LEVEL ASSESSMENT OF TRANSPORT INFRASTRUCTURE DEVELOPMENT AS A FACTOR OF SOCIO-ECONOMIC PROGRESS OF TERRITORIAL AGGLOMERATIONS

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Abstract: This article proposes a methodology for assessing the level of regional transport infrastructure as a factor of socioeconomic development of agglomeration territories. Based on this technique, the integral index was calculated and a detailed analysis of the cause-effect relationship of changes in the results of the composite criteria of the overall indicator was carried out.

Ключевые слова: Agglomeration territories, socioeconomic development, transport infrastructure, urban environment, sustainable development of the territory.

1 Introduction

A highly concentrated and developed urban environment with well-qualified labor market capable of realizing the functions of production of knowledge and technology, the flow control of goods and information, and the provision of services is being formed around the territorial agglomerations. Likewise, companies of financial and consulting services sectors, medicine, education, trade, culture and art, entertainment, engineering services, scientific and innovative activities are usually located within the capital city, which, in our case, acts as the agglomeration core. All these lead to the fundamental changes in the territorial and qualitative structure of the region.

According to Anas A., Lindsey R. (Anas & Lindsey, 2011), Crafts N. (Crafts, 2009), the city agglomeration transport infrastructure requires special emphasis due to its every day cargo and passenger transportation. It links the population and manufacturing sector acting as a means of daily labor pendulum migration from house to work; it also becomes an integral element of the rapid and effective implementation of management measures and organizational decisions.

Hörcher D., De Borger B. (Hörcher etal., 2020), Hazledine T., Donovan S.(Hazledine et al., 2017) detail the transport infrastructure as a medium ensuring population migration mobility, where the intensity of territorial settlement and areas of new development depend on it. Moreover, the transport system of the urban settlement should grow faster for the purpose of normal staged agglomeration progress.

This study is based on the modernized technique originally developed by Kudryavtseva A.M., Rudneva L.N. Graham D.J., Gibbons S. (Graham & Gibbons, 2019), Redding S.J., Rossi-Hansberg E(Redding & Rossi-Hansberg, 2017), Melo P.C., Brage-Ardao R(Melo et al., 2013), Glebova I.S., Vorobyev A.A(Glebova et al., 2015), Volchkova I.V., Danilova M.N.(Volchkova et al., 2016) advanced the methodological approaches to estimate the level of transport infrastructure development as a factor for socio-economic progress of territorial agglomerations.

2 Methods

As stated before, the methodology for estimating the level of regional transport infrastructure development is based on the modernized technique, which was adjusted and transport infrastructure development indicators as key estimation parameters were introduced (see Table 1).

Table 1: Transport Infrastructure Development Indicators

N	Indicator	Formula	Formula Description
1	Transport network density per 1000 km^2, D_{tn}	$D_{tn} = \dfrac{L_{red} * 1000}{S}$	L_{red} – reduced length of agglomeration transport lines, km; S - agglomeration area, km^2
2	Transport provision to the population, T_{pp}	$Tp_p = \dfrac{L_{red} * 10000}{P}$	L_{red} – reduced length of agglomeration transport lines, km; P – population size, people
3	Cargo mass density, D_{cm}	$D_{cm} = \dfrac{\sum Q_i}{L_{red}}$	Q_i – volume of goods transported by industries by the mode of transport, thousand tons; L_{red} – reduced length of agglomeration transport lines, km
4	The Engel Coefficient, C_e	$Ce = \dfrac{L_{red}}{\sqrt{S*P}}$	L_{red} – reduced length of agglomeration transport lines, km; S– agglomeration area, km^2 ; P– population size, people
5	Transport network provision (the Uspensky formula), C_u	$C_u = \dfrac{L_{red}}{\sqrt[3]{S*P*Q}}$	L_{red} – reduced length of agglomeration transport lines, km; S– agglomeration area, km^2 ;P – population size, people; Q– amount of cargo, thousand tons
6	Volume of investments in transport infrastructure, V_{iti}	$V_{iti} = \dfrac{I_{ti}}{I_t}$	I_{ti}– volume of investments in transport infrastructure of the agglomeration, thousand rubles; It - total investments in the agglomeration development, thousand rubles
7	Transport mobility of the population, T_{mp}	$T_{mp} = \dfrac{\sum HL_{pass}}{P}$	ΣHL_{pass} – passenger turnover, passenger-km; P – population size, people
8	Transport discrimination of the population, T_{dp}	$T_{dp} = \dfrac{P_{disc}}{P} * 100\%$	P_{disc} – locality population where transport accessibility between homeand work exceeds the norm by 10% ; P – population size, people
9	Passenger and freight traffic ratio, R	$R = \dfrac{\sum QL_c}{k * \sum HL_{pass}}$	k – reduced coefficient of passenger-kilometer to ton-kilometer; ΣQL_c – cargo turnover, t-km;ΣHL_{pass} – passenger turnover, pass-km
10	Average travel cost to the agglomeration center and back, P_{av}	$P_{av} = \dfrac{\sum P}{n}$	ΣP – total amount of travel cost on various modes of transport, rubles; n - number of agglomeration entities, units

