*Research Paper*

# Post-Soviet Street Patterns

## Measuring Network Connectivity in the Largest Russian Cities

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### Abstract

*The study is dedicated to the analysis of the street patterns, formed during the Soviet and post-Soviet periods, in the largest Russian cities and involves examining the configuration of street network, measuring its specific features and exploring their interrelation, accomplished by using the GIS tools and statistical methods.*

### Keywords

*post-Soviet cities, street patterns, network connectivity*

## 1. Introduction

Cities have historically grown around their streets and today the street network is the 'skeleton' of any urbanised area. Cities with properly developed and well-connected street network tend to be more liveable and productive (UN-Habitat, 2013a). A growing body of research suggests that street network connectivity has the largest effect on walking of all the built environment features and the significant effects on the transit use and the amount of driving (Ewing and Cervero, 2010). Thus, the high degree of network connectivity can contribute to better environmental sustainability (via reducing the use of motorised means of transport) and overall increased quality of life for citizens (by providing for optimal commuting times and raising the ease of access to various services).

The connectivity concept is widely researched and frequently applied in the built-environment studies coming from the developed countries, especially from North America (which is of no surprise given the widespread curvilinear design of the neighbourhoods of the US cities greatly hindering connectivity) (Handy, Paterson and Butler, 2003; Dill, 2004; Litman, 2017). Therewith, in Russia and other post-Soviet states it is not explored yet. There is no known attempt to examine the street connectivity in the context of post-Soviet spatial structure and to assess this quantitatively. The present study seeks to address the knowledge gap of the street network measures in Russian cities in order to draw attention to the concept of street connectivity and its potential in promoting healthy lifestyles and supporting vibrant environment. It implies the spatial analysis of the street patterns that formed during the Soviet and post-Soviet periods in the largest cities of Russia.

## 2. Post-Soviet Street Patterns

Streets and roads have always been a sore spot for Russian cities' residents. Despite the growing attention of the government to the development of the road system that has been in place in the last twenty years, its density and quality still do not meet the standards adopted in the developed countries. According to the World Economic Forum, the ranking of the Russian infrastructure (including roads, railroad infrastructure, air transport infrastructure as well as quality of electricity supply and others) is generally poor - 114 among 137 countries (World Economic Forum, 2018). Moreover, the quality of the road network does not correspond to the level of welfare of the country and the state of the overall infrastructure (see Figure 1). Yet these figures are only a perception of the Russian citizens as the quality of road infrastructure was assessed via responses to the following question: In your country, how is the quality (extensiveness and condition) of road infrastructure [1 = extremely poor—among the worst in the world; 7 = extremely good—among the best in the world]. So, what is the real degree of the road network development in the Russian cities comparing to the rest of the world and what are the factors hindering this development?

