The spatial dimension in the development of transport infrastructure in Russian regions

Marina Kurnikova[1*], *Alexandr* Timofeev[2]

[1]Samara State University of Economics, Sovetskoy Armii Str. 141, Samara, 443090, Russia
[2]Plekhanov Russian University of Economics, Stremyanny lane 36, Moscow, 117997, Russia

Abstract. The development of transport infrastructure is a key factor for the economic growth of the whole country and its individual territories. The objectives for the development of transport infrastructure in the regions are determined by the importance of the indicators that have been achieved and are planned, which reflect the transport availability and accessibility of the country's territories. This article focuses on the development of methodological approaches to assessing the transport availability and accessibility of the territory of the Russian Federation from the perspective of its constituent entities and federal districts based on non-linear coefficients. The authors explain the results of the calculations of the regional dimension in the development of transport infrastructure in Russia based on the Engel and Holz coefficients. The results of the study can be used in further econometric assessments of the influence of various factors on the overall socio-economic development of the regions.

1 Introduction

Adopted in November 2021, the «Transport Strategy of the Russian Federation to 2030 with a projection until 2035» (2021) is aimed at making the Russian economy grow, with the assistance of transport infrastructure which helps to increase the spatial connectivity of the country and the accessibility between its regions. The practical implementation of this strategic objective updates the studies of the spatial dimension in the development of transport infrastructure, which include an assessment of the two main aspects: 1) the spatial inequality in the infrastructure development across the country; 2) the accessibility of its regions. Without prejudice to the importance of each of these research issues, this article focuses on the study of interregional differences in the development level of the transport infrastructure of the Russian constituent entities as the most important causes of uneven transport accessibility of different regions, along with geographical characteristics.

In the managerial aspect, the development of transport infrastructure is a specific tool of the public administration over spatial development, aimed at reducing imbalances and inequalities in territorial development, and at achieving economic growth (Cigu et al., 2019) being implemented by means of transport policy (Short et al, 2005; Berg et al., 2017), the financial security of major infrastructure projects (Bayane, 2017).

[*]Corresponding author: mvkurnikova@gmail.com

In the most general sense, the development of transport infrastructure entails a reduction in transport costs for economic agents and an increase in factor productivity, and, for the territory, means more competition and higher overall performance of firms (Melitz and Ottaviano, 2008), as measured by the economic development of the territory, such as GDP, human development index and income distribution (Luz et al., 2016). An efficient transport system is crucial for sustained economic growth and modernization of the economy (Lal et al., 2017).

The importance of transport infrastructure for a country's spatial development is linked to the possibility of transport to directly influence the development of the territory's foreign economic activity and its border cooperation (Khmeleva et al., 2022). In that connection, transport facilities are particularly important in small open economies, such as the majority of Central and Eastern European Member States, where an efficient transport system increases international trade and, thus stimulates economic growth (Lenz et al., 2018). The internal integration role of transport infrastructure is linked to its ability to improve the internal cohesion of the territory, reduce the development gaps between its poor and rich localities, support the growth of the territories deprived of natural resources (Dash, 2008). Álvarez-Ayuso et al. (2016) use the production function to show the dependence between the value of regional production and the length of the road network to identify the possibility of Spain's regions using the road infrastructure of neighbors for their prosperity. The study shows that the availability of transport infrastructure to neighbors leads to an influence of domestic capital stock on total production and the relative importance of side effects as compared to domestic (own) effects increases with the level of territorial disaggregation. Moreover, and tide effects themselves are asymmetrical, showing negative values for poorer regions because they do not receive the capital gains from neighbors, as their richer counterparts.

Despite the high importance of transport infrastructure for the spatial development of any country, research discourse on the role of transport in the spatial development of the Russian Federation lacks sufficient studies, aimed at comprehensive research into the spatial organization of various types of transport infrastructure throughout the country, using linear indicators of transport infrastructure development. The purpose of this article is to fill this gap by assessing the distribution of transport infrastructure across Russian regions and its federal districts, the results of which may be used in answering questions about whether the level of transport development of individual regions and macro-systems of the Russian Federation is sufficient for carrying out the tasks of social and economic development.

2. Methods

In this study we are assessing the spatial dimension in the transport infrastructure for the Russian regions and federal districts based upon the available standard statistical data on the three main types of transport infrastructure: (1) operating length of public railway lines, km; (2) length of public roads, km; (3) length of inland waterways, including those with guaranteed fairway dimensions, km.