In general, it is more expedient to estimate the transport infrastructure development on the basis of calculating the overall indicator using the method of multidimensional average: correlation of individual values of estimated parameters for each agglomeration and average value of these parameters in Russia as a whole:

$$\overline{Tp_i} = \frac{\sum_{j=1}^{n} Tp_{ij}}{n}, \qquad (1)$$

$$Tp_{ij} = \frac{Ind_{ij}}{\overline{Ind_{ij}}}, \qquad (2)$$

where $\overline{Tp_i}$ is the general indicator of transport infrastructure development of the i-th agglomeration: T_{pij} represents value of single indicators of transport infrastructure development according to the j-th estimated parameter (its increase means growing or decreasing the level of transport infrastructure development); Ind_{ij} is the individual value of transport infrastructure development of the i-th agglomeration with respect to the j-th estimated parameter; $\overline{Ind_{ij}}$ is the average value of the j-th estimation parameter in Russia as a whole; i is the number of agglomeration in the study aggregate; j is number of the estimated parameter; n is the whole number of estimated parameters.

In order to reduce transport links to one of the types, namely, to 1 km of railways, L.I. Vasilevsky coefficients were used and transformed in this research work: 0.5 – motorway traffic, 0.3 – water (river) ways, 0.2 – regular highway traffic.

3 Results and Discussion

Tables 2-12 display the results of calculations using the methodology for estimation the level of regional transport infrastructure development as a factor of socioeconomic change of territorial agglomerations.

Table 2: Transport Network Density per 1000 km², D_{tn}

	2014		2015		2016		2017		2018	
The average Russian level	36.38		37.47		38.11		38.35		38.70	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	1526.66	–	1590.48	–	1577.64	–	1675.79	–	1702.10	–
St. Petersburg agglomeration	1221.20	1	1226.02	1	1207.93	1	1298.62	1	1312.75	1
Ufa agglomeration	1052.25	1	1258.67	1	1409.94	1	1429.95	1	1452.14	1
Kazan agglomeration	1929.92	3	1994.06	3	2028.71	3	2051.89	3	2069.10	3
Krasnoyarsk agglomeration	649.78	1	652.07	1	661.24	1	650.99	1	659.09	1
Perm agglomeration	948.37	1	972.68	1	1032.25	1	1042.54	1	1051.31	1
Voronezh agglomeration	836.63	1	843.89	1	846.63	1	861.44	1	874.75	1
Nizhny Novgorod agglomeration	1437.04	2	1451.43	2	1455.05	2	1466.19	1	1478.74	1
Novosibirsk agglomeration	243.32	1	247.92	1	270.65	1	272.39	1	273.31	1
Omsk agglomeration	565.19	1	572.86	1	570.30	1	570.63	1	581.77	1
Rostov agglomeration	1388.27	2	1396.00	1	1404.43	1	1414.09	2	1424.97	1
Samara-Tolyatti agglomeration	579.25	1	601.61	1	605.38	1	612.93	1	618.30	1
Ekaterinburg agglomeration	1297.61	1	1322.98	1	1338.49	1	1357.40	1	1368.25	1
Chelyabinsk agglomeration	1603.61	3	1637.38	3	1656.67	3	1690.85	3	1714.59	3

The transport network density is the ratio of the length of public transport lines to the area of the agglomeration territory. According to the density, these transport networks can be classified into six categories: I. Very small – up to 1.05; II. Small – 1.05-1.50; III. Moderate – 1.50-1.90; IV. Dense – 1.90-2.25; V. Very dense – 2.25-2.50; VI. Extremely dense – more than 2.50. Based on this classification, the agglomeration territories were distributed as follows:

I. Very small: Krasnoyarsk, Perm, Voronezh, Novosibirsk, Omsk, Samara-Togliatti agglomerations;

II. Small: St. Petersburg, Nizhny Novgorod, Rostov, Ufa, Yekaterinburg agglomerations;
III. Moderate: Moscow, Chelyabinsk agglomerations;
IV. Dense: Kazan agglomeration.