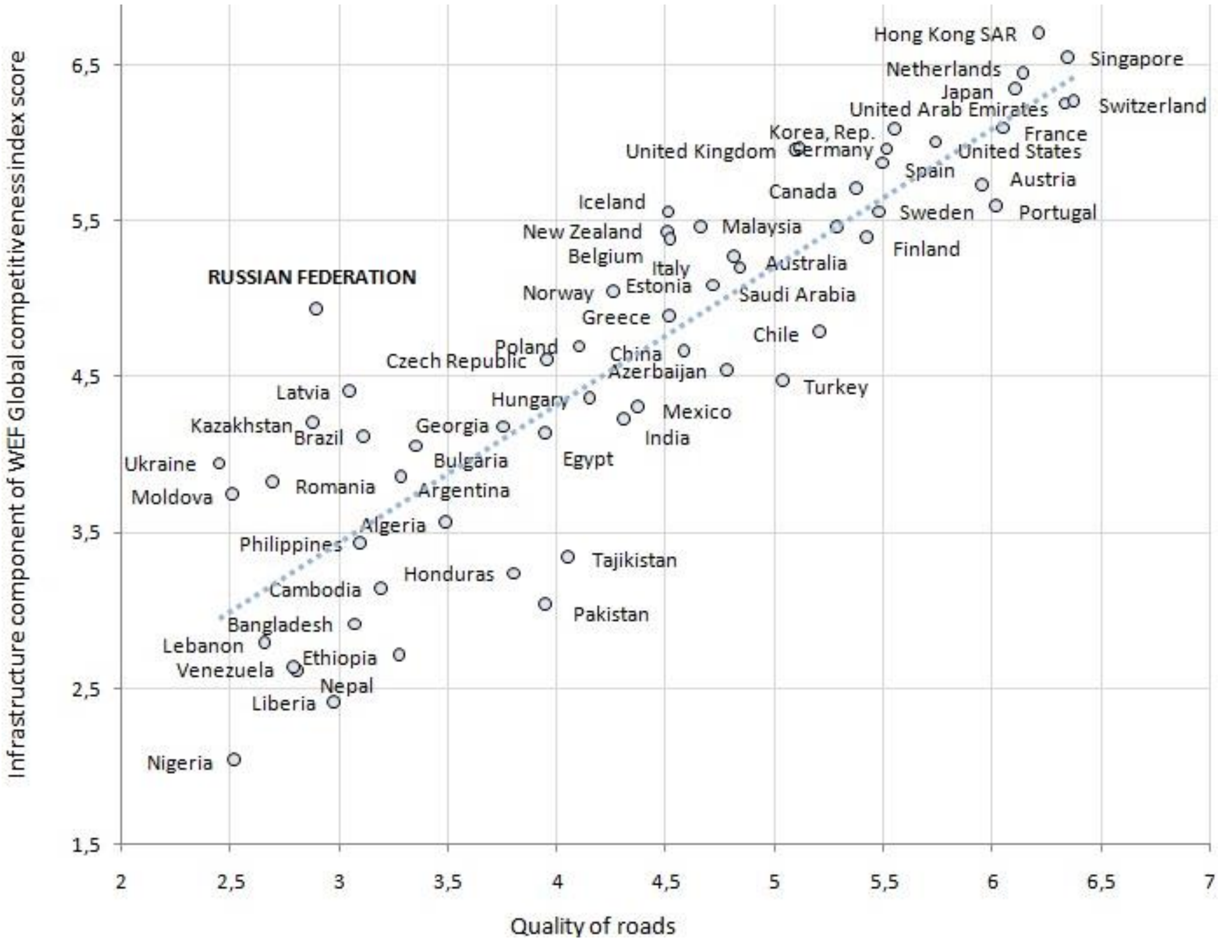

**Figure 1. Competitiveness and quality of transport infrastructure. Created by author based on The Global Competitiveness Report 2017–2018 by World Economic Forum, 2018.**

The current street networks of the Russian cities are still in many ways "Soviet": wide avenues laid during the Soviet period as the expression of the communist leaning towards the grandeur and megalomania are now present in every major city of Russia, in their centres and their peripheries. Many studies of the post-Soviet (or more broadly, post-socialist) urban structure highlight its peculiarities stemming from specific political and economic conditions under which it formed (Tosics, 2005). Rejection of private property and land market, abundant land resources and focus on urban growth resulted in the specific urban structure (unreasonably stretched urbanised areas, fragmented urban structure and peripheral clusters of high density). For the Russian cities in study the Soviet period of urbanisation became the defining one and in many ways paving the way for future development, since it is during this period that the main city growth took place, both population and territory-wise. As an essential element of urban structure, the street network of the post-Soviet city also has characteristic features that do not correspond to other found in the world.

The peculiar street patterns of the Russian cities are mainly a legacy of the Soviet period. The street network remained underdeveloped during the Soviet times: the share of the built-up area in a city reserved for urban street and road network was exceptionally low (Koncheva and Zalesskiy, 2016) . The main reason for that was the low motorisation rate typical of the Soviet cities. Since the transportation demand was supposed to be met solely by public transport, the motorisation rate prescribed by norms was 150-200 cars per 1000 inhabitants (Gosstroy SSSR, 1985) and the actual motorization rate did not exceed 80 cars per 1000 inhabitants. Thus, the road network of very modest density was sufficient to meet the mobility needs of that time.

By the end of the Soviet era, the share of streets and roads in the built-up area, or land allocated to streets (LAS), of Russian cities did not exceed 10 per cent. For comparison purposes, in modern North American cities, this parameter usually equals 30-35 per cent, and in Western Europe cities it is about 20-25 per cent (Blinkin and Koncheva, 2016). Yet, given the insignificant volume of car use, the transportation network was still sufficient enough to make traffic jams an unprecedented phenomenon.

Their appearance of wide boulevards that are common for all the major post-Soviet cities was, however, not due to the thoughtful transport planning. Figure 2, for example, shows one of the main transportation links in the central part of Perm with an unreasonably wide roadway used by rare motorised transport that is significantly outnumbered by pedestrians. Evaluating transport demand or perspectives of the motorization rate growth were often substituted by the purely architectural and aesthetic considerations. Later, in the 1970-80s Soviet transport planning has reached a high level in terms of methodology, modelling and traffic engineering, but transport planning and transportation-related decisions were still based on very artificial hypotheses about the transport behaviour of citizens (Kulakov and Trofimenko, 2016).

**Figure 2. One of the main transportation links in the central part of Perm, 1970s. Source: Perm State Archive of Social and Political History, 2014**

Another typically Soviet feature, negatively affecting the cities' spatial structure and particularly the street network, is the microrayons - high-density residential settlements each housing around ten thousand people situated at a considerable distance from the city centre. The idea of the development unit centred around school and complete with all necessary residential services has become an interpretation of the Clarence Perry concept of neighbourhood unit and also the way in which modernist movement exhibited itself on the Soviet soil. Microrayons were built with the intention to cover the transport demand fully by public transit (yet its provision often lagged). The microrayons with their peculiar layouts as in Figure 3, confusing system of inner driveways and arterial roads around the perimeter were ill suited for private cars and today fail to meet the new traffic demands.

**Figure 3. Examples of microrayon layout found in the largest Russian cities. Created by author**

As already noted, the capacity of the transport network developed during Soviet times was sufficient to carry the number of vehicles that existed at the time, yet the system has ceased to be underutilized already by the end of the 1980s. Thus, entering a new era, Russian cities had only modestly developed street networks, while the number of cars remained extremely low: with motorisation rate being around 60 cars per 1000 inhabitants there were about 200–250 m² of streets and roads per one vehicle. This equals to the current level of the average road network area per vehicle characteristic of such countries with extensive road systems US, Canada or Australia, where motorisation rate is several times higher - around 600-800 cars per 1000 inhabitants.