Based on these data, the calculations of the density of the transport network on N sq. km, the availability of transport infrastructure per N population and non-linear parameters for transport connectivity assessment (Engel, Holz, and Uspensky coefficients) are the most common means (Lavrinenko et al., 2019; Kremer, 2020) of assessing transport infrastructure:

In this study, we will calculate the infrastructure density (Carruthers, 2015) for the Russian regions and federal districts based on two coefficients:

- The Engel coefficient is based on a synthesis of the coefficients of population transport and road network density and reflects the level of service of the population in the area in question, calculated by the following formula:

$$EC = \frac{L}{\sqrt{S \cdot P}} \quad (1)$$

where *EC* is the Engel coefficient; *L* is the length of the transport tracks, km; *S* is the area, km^2; *P* is the population, million persons.

- Holz coefficient represents the availability of the territory's transportation network, calculated by the formula:

$$HC = \frac{L}{\sqrt{S \cdot LT}} \quad (2)$$

where *HC* is the Engel coefficient; *LT* is the number of local territories – Russian municipalities.

In the study, we calculate the Engel and Holz coefficients based on the distribution of three types of transport networks (rail, road, and waterway) across Russian regions and the federal districts of the Russian Federation, as well as specific coefficients for individual types of transport networks:

- EC-RW and HC-RW – Engel and Holz coefficients for the operating length of public railway lines;
- EC-R and HC-R – Engel and Holz coefficients for the length of public roads;
- EC-W and HC-W – Engel and Holz coefficients for the length of inland waterways with guaranteed fairway dimensions.

The selected non-linear coefficients are used in one study to obtain a more complete picture of the spatial organization of transport infrastructure across Russia. Since the Engel coefficient shows the density of the transport network per unit of territory, for Russia, with its uneven economic development and occupancy, the use of it as the sole indicator of estimation gives a distorted picture. The Golz coefficient uses the number of settlements instead of the population, thus providing a more reliable picture of the level of development of transport infrastructure from a spatial perspective.

3. Results

3.1. General characteristics of Russian transport infrastructure by the federal districts

The federal districts of the Russian Federation are the consolidated administrative and territorial entities of the federal subordination in which the city-centers are defined, with the governing and coordinating bodies in the form of a plenipotentiary representative of the President, his office, and the departments of federal agencies. As of 1 January 2022, there are 8 federal districts in the Russian Federation, ranging from 6 (Ural Federal District) to 18 (Central Federal District) of the Russian Federation, with an area of between 170,439 km^2 (North Caucasus Federal District) to 6,952,555 km^2 (Far Eastern Federal District), with a population of between 8,083,648 people (Far Eastern Federal District) and 39,086,462 people (Central Federal District).

A study of the location of three types of transport infrastructure (rail, road, and inland waterways) across the Russian Federation by the federal districts shows a very uneven development (Figure 1).

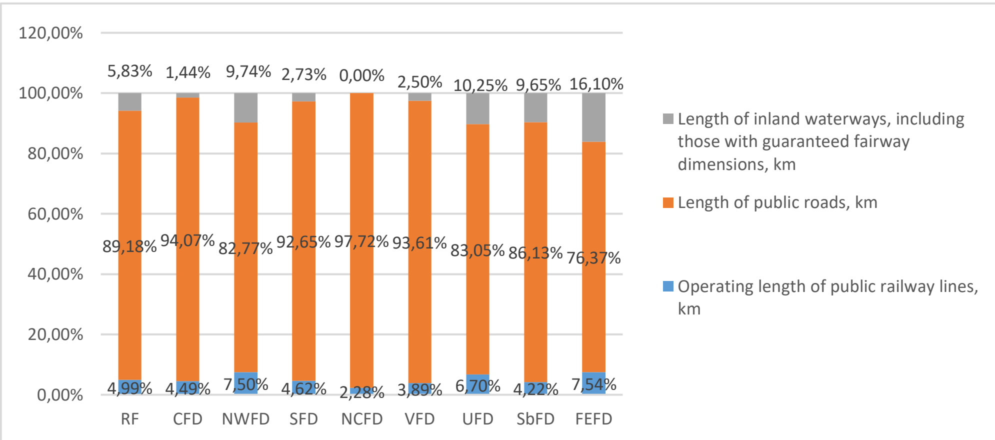

Fig. 1. Distribution of transport infrastructure by transport in the federal districts of the Russian Federation (Abbreviations used hereafter in figures and tables: CFD - Central Federal District, NWFD - North-West Federal District, SFD - Southern Federal District, NCFD - North Caucasus Federal District, VFD - Volga Federal District, UFD - Ural Federal District, SbFD - Siberian Federal District, FEFD - Far Eastern Federal District.