Therefore, one can conclude that the transport networks in the agglomeration territories are not sufficiently developed; this interferes with the free movement of citizens and labor migrants and negatively affects the duration of transport and freight movements. However, agglomeration territories indicators are significantly higher than the national average.

Table 3: Transport Provision to the Population, Ton

	2014		2015		2016		2017		2018	
The average Russian level	4.33		4.38		4.45		4.47		4.50	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	15.16	–	15.57	–	15.63	–	15.56	–	15.73	–
St. Petersburg agglomeration	20.00	3	20.19	3	19.94	3	19.69	3	19.64	3
Ufa agglomeration	99.53	3	117.82	3	130.87	3	131.93	3	133.00	3
Kazan agglomeration	116.70	3	119.05	3	119.86	3	119.71	3	119.44	3
Krasnoyarsk agglomeration	128.11	3	126.52	3	126.70	3	122.96	3	123.39	3
Perm agglomeration	80.49	3	81.82	3	86.38	3	86.74	3	87.07	3

Voronezh agglomeration	82.86	3	83.06	3	82.78	3	83.28	3	84.21	3
Nizhny Novgorod agglomeration	72.84	3	73.54	3	73.76	3	74.51	3	75.27	3
Novosibirsk agglomeration	41.82	3	42.36	3	45.81	3	45.64	3	45.51	3
Omsk agglomeration	71.92	3	72.46	3	71.91	3	71.99	3	73.78	3
Rostov agglomeration	80.28	3	80.36	3	80.60	3	80.88	3	81.24	3
Samara-Tolyatti agglomeration	41.35	3	42.93	3	43.26	3	43.74	3	44.22	3
Ekaterinburg agglomeration	75.80	3	76.61	3	76.88	3	79.96	3	80.10	3
Chelyabinsk agglomeration	97.38	3	98.47	3	99.01	3	100.38	3	101.57	3

Transport provision to the population shows kilometers of transport routes per 10,000 inhabitants. The average Russian indicator is 4.3-4.5 km / 10,000 individuals; the agglomeration indicators are 8-10 times higher than the average Russian level.

Table 4: Cargo Mass Density, D_{cm}

	2014		2015		2016		2017		2018	
The average Russian level	11.28		10.60		10.26		10.25		10.26	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	6.85	–	6.65	–	6.91	–	5.43	–	6.66	–
St. Petersburg agglomeration	7.47	2	6.78	2	6.32	1	5.63	2	5.64	1
Ufa agglomeration	6.27	1	5.36	1	3.70	1	3.48	1	3.52	1
Kazan agglomeration	5.87	1	5.04	1	4.53	1	4.49	1	4.45	1
Krasnoyarsk agglomeration	11.10	2	10.04	2	9.11	2	8.28	2	8.24	2
Perm agglomeration	9.94	2	8.85	2	7.45	2	6.51	2	6.91	2
Voronezh agglomeration	2.57	1	3.01	1	3.09	1	2.14	1	2.01	1
Nizhny Novgorod agglomeration	3.03	1	3.18	1	3.84	1	2.87	1	2.52	1
Novosibirsk agglomeration	5.03	1	4.66	1	3.90	1	3.99	1	4.22	1
Omsk agglomeration	3.84	1	3.83	1	3.67	1	3.30	1	3.28	1
Rostov agglomeration	4.86	1	4.58	1	4.41	1	4.40	1	4.43	1
Samara-Tolyatti agglomeration	5.86	1	5.74	1	5.42	1	4.67	1	5.22	1
Ekaterinburg agglomeration	7.32	2	6.62	1	6.10	1	6.02	2	5.99	1
Chelyabinsk agglomeration	7.91	2	7.53	2	6.73	1	6.19	2	6.10	1

The cargo mass density determines kilograms of transported goods per 1 km of agglomeration transport lines. The average Russian indicator is 11.2 thousand tons / km, which exceeds the agglomeration indices. This is due to the fact that most agglomerations are characterized by the developed sphere of services and technologies, while industries, which are precisely related to the need to transport cargo mass, are outside agglomerations.