Since the 1990s, the automobile ownership in Russia has increased fivefold: from 9 million of cars in 1990 to the current 45 million. The road network has also seen some development but the scope of improvement cannot be compared with the car ownership growth. Figure 4 shows the striking difference between the growth rate of the private vehicle fleet and of the roads' length during the last three decades. As a result, Russian cities today possess urban street network most of which was designed and constructed during the Soviet period with the intention of carrying vehicular traffic far below the current levels. By now the estimated value of the average road network area per vehicle is only 25-40 m² (Koncheva and Zalesskiy, 2016).

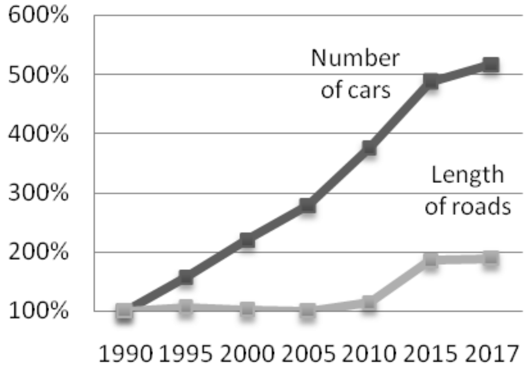

**Figure 4. The growth rates of the private vehicle fleet and the road network in Russia. Created by author based on the data from Federal State Statistics Service (ROSSTAT), 2018**

This underdevelopment of the street network is one of the factors contributing to the currently escalating mobility issues. The Russian cities, which inherited all the flaws of the Soviet style urban structure, including the dense residential neighbourhoods at the periphery and street network of insufficient capacity, now struggle to cope with the heavy traffic generated by the rapidly growing vehicle fleet. Yet having a high percentage of urban land allocated to streets is a necessary but insufficient condition for improving the city’s network: wide streets in a very limited street network and low intersection density do not usually imply high connectivity. While the construction of more roads is important to create the conditions to design effective transport solutions, it should be planned very carefully. This paper aims to assess the current state of the street network in a number of Russian cities in order to determine its specificities and to outline the ways for its improvement in terms of connectivity.

## 3. Methodology

The study includes analysis of such components of street network connectivity as street density (the total network distance, ignoring the number of lanes on a road divided by the built-up area or population); LAS - land allocated to streets (the area of streets divided by the built-up area); intersection density (the number of nodes divided by the built-up area); and the link/node ratio (the total number of links divided by the total number of nodes). The three main objectives envisaged by this research - examining the configuration of street network, measuring its specific features and exploring their interrelation - are accomplished by using the GIS tools and statistical methods.

The network design and configuration have been analysed based on the Open Street Map Highway dataset including the following street classes within the dataset: trunk (partially), primary, secondary, tertiary and residential. The so called ‘named streets’ approach (based on the same street name to merge individual street segments (Jiang and Claramunt, 2004)) was used for obtaining meaningful streets from the OSM dataset. Due to the gaps in attribute information, the average width for each type of street has been estimated using orthophotos.

As already mentioned, the empirical analysis of the street patterns is performed on a sample of the largest cities of Russia. In terms of population, there are 15 Russian cities that may be considered as "the largest" (over 1 million inhabitants) including metropolitan cities Moscow and Saint Petersburg. Due to the peculiarities of their spatial structure and its evolution, this study bypasses the two Russian capitals - Moscow and St. Petersburg - and concentrates on the other 13 Russian cities with a population of over 1 million people, namely: Novosibirsk, Yekaterinburg, Nizhny Novgorod, Kazan, Chelyabinsk, Omsk, Samara, Rostov-on-Don, Ufa, Krasnoyarsk, Perm, Voronezh, Volgograd. These cities demonstrate very common development patterns that may be also found in many other cities with Soviet past and allow forming the general picture of the post-Soviet street patterns.

## 4. Analysis of connectivity indicators

Four connectivity indicators including network density (per capita and per km$^2$ of urbanised area), LAS, intersection density (overall and average per km$^2$) and the link/node ratio were calculated for all the 13 cities in study. Table 1 summarises all the obtained results, which are consistently analysed further.