Road transport is the backbone of Russia's transport infrastructure in all federal districts, and the total length of public roads is about 1,55 million km, very unevenly located - about half of all roads are located in the Central Federal District (22.91%) and the Volga Federal District (22.85%) (see Fig. 1). In almost all federal districts, roads account for at least 80 percent of the total transport network, except the Far Eastern Federal District (76.37 percent) which has developed inland waterways on navigable northern rivers and a fairly long operating length of public railway lines - about 12,600 km.

3.2 The Engel coefficient: assessing the transport development of the territory of the Russian Federation

In order to calculate the Engel coefficient, we used standard statistical data on the length of railway and waterways, public roads across the territory of Russian subjects, as well as corresponding data on the area of the territory in annual average terms for 2020, as well as the population numbers as of 1 January 2021 available in official statistical publications. The calculation was carried out for each type of transport infrastructure for each subject according to formula (1). In order to assess the heterogeneity in the transport development of the territory of Russia across its entities, we have grouped our research objects using the standard method involving the following steps:

1) Ranking units of the total set of indicators for each type of infrastructure,
2) Calculating the size of the resulting variation,
3) Determining the optimal number of groups for a given population of units according to the standard Sturges formula:

$$n = 1 + \lfloor \log_2 N \rfloor \quad (3)$$

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where n is the number of intervals, N is the total number of observations in the dataset.

The number of observations in our case is different for each type of transport infrastructure: 85 – for public roads (by the number of subjects of the Russian Federation), 79 for railways, and 53 for waterways with guaranteed fairway dimensions, due to the absence of the latter two types of infrastructure in some regions of the Russian Federation.

4) Calculating the intervals for the optimal number of groups for each of the three groups;

5) Dividing the subjects of the Russian Federation into groups according to the obtained computations EC-R, EC-RW, EC-W.

The results of the calculations are presented in Tables 1-3.

Table 1. Groups of Russian regions according to the calculation of the Engel coefficient for the length of public roads – EC-R. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of EC-R in the group	Average EC-R
1	136.79	118.10	3	388.1906	129.3969
2	118.10	99.41	8	863.6269	107.9534
3	99.41	80.71	17	1508.33	88.72527
4	80.71	62.02	17	1243.178	73.12809
5	62.02	43.33	14	720.2264	51.44474
6	43.33	24.64	17	601.4251	35.37795
7	24.64	5.94	11	157.6173	14.32884

Table 1 presents the data for the formed groups of the Russian regions according to the calculation of the Engel coefficient on the length of public roads. This type of transport infrastructure is available in each Russian entity, therefore an optimal number of groups calculated according to the Sturges formula (3) for 85 units of observation was 7. The pattern of asymmetry in the development of this mode of transport among the subjects of the Russian Federation was almost the same as that in the development of railway tracks: a small number of subjects in the first three groups of leaders, the distribution of regions among the other groups is almost even. The first group was composed of the NWFD entities – the Leningrad, Novgorod, and Pskov regions, the number one in the rating - the Republic of Karelia. The second group is represented by the entities of the NWFD and CFO, but also includes a Far East region – the Amurskaya region. The regions of the Volga Federal District appear in the rating starting from the third group – the Saratov region fell into it, the regions of the Urals - from the fourth, Siberia - from the fifth group. It is interesting that according to this kind of infrastructure the cities of federal importance reached only the fifth (Sevastopol and Saint-Petersburg) and sixth (Moscow) groups.

Table 2. Groups of Russian regions according to the calculation of the Engel coefficient for the operating length of public railway lines – EC-RW. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of EC-RW in the group	Average EC-RW
1	6.71219	5.832454	4	25.351	6.2345
2	5.832454	4.952719	8	42.588	5.3235
3	4.952719	4.072984	6	27.758	4.6263
4	4.072984	3.193249	16	56.212	3.5132
5	3.193249	2.313514	20	55.786	2.7893
6	2.313514	1.433779	12	23.674	1.9728
7	1.433779	0.554044	14	13.618	0.9799

The data in Table 1 show a clear asymmetry in the development of the basic type of transport infrastructure - the railway tracks. The first group of regional leaders consisted of 2 CFD entities (the Smolensk and Orlovskaya regions) and one NWFD entity (the Pskov region). The second group consisted mainly of the most developed entities of the Central European territory of Russia from the CFD, the NWFD, and the VFD, except the Republic of Ingushetia, which falls into this group because of the high density of railway tracks based upon the small size of the territory and population. The Ural is represented by one region in the third group - it includes the Altai Krai, the vast majority of UFD entities are located in the fourth and fifth groups, and Siberia - the fifth and sixth groups.