Table 5: The Engel Coefficient, C_e

	2014		2015		2016		2017		2018	
The average Russian level	0.01		0.01		0.01		0.01		0.01	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	0.05	–	0.05	–	0.05	–	0.05	–	0.05	–
St. Petersburg agglomeration	0.05	3	0.05	3	0.05	3	0.05	3	0.05	3
Ufa agglomeration	0.10	3	0.12	3	0.14	3	0.14	3	0.14	3
Kazan agglomeration	0.15	3	0.15	3	0.16	3	0.16	3	0.16	3
Krasnoyarsk agglomeration	0.09	3	0.09	3	0.09	3	0.09	3	0.09	3
Perm agglomeration	0.09	3	0.09	3	0.09	3	0.10	3	0.10	3
Voronezh agglomeration	0.08	3	0.08	3	0.08	3	0.08	3	0.09	3
Nizhny Novgorod agglomeration	0.10	3	0.10	3	0.10	3	0.10	3	0.11	3
Novosibirsk agglomeration	0.03	2	0.03	2	0.04	2	0.04	2	0.04	2
Omsk agglomeration	0.06	3	0.06	3	0.06	3	0.06	3	0.07	3
Rostov agglomeration	0.11	3	0.11	3	0.11	3	0.11	3	0.11	3
Samara-Tolyatti agglomeration	0.05	3	0.05	3	0.05	3	0.05	3	0.05	3
Ekaterinburg agglomeration	0.10	3	0.10	3	0.10	3	0.10	3	0.10	3
Chelyabinsk agglomeration	0.12	3	0.13	3	0.13	3	0.13	3	0.13	3

The Engel coefficient estimates the level of provision of the region's transport network; and if the value is greater than "1", this indicates a sufficient level of transport system development. The analysis shows that no agglomeration territory is close to this value; this confirms the previous conclusion about the insufficiency of transport services provision.

Table 6: Transport Network Provision (the Uspensky formula), C_u

	2014		2015		2016		2017		2018	
The average Russian level	0.241		0.25		0.25		0.26		0.257	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	0.07	–	0.07	–	0.07	–	0.08	–	0.07	–
St. Petersburg agglomeration	0.07	2	0.07	3	0.07	3	0.08	2	0.08	3

Ufa agglomeration	0.12	3	0.14	3	0.17	3	0.18	3	0.18	3
Kazan agglomeration	0.16	3	0.17	3	0.18	3	0.18	3	0.18	3
Krasnoyarsk agglomeration	0.09	3	0.09	3	0.10	3	0.10	3	0.10	3
Perm agglomeration	0.09	3	0.10	3	0.11	3	0.11	3	0.11	3
Voronezh agglomeration	0.14	3	0.13	3	0.13	3	0.15	3	0.15	3
Nizhny Novgorod agglomeration	0.15	3	0.15	3	0.14	3	0.16	3	0.16	3
Novosibirsk agglomeration	0.06	2	0.06	1	0.07	2	0.07	2	0.07	2
Omsk agglomeration	0.10	3	0.10	3	0.10	3	0.11	3	0.11	3
Rostov agglomeration	0.13	3	0.13	3	0.14	3	0.14	3	0.14	3
Samara-Tolyatti agglomeration	0.07	3	0.08	3	0.08	3	0.08	3	0.08	3
Ekaterinburg agglomeration	0.11	3	0.12	3	0.12	3	0.12	3	0.12	3
Chelyabinsk agglomeration	0.13	3	0.13	3	0.13	3	0.14	3	0.14	3

The Uspensky formula is a modification of the Engel coefficient; it takes into account the weight of goods sent in the agglomeration territory and denotes the level of transport provision in the manufacturing sector. The results are close to the Engel coefficient, hence, the amount of cargo transportation in the territorial agglomerations is not significant.