**Table 1. Summary of connectivity indicators of the largest Russian cities**

| # | City | Population, million people | Built-up area, km$^2$ | Road length, km | Network density per km$^2$ of BUA, km/km$^2$ | Network density per capita, m/person | Total area of streets, km$^2$ | LAS, % | Number of inter-sections | Intersection density, overall | Inter-section density, average per km$^2$ | Link/node ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Novosibirsk | 1,603 | 273,75 | 1483,9 | 5,42 | 0,9 | 28,66 | 10,5% | 3891 | 14,2 | 8,70 | 2,00 |
| 2 | Yekaterinburg | 1,456 | 296,94 | 1521,0 | 5,12 | 1,0 | 34,33 | 11,6% | 3070 | 10,3 | 5,70 | 2,22 |
| 3 | N. Novgorod | 1,262 | 221,03 | 1075,7 | 4,87 | 0,9 | 14,64 | 6,6% | 2749 | 12,4 | 8,41 | 2,41 |
| 4 | Kazan | 1,232 | 240,19 | 1587,8 | 6,61 | 1,3 | 28,32 | 11,8% | 4115 | 17,1 | 9,38 | 2,04 |
| 5 | Chelyabinsk | 1,199 | 276,59 | 1100,8 | 3,98 | 0,9 | 23,59 | 8,5% | 2908 | 10,5 | 7,56 | 1,96 |
| 6 | Omsk | 1,178 | 316,70 | 1470,9 | 4,64 | 1,2 | 30,62 | 9,7% | 4306 | 13,6 | 8,31 | 1,95 |
| 7 | Samara | 1,170 | 188,47 | 1173,8 | 6,23 | 1,0 | 24,46 | 13,0% | 2756 | 14,6 | 8,05 | 2,05 |
| 8 | Rostov-on-Don | 1,125 | 171,66 | 1419,2 | 8,27 | 1,3 | 25,70 | 15,0% | 5172 | 30,1 | 19,65 | 1,94 |
| 9 | Ufa | 1,116 | 234,88 | 1200,2 | 5,11 | 1,1 | 24,46 | 10,4% | 2390 | 10,2 | 5,22 | 2,00 |
| 10 | Krasnoyarsk | 1,083 | 209,34 | 958,4 | 4,58 | 0,9 | 20,89 | 10,0% | 2038 | 9,7 | 5,89 | 2,18 |
| 11 | Perm | 1,048 | 255,21 | 1158,9 | 4,54 | 1,1 | 26,41 | 10,3% | 2628 | 10,3 | 5,79 | 1,89 |
| 12 | Voronezh | 1,040 | 215,87 | 1329,6 | 6,16 | 1,3 | 24,13 | 11,2% | 3819 | 17,7 | 9,25 | 1,86 |
| 13 | Volgograd | 1,016 | 270,73 | 1588,7 | 5,87 | 1,6 | 28,82 | 10,6% | 4512 | 16,7 | 10,16 | 2,02 |
|  | Average |  |  |  |  |  |  | 10,7% |  | 14,4 | 8,4 | 2,04 |

## 4.1. Network Density

The density of street network was assessed with the help of two indicators: the street network density per km² of urbanised (built-up) area and the street network density per capita. Low values of the first measure in the largest Russian cities (right part of the diagram from Figure 5) indicate both the scarcity of roads and unreasonably big urbanised areas. Artificially expanded built-up areas, inherited from the Soviet times, today cannot be sustained by cities' budgets given the comparatively low average population densities. Less road length per person is usually a sign of more sustainable urban form, subject to the prevalence of public transport or non-motorised modes. Otherwise, in case of reliance on private modes, low values of road density per capita only enhance congestion levels. The optimal combination of the two indicators, thus, consists of higher network density per km² of urbanised area and lower network density per capita.

Figure 5, firstly, demonstrates that such a combination may be rarely found in the largest Russian cities and, secondly, confirms the perception mentioned earlier showing that street density values in the largest Russian cities are indeed significantly lower in comparison with Western cities.

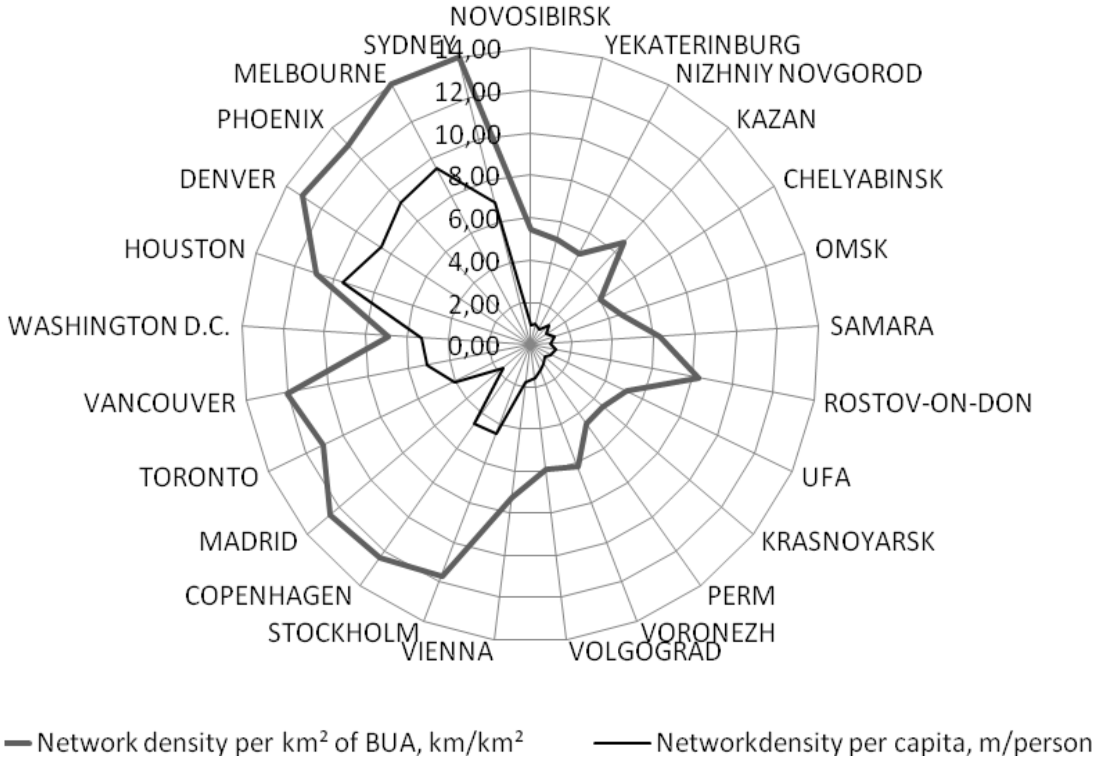

**Figure 5. Network density per capita and per km² of urbanised area in the largest cities of Russia (right) and selected world cities (left). Created by author based on the own calculations**

