b), and four (Pokrov of the Vladimir region, Nizhnekamsk of the Republic of Tatarstan, Kuznetsk of the Penza region, and Sayanogorsk of the Republic of Khakassia) are fully dependent (100 %) on the international ASNs (d). No Russian city hosting an autonomous system centre falls within type three (c), which means that the international systems account for 50 % of the Internet traffic. Thus, 1.34 % of the cities and towns under consideration depend on the transboundary links.

During the redistribution of information flows, some providers (uplinks) route Internet traffic from their autonomous systems, whereas the others (downlinks) receive this Internet traffic. This is how the relations among the communications service providers develop. All these relations are shown in a full BGP table.[3] These data make it possible to identify the international ASNs routing Internet traffic to the Russian communications service providers (Table 2). In our case, most of these providers are registered in Moscow. As to the cities and towns, the 299 locations have

[3] *Autonomous systems* (russia). URL: http://www.expertsvyazi.ru/index.php?id=bgpcity (accessed 02.01.2017).

823 connections, 191 of which are accounted for by the foreign cores. When calculated this way, the impact of transboundary links on the system of the Russian cities reaches 23.21 %.

Table 2

International autonomous systems (uplinks) providing Internet traffic to most Russian systems (downlinks) as of January 1, 2017

International uplink		The number of the Russian downlinks registered in		
No.	Name	Moscow	Saint Petersburg	Other locations
AS9002	RETN	137	45	75
AS1299	TeliaSonera	73	11	30
AS6939	Hurricane Electric	28	7	18
AS50384	W-IX	16	2	13
AS3356	Level3	16	4	2
AS174	Cogent Communications	13	3	4
AS13030	Init Seven	10	4	1
AS25160	Vorboss	9	5	1

Source: prepared by the author based on the data from the *Autonomous systems* (Russia). URL: http://www.expertsvyazi.ru/index.php?id=bgpcity

To correlate the uplink/downlink relations of the communications service providers with the transboundary links, we used the data on the Internet exchange points.[4] Most of the Russian ASNs that are connected to such points to increase the Internet traffic exchange rate using the domestic resources. In Russia, the Internet exchange points (IXPs) are located in Moscow (4 points), Saint Petersburg (4), Voronezh (2), Krasnoyarsk (2), Novosibirsk (2), Vladivostok (1), Vladimir (1), Ekaterinburg (1), Kazan (1), Krasnodar (1), Nizhny Novgorod (1), Omsk (1), Rostov-on-Don (1), Samara (1), Stavropol (1), and Ulyanovsk (1). The largest international IXPs are AMS-IX (Amsterdam, the Netherlands; it facilitates 616 ASNs), DE-CIX Frankfurt (Frankfurt am Main, Germany; 513), LINX Juniper LAN (London, the UK; 500), MSK-IX (Moscow, Russia; 420), and PTTMETRO San Paulo (São Paulo, Brazil; 265). Six international exchange points facilitate at least five Russian autonomous systems each (Table 3).

[4] *Internet Exchange Points* (IX) [E-resource]. URL: https://www.expertsvyazi.ru/index.php?id=bgp2ix (accessed 02.01.2017).

Table 3

The international Internet exchange points facilitating the most autonomous systems of Russia (as of January 1, 2017)

Internet exchange point	City	Russian autonomous systems registered in		
		Moscow	Saint Petersburg	Other cities
De-CIX Frankfurt	Frankfurt am Main	28	4	2
AMS-IX	Amsterdam	19	4	1
LINX Juniper LAN	London	14	3	0
NetNod Stockholm	Stockholm	7	2	0
DTEL-IX	Kiev	5	1	2
LINX Extreme LAN	London	5	1	0

Source: prepared by the author based on *The Internet Exchange Points (IX)*.

The identification of the shortest telecommunications routes between each of the 69 Russian cities hosting the ASNs that receive Internet traffic from abroad and the international IXPs shows that the major information flows go along the following paths: Stockholm — Helsinki — Saint Petersburg, Amsterdam — Berlin — Warsaw — Pskov, Frankfurt am Main — Smolensk, Frankfurt am Main — Budapest — Kiev — Belgorod, and London — Paris — Frankfurt am Main — Vienna — Kiev — Rostov-on-Don. Thus, most information flows are carried to Russia's border via transboundary links 4, 10, 11, 13, 17, and 18 (the numbers are given in Table 1). Since most Internet traffic from abroad is routed to the Moscow and Saint Petersburg communications service providers (see Table 3) and later redistributed to the other Russian cities, the direct effect of international autonomous systems on the Russian cities is very insignificant. In terms of the number of the ASNs receiving Internet traffic from abroad, it is 5.16% (136: 2636 = 0,051593), which corresponds to type (b).

Digital connectivity

The development of the information and communications technology observed over the past decade has led to a situation where the study of the first two levels is not sufficient for understanding the phenomenon of connectivity. Artificial intelligence, M2M communication, and the other elements of the fourth industrial revolution [25—28] have set new connectivity standards. Understanding them requires new connectivity criteria. One of them is delay. Digital agglomerations are identified based on ultra-low delays [3]. Within this approach, connectivity exists within agglomerations and does not beyond them.

A digital agglomeration comprises a core (a city with a population of over 500 thousand people or of 250—500 thousand people if its population combined with that of satellite towns amounts to the same numbers) and the towns that interact via telecommunications lines with the core, provided the delay does not exceed 1 millisecond. A study [3] has established that there are 43 digital agglomerations in the Russian Federation. They bring together 736 cities and towns. In this case, only the Russian locations and delays among them are taken into account. However, amid globalisation, one cannot rule out the influence of international cores on the Russian cities. If a city is located close to a transboundary fibre optic link to a core in the neighbouring state, the delay from the domestic core can be longer than that from an international one. In this case, the Russian city may become part of an international digital agglomeration in information and communications terms.