Table 7: Volume of Investments in Transport Infrastructure, V_{iti}

	2014		2015		2016		2017		2018	
The average Russian level	0.275		0.254		0.229		0.203		0.186	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	0.28	–	0.27	–	0.27	–	0.26	–	0.25	–
St. Petersburg agglomeration	0.36	3	0.27	2	0.22	2	0.27	3	0.33	3
Ufa agglomeration	0.18	2	0.19	2	0.20	2	0.15	2	0.12	2
Kazan agglomeration	0.19	2	0.12	2	0.09	2	0.10	2	0.13	2
Krasnoyarsk agglomeration	0.13	2	0.14	2	0.15	2	0.15	2	0.16	2
Perm agglomeration	0.23	2	0.11	2	0.08	2	0.09	2	0.12	2
Voronezh agglomeration	0.12	2	0.11	2	0.10	2	0.19	2	0.13	2
Nizhny Novgorod agglomeration	0.18	2	0.17	2	0.15	2	0.18	2	0.23	2
Novosibirsk agglomeration	0.26	2	0.27	2	0.27	3	0.25	2	0.22	2
Omsk agglomeration	0.21	2	0.26	2	0.28	3	0.23	2	0.18	2
Rostov agglomeration	0.21	2	0.28	3	0.30	3	0.30	3	0.31	3
Samara-Tolyatti agglomeration	0.20	2	0.18	2	0.17	2	0.18	2	0.19	2
Ekaterinburg agglomeration	0.29	3	0.17	2	0.15	2	0.19	2	0.21	2
Chelyabinsk agglomeration	0.16	2	0.15	2	0.14	2	0.12	2	0.11	2

The volume of investments in transport infrastructure shows investor interest in the development of the agglomeration transport system. According to the estimates of the National Commission for Profitability Study and Ground Transportation Policy, from 2008 to 2035, the shortage of capital needed to improve the world transport infrastructure will amount to 71%.Thus, the share of investments in transport infrastructure in the total volume of investments in the agglomeration constitutes 13-36%, and the average agglomeration indicator is approximately comparable to the average Russian level. The downward trend in the share of investments in transport infrastructure is characteristic both for Russia as a whole and for most agglomerations, which predictably will worsen the transport situation.

Table 8: Transport Mobility of Population, T_{mp}

	2014		2015		2016		2017		2018	
The average Russian level	3806.54		3800.41		3617.75		3540.87		3816.88	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	6777.48	–	6664.89	–	6611.24	–	6543.04	–	6523.65	–
St. Petersburg agglomeration	4860.66	2	4761.67	2	4745.37	2	4696.22	2	4656.00	2
Ufa agglomeration	2511.31	2	2784.18	2	3194.96	2	3027.43	2	2722.04	2
Kazan agglomeration	1953.90	1	1995.09	1	1997.79	1	1856.09	1	1715.94	1
Krasnoyarsk agglomeration	1990.03	1	2631.67	2	2401.43	1	2327.45	1	2158.47	1
Perm agglomeration	3981.87	2	3322.72	2	3446.10	2	3126.31	2	3337.94	2
Voronezh agglomeration	2191.03	1	1985.21	1	1946.35	1	1681.37	1	1556.01	1
Nizhny Novgorod agglomeration	1926.58	1	2166.58	1	2259.25	1	2085.18	1	2055.07	1
Novosibirsk agglomeration	616.47	1	916.91	1	1042.70	1	1207.09	1	1401.59	1
Omsk agglomeration	973.88	1	1243.10	1	1183.37	1	1050.54	1	926.19	1
Rostov agglomeration	1674.75	1	1581.81	1	1611.29	1	1615.84	1	1557.07	1
Samara-Tolyatti agglomeration	2280.01	1	2495.55	1	2203.48	1	2411.41	1	2464.01	2

Ekaterinburg agglomeration	1525.58	1	1353.42	1	1384.60	1	1418.26	1	1344.16	1
Chelyabinsk agglomeration	1764.06	1	1379.63	1	1944.64	1	1445.51	1	996.51	1

The population transport mobility is determined by the ratio of people using the public transport to the total population of the territory. This is one of the most important characteristics which makes it possible to reasonably estimate and calculate the need for vehicles and the provision of public transport services, and consequently undertake measures for their improvement. Given the fact that the population of the agglomeration is mostly labor migrants, it is imperative for them to be as mobile as possible. An analysis of the results showed that the average Russian mobility level is approximately 3800 (including railways, cars and river transport). However, only a small part of the agglomerations exceeded the average Russian indicators or at least they are close to them; this again confirms the under development of transport networks.