## 4.2. LAS

In various studies the degree of street network's connectivity is often measured by its proxy - the share of street network in the urban fabric. The share of streets or the land allocated to streets (LAS) in the urbanised area is expressed as the ratio of urban land allocated to streets with the total built-up area of the city. Thus, enhancing connectivity often involves increasing the percentage of urban land allocated to streets and roads: limited street infrastructure in cities with low LAS values obstructs accessibility required for development of more sustainable urban mobility patterns.

All of the cities in study have comparatively low values of LAS with the average value 10.7 per cent (see Figure 6). The values calculated for the largest Russian cities are in line with the previous studies. Blinkin and Koncheva (2016), for instance, claim that the average LAS values for the Russian cities do not exceed 10 per cent. While the obtained result is at the expected level, it is very low comparing to cities in Europe or Northern America. The average values of LAS calculated in the study by UN-Habitat (2013b) for a number of world cities are significantly higher: 27.5 per cent for European cities, 23.2 per cent for North American and Australian cities and 25.8 per cent for Asian cities.

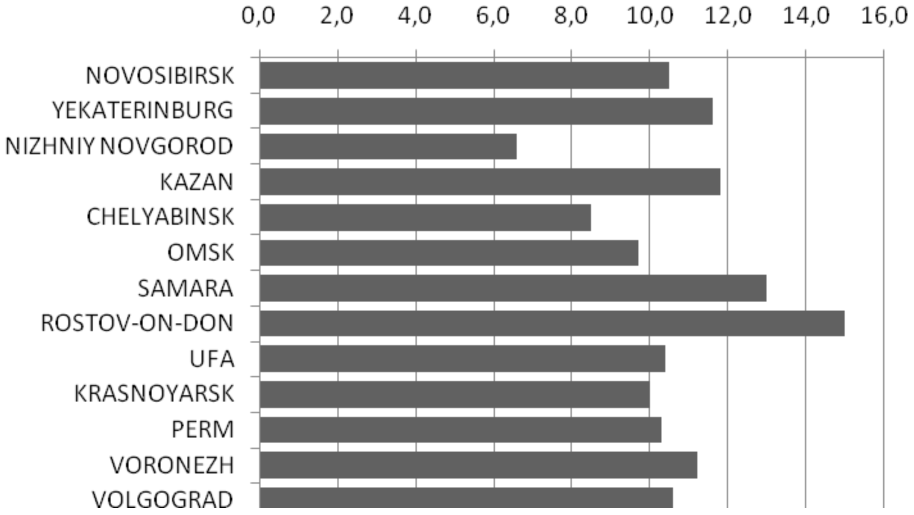

**Figure 6. Land allocated to streets in the largest Russian cities. Created by author**

## 4.3. Intersection Density

Intersection density is another fundamental element of network connectivity. According to Ewing and Cervero (2010) it has large effects on transit use and the amount of driving. It also plays a vital role in providing the appropriate level of walkability in street network: the more intersection density there is, the more walkable the streets are.

The cities in study have all shown very modest values of intersection density, as presented in Table 1. The intersection density is also not uniform across the cities' territories. The example of Kazan - the city with one of the highest results - clearly shows that most intersections are concentrated either in the historical city centre or in the peripheral residential areas of suburban type (see Figure 7). At the same time the middle part of the city situated closely adjacent to the centre constitutes the areas of poorly connected street network. This is the Soviet period belt of either industrial or residential neighbourhoods.