Table 3. Groups of Russian regions according to the calculation of the Engel coefficient for the length of inland waterways with guaranteed fairway dimensions – EC-W. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of EC-W in the group	Average EC-W
1	20.40877	17.01626	1	20.40877	20.40877
2	17.01626	13.62375	0	-	-
3	13.62375	10.23124	2	24.08309	12.04154
4	10.23124	6.838726	2	16.11186	8.055931
5	6.838726	3.446216	8	34.1863	4.273288
6	3.446216	0.053705	40	33.89054	0.847263

Table 3 illustrates the data obtained from similar calculations for the third type of transport infrastructure - waterways with guaranteed navigable clearance, i.e. the length of routes on Russian navigable rivers for goods transport. Such water routes exist in only 53 constituent entities of the Russian Federation, located in 7 federal districts of the Russian Federation, and they do not exist at all in the territory of the North Caucasus because of the specific topography and water bodies of that part of the country. The Sturgess formula (3) calculation showed that the optimal number of groups for a given set of observations would be six groups. The distribution of the number of entities by the group is quite interesting - a small number of regions lead the level of transport development in this type of way: the Yamal-Nenets Autonomous Region is uniquely included in the first group, the Magadan region and the Sakha Republic (Yakutia) in the third, the Jewish Autonomous Region and the Republic of Karelia - in the fourth group, 8 entities of Siberia and the Far East - in the fifth group, the other 40 regions - in the last sixth group.

In general, in response to the question on the territorial dimension of the constituent entities of the Russian Federation according to the level of transport development of the territory in terms of three basic types of transport infrastructure per area and population, it should be noted that there is a clear advantage in the development of the regions of the central and north-western parts of the country, part of the South and the Volga region, and a very unsatisfactory development of transport infrastructure in the Urals, in Siberia, and the Far East. At the same time, the developed navigation on the major northern rivers of Russia (Yenisey, Ob, Irtysh, and Lena) makes it possible to link with them the development of freight transport in this region, passenger navigation, and support the development of tourism in large cities along these rivers.

3.3. The Holz coefficient: assessing the transport accessibility of the territory of the Russian Federation

We made similar calculations using the same statistics on the development of the three types of transport infrastructure to calculate the Holz coefficient according to formula (2), the denominator of which is the number of settlements, as nodes in the transport system. As such, we used data on the number of municipalities - special administrative and territorial units with local self-government units and competence to deal with local issues in Russia. As a result, we received the data presented in tables 4-6 based upon the formation of groups of Russian subjects according to the level of transport accessibility under the grouping procedure described above in section 3.3.

Table 4 shows the distribution of the Russian constituent entities according to the level of accessibility of the territory by rail. Very few were the first three groups, the first of which included the Moscow and Kaliningrad regions, the second was represented by St. Petersburg, and the third was represented by Moscow and the Sverdlovskaya region. The four entities of the fourth group of regions represent the SFD (Stavropol Territory), NWFD (Leningrad Oblast), UFD (Kemerovo Oblast), CFD (Tula Oblast). The pattern of asymmetry in the territorial organization of railway lines, adjusted by the number of localities, clearly shows that the leaders are the regions with the highest positions in the hierarchy of "central locations" with major transport facilities of this type serving neighboring areas.

Table 4. Groups of Russian regions according to the calculation of the Holz coefficient for the operating length of public railway lines – HC-RW. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of HC-RW in the group	Average HC-RW
1	41.09109	35.33851	2	77.71937	38.85969
2	35.33851	29.58593	1	34.61428	34.61428
3	29.58593	23.83335	2	51.63459	25.8173
4	23.83335	18.08078	4	76.17752	19.04438
5	18.08078	12.3282	9	122.9252	13.65836
6	12.3282	6.575617	27	246.3388	9.123658
7	6.575617	0.823038	33	134.6742	4.081037

Table 5 illustrates the results of the calculation of the Holz coefficient by public roads. From the data presented, it can be seen that a very small group of the leading regions of the first three groups make up only 2 entities of the Russian Federation – the Moscow region (group 1) and the Kaliningrad region (group 3). Three regions occupy average positions in this indicator: the Stavropol Territory, the Republic of Ingushetia, and Sevastopol. The rest of the Russian Federation is almost evenly distributed among groups of outsider regions, with the fourth group being the CFD regions.