Table 9: Passenger and Freight Traffic Ratio

	2014		2015		2016		2017		2018	
The average Russian level	4.47		4.58		4.82		4.99		4.90	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	0.96	–	0.96	–	0.91	–	0.85	–	1.09	–
St. Petersburg agglomeration	0.93	1	0.86	1	0.78	1	0.76	1	0.75	1
Ufa agglomeration	8.01	2	8.41	2	7.63	2	7.66	2	8.08	2
Kazan agglomeration	3.42	2	3.59	2	3.84	2	4.01	2	4.24	2
Krasnoyarsk agglomeration	11.65	2	11.07	2	11.85	2	12.49	2	13.04	2
Perm agglomeration	6.98	2	7.87	2	7.60	2	7.80	2	8.60	2
Voronezh agglomeration	1.99	2	2.14	2	2.52	2	3.22	2	3.43	2
Nizhny Novgorod agglomeration	1.54	2	1.56	2	1.50	2	1.62	2	1.62	2
Novosibirsk agglomeration	1.41	2	1.35	2	1.20	2	1.34	2	1.75	2
Omsk agglomeration	5.70	2	5.79	2	5.83	2	5.58	2	5.79	2
Rostov agglomeration	2.57	2	2.46	2	2.67	2	2.80	2	4.71	2
Samara-Tolyatti agglomeration	3.54	2	3.54	2	3.90	2	3.20	2	3.03	2
Ekaterinburg agglomeration	6.49	2	7.09	2	6.92	2	6.91	2	7.20	2
Chelyabinsk agglomeration	20.29	2	23.97	3	21.48	2	22.32	2	24.86	3

The ratio of passenger and freight traffic represents the number of ton-kilometers per 1 passenger-kilometer. In this formula, the coefficient reduction of passenger-kilometer to ton-kilometer equals 1.On average, in Russia, freight transportation exceeds passenger traffic 4-5 times, while the Chelyabinsk agglomeration accounts for the highest value due to its prevailing industrial development.

Table 10: Transport Discrimination of Population

	2014		2015		2016		2017		2018	
The average Russian level	12.37		12.32		12.21		12.19		11.94	
Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	21.41	–	21.60	–	20.75	–	20.82	–	17.52	–
St. Petersburg agglomeration	17.52	1	17.66	1	17.63	1	17.66	1	17.73	2
Ufa agglomeration	13.15	1	13.15	1	13.18	1	13.22	1	13.20	1
Kazan agglomeration	16.27	1	16.29	1	16.35	1	16.38	1	16.46	1
Krasnoyarsk agglomeration	10.00	1	9.90	1	9.85	1	9.80	1	9.92	1
Perm agglomeration	12.84	1	12.78	1	12.77	1	12.78	1	12.88	1
Voronezh agglomeration	4.39	1	4.29	1	4.21	1	4.09	1	4.03	1
Nizhny Novgorod agglomeration	15.88	1	15.76	1	15.74	1	15.76	1	15.75	1
Novosibirsk agglomeration	14.07	1	13.84	1	13.68	1	13.55	1	13.44	1
Omsk agglomeration	5.51	1	5.45	1	5.41	1	5.36	1	5.34	1
Rostov agglomeration	21.20	1	21.05	1	20.85	2	20.67	1	20.56	2
Samara-Tolyatti agglomeration	10.50	1	10.43	1	10.39	1	10.31	1	10.22	1
Ekaterinburg agglomeration	7.71	1	7.61	1	7.49	1	7.65	1	7.53	1
Chelyabinsk agglomeration	2.75	1	2.66	1	2.65	1	2.65	1	2.61	1

The indicators of transport discrimination and the average travel cost to the agglomeration center and back were calculated on the basis of different travel options between the constituent parts of the agglomeration.

The transport discrimination indicator determines the percentage of population living far from the agglomeration center. In this case, the following time intervals were used to group districts by the type of transportation provision:

I) Optimal: from 0.1 to 1 hour
II) Affordable: from 1.1 to 2 hours
III) Marginal: from 2.1 to 3 hours
IV) Discriminatory: more than 3 hours.