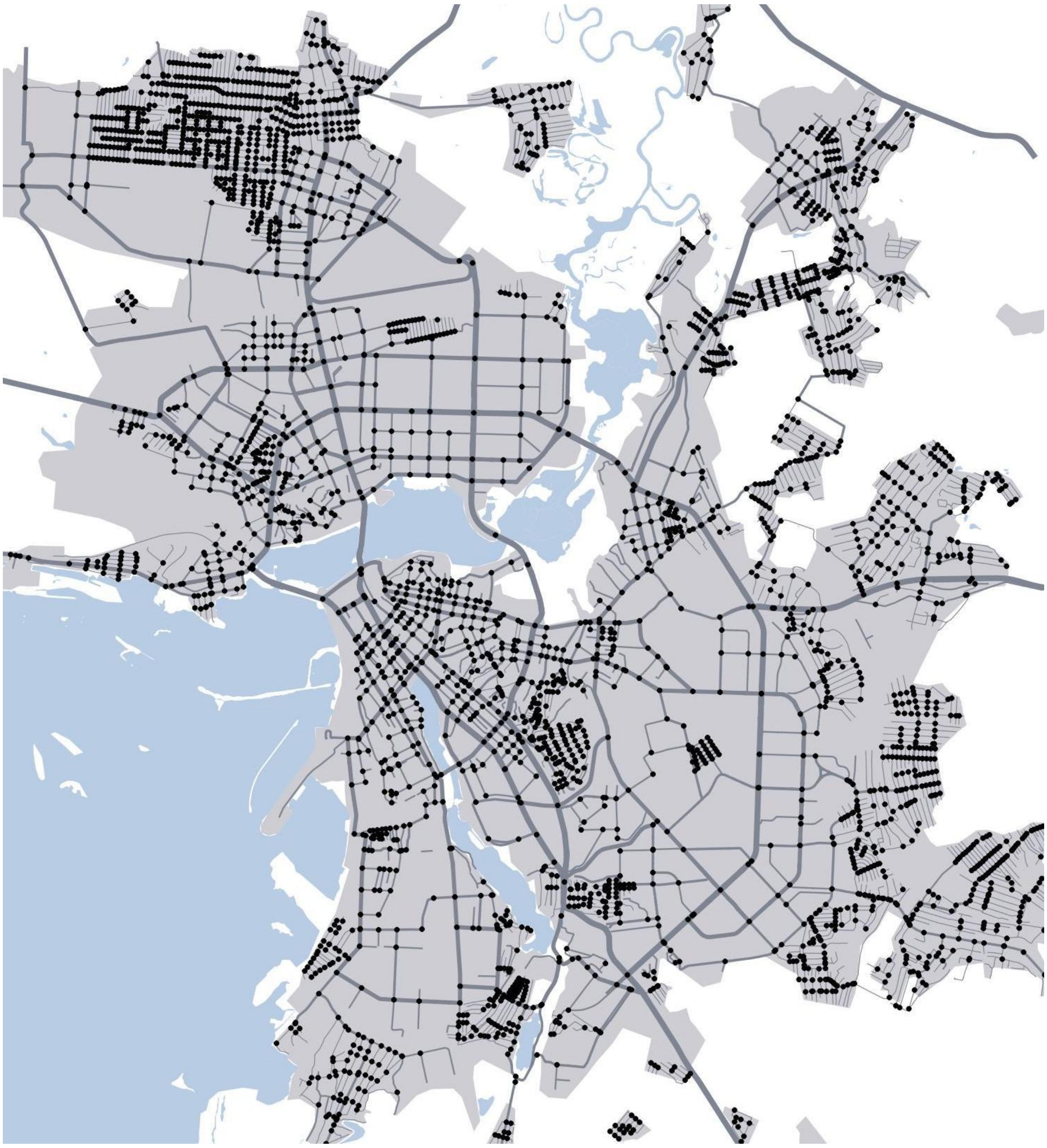

Figure 7. Intersection density in Kazan. Created by author

## 4.4. Link/Node Ratio

In the Link/Node Ratio indicator, links are defined as street segments between two nodes and nodes are intersections or the end of a cul-de-sac. Higher link/node ratio implies higher street connectivity. While a perfect grid has a ratio of 2.5, Ewing (1996) proposes a value of 1.4 as a target for planning a walkable network with decent level of connectivity. The obtained values of Link-to-Node Ratio was pretty high for all the cities in study (average value was 2,04), yet this result might be misleading for several reasons. Firstly, it is very much affected by the selection of links and nodes that are included in the calculation. The study did not take into account local driveways inside the residential quarters, which are often cul-de-sacs in contrary with proper residential streets – the lowest level in the hierarchy of streets included in the calculation – that are in most cases connected with each other or major streets. Secondly, this indicator does not reflect the length of the links in any way. It means that a grid of 500/700-meter blocks, typical of the Soviet microrayons, have the same link-node ratio as a grid with 150/200-meter blocks, as in the older parts of the city (see example in Figure 8).