To verify whether such a situation is possible, we identified the large international cities (over 500 thousand residents as of January 1, 2017) and capitals (some of them have a population of fewer than 0.5 million people) that are the closest to the main transboundary links in terms of telecommunications lines (see the right column of Table 1). The calculation of delay among the core and other Russian cities shows that there are ten cities located closer to the international cores than to the centres of the Russian digital agglomerations. These are six locations in the Belgorod region (Belgorod, Valuyki, Grayvoron, Korocha, Novy Oskol, and Shebekino; the delay from Kharkiv is shorter than that from Kursk) and four in the Amur region (Belogorsk, Blagoveshchensk, Zavitinsk, and Ratchikhinsk; Heihe is preferable to Khabarovsk when it comes to delay). A conditional estimate of the effect of the transboundary links that ‘pull’ the Russian cities towards the international cores, on the digital connectivity of the Russian cities is 0.9 % if the number of the cities is considered (10: 1112 = 0.008993), or 0.80 % if the population is taken into account (818624: 101854049 = 0.008037).

Discussion

The three levels of connectivity respond differently to the information flows carried via transboundary links. A more accurate conditional estimate of such responses can be obtained if other benchmark data sources are used or new communications lines are created. For example, the physical connectivity of the cities of the Russian Federation will be upgraded to the second category (see Fig. 1) if an SFOCL running along the bottom of the Baltic Sea connects Saint Petersburg and Kaliningrad. If this happens, there will be 31 Russian cities forced to connect to the international networks when the Russian line is damaged. Alongside the 22 cities and towns of the Kaliningrad region, these are Gukovo, Dagestanskiye Ogni, Derbent, Ivangorod, Izberbash, Isilkul, Makushino, Nevelsk, and Pechory. In this case, the second category will account for 2.79% if the number of cities is taken into account (31: 1112 = 0.027878) and for 1.14% if the population is considered (1157718: 101854049 = 0.011366). Another possible change in the effect of transboundary links is associated with the use of 'big data' and the possibility to processes the quantitative characteristics of the FOCL information flows handled by each Russian communications service provider. Researchers will be able to rank transboundary links according to their significance in terms of information and communications for the system of the Russian cities. Another possible avenue of research is the analysis of long-term dynamics of putting transboundary telecommunications lines into service, as well as the associated changes in physical connectivity.

The economic connectivity of the Russian cities is expected to remain mostly internal if the interactions among the communications service providers are accounted for differently or if the governmental regulation is tightened. A promising development will be big data disclosure, which will make information on the Internet traffic exchange among the providers available. Another problem is the absence of open data on the routes of information flows within each autonomous system. The disclosure of these data will help to assess the interactions among all the Russian cities and towns, not only among the ASN cores. In this study, we did not identify the trends in inter-city Internet traffic exchange. However, a promising area of research is the comparison of the dynamics of transboundary link and telecommunications line creation with the trends in Internet traffic exchange. This would make it possible to juxtapose the two levels of connectivity, which we did not attempt in this article. If the time series of the fluctuation of the digital agglomeration size (composition) are modelled, three levels may be compared in the future.

Since the breakthrough information and communications technology, such as the Tactile Internet, and the 'smart' cities are still a thing of the future, it is possible that the delimitation of digital agglomerations and, therefore, the estimate of digital connectivity will require the criteria that have nothing to do with the delay. Another prospect, the consequences of which are not completely clear, is the creation of cores in the neighbouring states. In this study, we assumed that the cores developed simultaneously in Russia and abroad. However, this synchronicity may not be observed in the future. If Russia decelerates, the other states may outstrip it as regards information and communications technology. Should this process be accompanied by the creation of new transboundary links, many more Russian cities and towns will be dependent on the international cores than are now according to the above estimates.

Conclusions

This first attempt to estimate the effect of transboundary links on the persistence of the information and communications connectivity of the Russian cities should be considered as an introduction to an entirely new research area. Earlier, the transboundary links, telecommunications lines, autonomous systems, Internet traffic, 'smart' object and cities were examined outside the context of spatial connectivity. This pioneering study could not cover all the pertinent aspects. Thus, they should be considered in further research. These aspects include the interrelations among all the levels of connectivity, the modelling of the tolerance of Russia's information and communications network to transboundary link blockade, and an assessment of the effect of these links on the social connectivity of the cities.

This study demonstrates that the effect of the transboundary links on the information and telecommunications system of the Russian cities is insignificant. An estimate based on the number of cities showed the following. As to physical connectivity, 22 cities and towns (all of them in the Kaliningrad region) do not have connections to the others via the national telecommunications lines. The autonomous systems of four locations receive Internet traffic only from abroad. Ten locations may become dependent on the international digital agglomeration cores. Although the effect of the transboundary links on the connectivity of 1112 cities and towns is minor, there are several problems. These are the presence of externally dependent connectivity (the least desirable category) and the considerable proportion of international Internet traffic received by the local and regional networks (the international networks account for up to one-fourth of all the connections of the Russian autonomous systems). Another serious problem is the orientation towards Western European Internet exchange points (Frankfurt am Main, Amsterdam, London, and Stockholm) without a diversification of the information flows (Hong Kong, Shanghai, and Tokyo are used as backup exchange points).

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