This interval series is also stipulated by the recommendations on urban planning (SNiP 2.07.01-89 * standards). They state that travel time between home and work for 90% of working people should not exceed 45 minutes (with population of more than 2000 thousand individuals); considering labor migrants – no more than 1 hour 30 minutes a day.

Thus, according to the calculation results, the average indicator is about 12%, whereas the highest number of the population discriminated in terms of transport accessibility relates to the Moscow and St. Petersburg agglomerations, and the lowest – to the Chelyabinsk agglomeration.

Table 11: Average Travel Cost to the Agglomeration Center and Back

Agglomeration territory	Pas. cars per day	Pas. cars per month	Railtr. perday	Rail tr. per month	Bus per day	Bus per month	Transportation costs per month, percentage of income		
							Pas. cars	Railtr	Bus
Moscow agglomeration	279.38	5866.98	227.16	4770.39	181.59	3813.37	12.82	10.43	8.33
St. Petersburg agglomeration	449.18	9432.70	336.95	7075.89	369.33	7755.93	25.33	19.00	20.83
Ufa agglomeration	452.53	9503.20	300.32	6306.72	241.33	5067.83	39.37	26.13	21.00
Kazan agglomeration	314.79	6610.68	101.33	2128.00	202.14	4245.00	26.76	8.62	17.19
Krasnoyarsk agglomeration	404.15	8487.08	312	6552.00	271.93	5710.60	29.17	22.52	19.63
Perm agglomeration	350.99	7370.86	169	3549.00	227	4767.00	23.65	11.39	15.30
Voronezh agglomeration	397.30	8343.20	269.78	5665.33	257.42	5405.78	33.88	23.01	21.95
Nizhny Novgorod agglomeration	310.37	6517.74	216.8	4552.80	227.03	4767.60	24.93	17.42	18.24
Novosibirsk agglomeration	303.04	6363.88	167.75	3522.75	406.67	8540.00	22.60	12.51	30.33
Omsk agglomeration	279.71	5873.95	989.5	20779.50	502.7	10556.70	27.64	97.77	49.67
Rostov agglomeration	278.34	5845.18	186.5	3916.50	470.9	9888.90	24.28	16.27	41.08
Samara-Tolyatti agglomeration	654.07	13735.41	473.37	9940.74	573.13	12035.64	54.77	39.64	47.99
Ekaterinburg agglomeration	301.43	6330.02	170.4	3578.40	305.49	6415.20	20.80	11.76	21.08
Chelyabinsk agglomeration	249.20	5233.20	0.0	0.00	192.33	4039.00	22.11	0.00	17.06

The average cost of travel to the agglomeration center and back is calculated with respect to the three most common modes of transport, namely: personal car, railway transport, and bus service. The calculation of cost per day in a personal car was made considering gasoline consumption of 7 liters per 100 km; the cost of 92 gasoline is taken as the region's average. Thus, the average cost from different points of the agglomeration to its center amounts to 359 rubles; the most expensive cost falls on the Samara-Togliatti agglomeration, and the lowest – on the Chelyabinsk territory.

Average railway cost is 280 rubles; the most expensive is the Omsk agglomeration, and the lowest indicator is in the Perm and Yekaterinburg agglomerations. Average bus services amount to 360 rubles with the highest and the lowest indicators in the Samara-Togliatti and the Moscow agglomerations respectively. If we calculate time spent on traveling from the place of residence to the place of work and back per month, and compare it with the average per capita income, provided an average of 21 working days per month is taken into account, we get the following data (see Fig. 1).
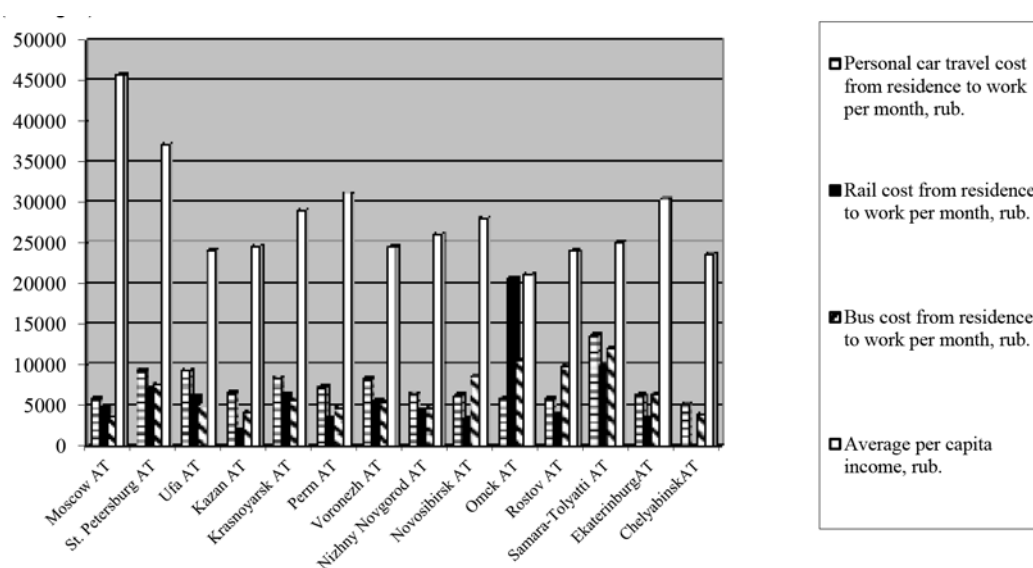