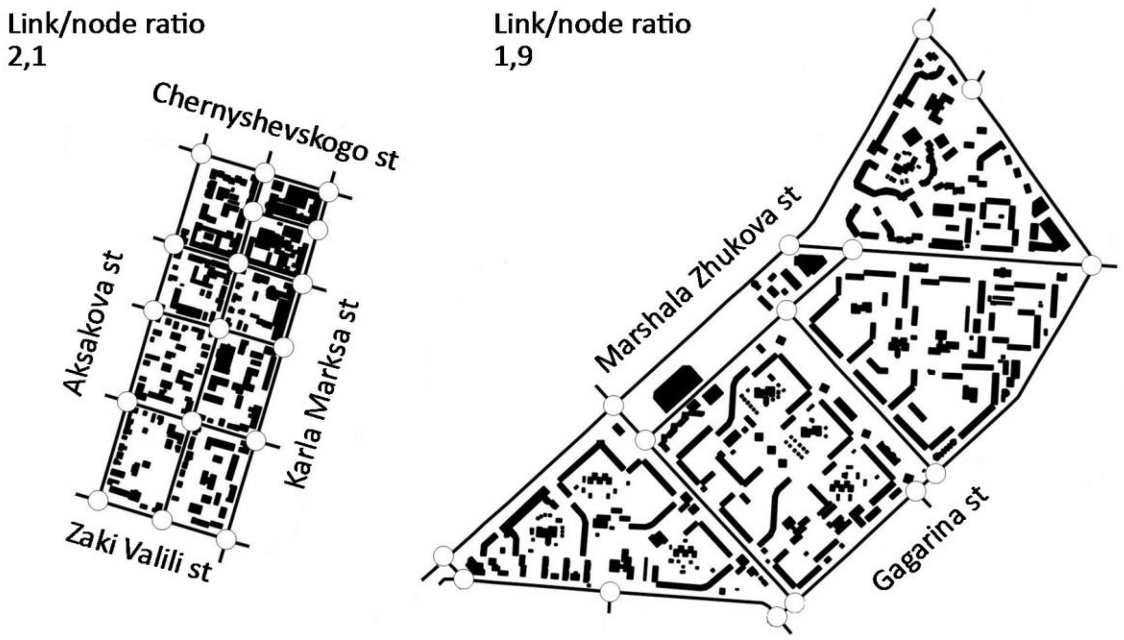

**Figure 8. Areas with similar link/node ratio in the old centre and in the microrayon Sipailovo of Ufa, same scale. Created by author**

### 4.5. Interrelations between connectivity indicators

All the considered indices - network density, land allocated to streets, intersection density and link-to-node ratio - taken together determine the level of street network connectivity. It is important that each of them is considered in conjunction with others to obtain an objective picture of streets patterns. It would be also interesting to evaluate the interrelation between them and to create a composite index subject to their positive correlation.

Using the Pearson correlation, it has been established that all the considered indices are highly correlated with each other (see Figure 9). The most direct association is between network density and intersection density, as shown by the coefficient of correlation of 0.92 between them (Figure 9 top right). Herewith, the density of intersections is not just linked with the overall density of streets but mostly with the local network density including tertiary and residential streets (Figure 9 bottom right).

The weakest association is between intersection density and the percentage of urban land allocated to streets. While the index of LAS is important on its own terms, the high values of it do not always translate into high connectivity. While the post-Soviet cities have many wide streets, considerable block sizes in the Soviet period neighbourhoods result in low intersection density. It is important that the street network that is to be considered effective in terms of connectivity has not only enough space dedicated to streets but also adequate intersection density.