Table 5. Groups of Russian regions according to the calculation of the Holz coefficient the length of public roads – HC-R. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of HC-R in the group	Average HC-R
1	871.8588	749.1208	1	871.8588	871.8588
2	749.1208	626.3827	0	-	-
3	626.3827	503.6447	1	568.265	568.265
4	503.6447	380.9067	2	837.4428	418.7214
5	380.9067	258.1687	14	4318.527	308.4662
6	258.1687	135.4307	36	6748.388	187.4552
7	135.4307	12.69268	31	2219.439	71.59481

Table 6 below summarizes the data obtained from the calculation of the Holz Coefficient by the type of transport - waterways with guaranteed fairway dimensions. Interestingly, with an adjustment for the number of settlements, among the regions, the leaders in this indicator were the NWFD entities that have maritime routes within their waters – the Kaliningrad Oblast, the Jewish Autonomous Oblast, the Republic of Karelia, the Tomsk Oblast, and the Leningrad Oblast. The exception – the Yamal-Nenets Autonomous Region - was included in the second group of entities.

Table 6. Groups of Russian regions according to the calculation of the Holz coefficient for the length of inland waterways with guaranteed fairway dimensions – EC-W. Source: authors.

Group number	Upper boundary	Lower boundary	Number of Russian subjects	Total of HC-W in the group	Average HC-W
1	19.47729	16.25332	2	38.63322	19.31661
2	16.25332	13.02935	1	17.20928	17.20928
3	13.02935	9.80538	3	32.92064	10.97355
4	9.80538	6.58141	8	59.39464	7.42433
5	6.58141	3.357439	14	66.09946	4.72139
6	3.357439	0.133469	25	40.55102	1.622041

Thus, as a result of the research into the transport accessibility of individual localities (in our calculations - municipalities) of the territory of the Russian Federation, it becomes clear that there is a specific asymmetry characterized by the presence of several major transport nodes (different by type of transport infrastructure surveyed), which together form the framework of the population support network. At the same time, based on research, there is an even distribution of such infrastructure among the rest of the Russian Federation, and the gap between them and the leaders poses a significant problem in the spatial connectivity and transport accessibility of the Russian regions.

4. Discussion

An analysis into the regional dimension of transport availability in the Russian context (based upon the Engel coefficient) and transport accessibility (using the Holz coefficient) has been carried out for three main types of transport routes: railways, public roads, and waterways.

Although the Engel and Holz coefficients are often assumed to be roughly identical (Lavrinenko et al., 2019), the calculations of the regional transport situation in the Russian Federation give a very different picture of the territorial organization of transport infrastructure in the country under study. Despite the estimates already made, there is no uniformity in the country's transport accessibility (Transport Strategy, 2021), the use of the above-mentioned indicators in the evaluation allows forming an elaborate picture of the nature of the asymmetry: approximately equal distribution of the Russian subjects by groups in the rating - with 2-3 explicit leaders in the first group versus 5-6 entities in the groups of regions with high and middle positions, and the vast majority of regions in the remaining groups.

The way the transport network is distributed across Russian regions makes it possible to find out the territories of the complete economic development, which include the ones of such federal districts as the Central Federal District and the North West Federal District, which have a fairly dense transport network. It has a beam-like configuration at major industrial and administrative centers (cities) and favorably located transport stops (railway stations, river, and seaports) with production and distribution bases (warehouses). This network includes major transport nodes and logistics centres included in the International Transport Corridors. The rest of the Russian territory becomes the territory of selective economic development in the form of separately located industrial hearths in the Volga region, in the south of the country, on the Urals, in Siberia, and the Far East.

Thus, the general conclusion of the assessment of asymmetries in the development of transport infrastructure among the constituent entities of the Russian Federation is the idea of a significant territorial contrast in the location and character of the structural elements of transport systems, which is mainly due to imbalances in the distribution of freight production, resources, production centers, and export destinations.

5. Conclusion

Today, a well-functioning infrastructure is becoming a key factor in the development of the regions, as an element of their sustenance, and as the ultimate determinant of the quality of life of the population. Transport is an essential part of the infrastructure, so the key to increasing the efficiency of public production is the development of transport infrastructure, promoting the development of regions through the provision of quality transport services to ensure the coherence of the economic space. Recent experience has shown that regions with better transport access to material, natural resources, and markets tend to be more developed. Therefore, one of the main priorities of the Transport Strategy of the Russian Federation is to make transport services accessible to cargo owners and the public.

The potential for using the proposed method for assessing spatial differentiation in the development of transport infrastructure among the constituent entities of the Russian Federation can be seen in the following areas: (1) an explanatory component in econometric studies of the influence of various factors on the overall socio-economic development of the territories; (2) a tool for the compilation of interregional rankings.

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