Fig. 1: The ratio of travel cost from home to work and back on various modes of transport to average per capita income

Thus, these data indicate that the territorial agglomeration population spends an average of 27% of their income if they travel by car, 23% – by rail, and 2.5% – by bus. At the same time, the residents of the Samara-Togliatti agglomeration expend the largest percentage of income moving in a personal car(54%), while the Moscow agglomeration spends only 12%;when traveling by rail, the largest sum is spent by the residents of the Omsk agglomeration (98%), and the lowest indicator goes to the Kazan agglomeration (8%);when traveling by bus, the population of the Omsk agglomeration spends the largest amount

(5%), and the smallest one –the residents of the Moscow agglomeration (0.8%).

4 Summary

After analyzing all methodology indicators, the overall indicator of the transport infrastructure development $\overline{Tp_i}$ was measured (Table 12).

Table 12: Overall Indicator of Transport Infrastructure Development

Agglomeration territory	2014	Points	2015	Points	2016	Points	2017	Points	2018	Points
Moscow agglomeration	5.57	–	5.64	–	5.53	–	5.77	–	5.79	–
St. Petersburg agglomeration	4.85	2.1	4.73	2.1	4.60	1.9	4.85	1.9	4.89	2
Ufa agglomeration	6.65	2.1	7.67	2.1	8.36	2.1	8.38	2.1	8.40	2.1
Kazan agglomeration	9.73	2.1	9.76	2.1	9.73	2.1	9.75	2.1	9.73	2.1
Krasnoyarsk agglomeration	6.16	2.1	6.03	2.2	5.98	2.1	5.84	2.1	5.85	2.1
Perm agglomeration	5.84	2.1	5.79	2.1	5.98	2.1	5.99	2.1	6.02	2.1
Voronezh agglomeration	5.25	2	5.17	2	5.10	2	5.18	2	5.19	2
Nizhny Novgorod agglomeration	6.90	2	6.82	2	6.74	2	6.78	1.9	6.81	1.9
Novosibirsk agglomeration	2.30	1.7	2.31	1.6	2.44	1.8	2.45	1.7	2.44	1.7
Omsk agglomeration	4.15	1.9	4.15	1.9	4.08	2	4.04	1.9	4.07	1.9
Rostov agglomeration	7.04	1.9	6.94	1.9	6.89	2	6.91	2	6.95	2
Samara-Tolyatti agglomeration	3.50	2	3.55	2	3.52	2	3.54	2	3.55	2.1
Ekaterinburg agglomeration	6.66	2.1	6.58	1.9	6.52	1.9	6.65	2	6.66	1.9
Chelyabinsk agglomeration	8.43	2.1	8.44	2.2	8.33	2	8.41	2.1	8.48	2.1

According to the results in Table 12, the highest indicators are in the Ufa, Kazan, Krasnoyarsk, Perm and Chelyabinsk agglomerations.

Summarizing, it is worth noting that the level of transport infrastructure development in the studied agglomerations is predominantly above average, which is definitely a positive trend.

5 Conclusions

Although the infrastructural upgrading of individual agglomerations often occurs at a faster rate than the average Russian rate, it requires special attention due to the increasing flow of labor pendulum migrants.

Acknowledgements

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