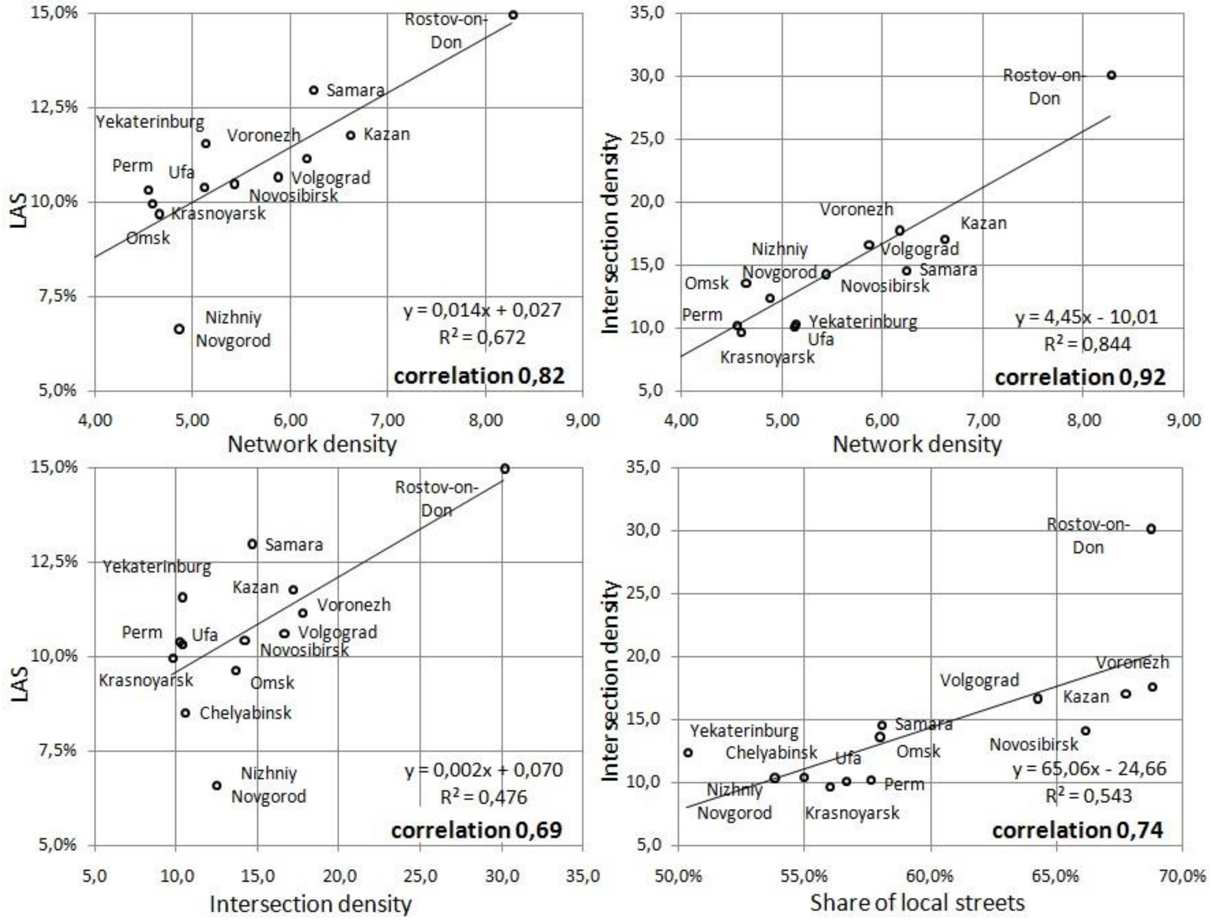

**Figure 9. Interrelation between different elements of network connectivity. Created by author**

## 5. Conclusions and practical recommendations

This study, carried out through affordable geographic information systems and open-source data, has provided an estimation of the street network patterns in the largest cities of Russia. Even this preliminary examination with the level of precision, which could be sustained by the open source software, allowed to identify some interesting patterns and provide recommendations.

The results reveal major dysfunctionalities in the post-Soviet street patterns: all the Russian cities covered in the present study have comparatively low values of all four calculated connectivity components that are crucially important for creating an efficiently laid out street network. The Russian cities have inherited the Soviet urban structure with underdeveloped street network. The low motorisation rate typical of the Soviet cities resulted in the extremely low share of street network in the urban fabric: the indicator LAS in the largest Russian cities is characteristic of the cities in the pre-automobile era and 2-3 times lower than in the European and North American cities. The values of other indicators calculated for the Russian cities are also significantly lower in comparison with their 'western' counterparts.

While the estimations of the road density and connectivity show significant lag of the Russian cities in this area and confirm the necessity of the construction and transformation of the current street networks, city authorities should ensure that the investment in urban transportation infrastructure are made where they are most needed. The cities with post-Soviet street patterns need to invest in adequate and well-laid out street networks, paying special attention to the improvement of the network quality characteristics such as permeability and uniformity and increasing the density and connectivity of the network, especially on the periphery to relieve the city centres from being transit points.

Regretfully, little can be done to remedy the existing lack of connectivity in the Soviet microrayons. Their bizarre layouts designed without due consideration to connectivity are difficult to retrofit due to topography or existing physical obstacles such as houses and other development. But at least new development projects should take into account connectivity issues. Yet, various examples of maintaining of Soviet style development practice can be found in contemporary Russian cities. The reproduction of the Soviet model of urban development is not only in the continued high-density development at the outskirts of the cities but also in the maintaining of the "microrayon" type of structure in new urban development projects. Figure10 shows an example of recently developed microrayon Akademicheskiy at the periphery of Yekaterinburg bounded by major streets intersecting only every 600-700 meters.

**Figure 10. Modern development with microrayon type of structure in Yekaterinburg. Source: Yandex Maps and Dranichnikov, 2016**

For a particular neighbourhood, connectivity applies both internally (streets within that area) and externally (connections with primary streets and other neighbourhoods). It is still a commonplace in Russian cities when particular buildings and even large development projects are designed ignoring the context including the network of streets as in Figure 11 illustrating the new residential development Krasnye Kazarmy in Perm. Municipalities and developers must change their understanding of residential development from considering each new neighbourhood as an isolated island to seeing it as an indispensable part of wider environment. When connecting new developments with streets is not possible without severe violations of the transport scheme or due to environmental constraints connecting neighbourhoods via a sidewalk or path should be performed at least. A poorly-connected street network not only encourages the use of the private automobile over other travel modes, it also creates longer trips, divides neighbourhoods, limits alternative routes to schools and local services. Moreover, emergency services, such as fire trucks and ambulances, have to navigate inefficient routes that cause unnecessary delay.

**Figure 11. An example of new development in Perm, where internal streets are not connected with primary streets or adjacent network having only one exit from the whole neighbourhood. Source: Yandex maps**

In order to ensure that the new development compiles with the principles of network connectivity, street connectivity standards or goals may be adopted within local regulations for urban planning. The considered measures of street connectivity are relevant for policies and should be easy for local practitioners to implement on a GIS platform. The more so because now every major city is in possession of some kind of GIS-based model. Such data will help to support the development of regulatory frameworks that promote creating well-connected network and neighbourhoods with walkable environment. Possible regulations for network planning may include requirements for minimum share of streets in the new developments or link-node ratio standards, which, however, should not applied in isolation but probably combined with an intersection spacing standard or maximum block length due the issues described above. In this connection the Connectivity Index might be a useful measurement tool for municipal planning in evaluating and promoting connectivity in proposed plans of new development. Since all the connectivity measures are positively correlated, they can be easily combined in such summary Connectivity index, which will allow for greater flexibility than using specific requirements.

The efficient network needs to be formed considering the hierarchy of streets and be convenient for private cars and for public transport as well as for non-motorised travel such as walking and cycling. The latter currently seems to attract less attention in Russian cities. Whether it be in the interest of public health, in reducing automobile dependence or in supporting vibrant urban communities, environment friendly travel should be encouraged and well-connected network is one of the most important factors that may support it. Connectivity, thus, should become a major benchmark for creating a more effective and sustainable urban mobility model.

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