Passenger Rail Transport: Issues of Functioning in Agglomerations of Millionaire Cities

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Abstract. The article is devoted to the study of the existing system of passenger rail transport in cities with a population of one million. Transport infrastructure is an important element of urban infrastructure and participates in the formation of agglomeration links. The article discusses the issue of the connectivity of the outer zone of the city with the agglomeration due to the existing system of using rail transport. Three cities with a population of one million, with similar socio-economic and physical-geographical characteristics - Yekaterinburg, Kazan and Perm, were selected as territorial objects. The similar and different aspects of the formed passenger railway transport systems are revealed. It is concluded that the integral indicator of the level of development of suburban and intracity transport links of external zones demonstrates a strong Perm lag behind Yekaterinburg and Kazan. Yekaterinburg and Kazan possess highly differentiated links between the individual sectors of the city's outer zone. The "gap" between cities also takes place without taking into account the integration of electric trains with the metro, and becomes even stronger when taking into account the interaction of the two off-street transport systems.

1. Introduction
The modern stage of urbanization processes in Russia is characterized by the active development of agglomerations of cities with a million inhabitants. In the agglomeration zone, directly adjacent to the city boundaries, the following trends are clearly manifested:

- expansion of housing construction, both individual and multi-apartment;
- expanding the variety of recreational functions focused on natural objects - water and forest;
- conversion of seasonal dwellings "dacha", previously mainly used only in summer, into all-season or permanent dwellings;
- growth in demands for social infrastructure - kindergartens, schools, clinics;
- an increase in tourist flows and movements associated with visiting natural and historical and cultural sites.

Obviously, the listed processes are associated with an increase in the amount of movement between the city and its agglomeration and, accordingly, require a transport infrastructure adequate to the growing demands for movement.
The development of various types of transport, the balance of the use of personal and public transport is possible on the basis of studying the existing possibilities of the territory of the urban agglomeration, the existing infrastructure and taking into account the experience of other countries. In this regard, it is of research interest and practical importance to study passenger rail transport using the example of millionaire cities with similar socio-economic and physical-geographical characteristics. The objects of research are Yekaterinburg, Kazan and Perm. In recent years, issues of public transport have become the subject of close scientific interest, including public transport in these cities [1-3].

In scientific literature, attention is paid to the issue of the agglomeration's transport system from various points of view. A number of publications are devoted to the role of transport, including passenger rail transport, in ensuring the functioning of city agglomeration; interrelation of urban and transport planning; mathematical modeling tools public efficiency of rail transport of megalopolis [4-11]. A significant number of publications are devoted to case-studies of various cities and agglomerations of the world in the development of the transport system [12-18].

**2. Method**

Under the external zones of Russian cities, relying on the approaches of E.N. Pertzik [24], we understand the territories located between the large center and the boundaries of urban districts. If in Russian cities these territories are controlled by the administrations of cities (urban districts), then in many European states, these are already independent municipalities, albeit closely integrated into the agglomeration space.

In Russia, the transformation of the external zones has its own specifics. On the one hand, in comparison with the Soviet period, there is a large-scale diversification of their functional structure. On the other hand, the processes of spatial differentiation of the territories under consideration by the level of socio-economic development and the quality of the environment are intensifying.

The transformation and enrichment of the functional structure of the external zones of Russian cities is largely caused by the need to develop many promising and core functions for millionaire cities - healthcare, higher education, science, sports, tourism, trade, etc. Which are not always such for a large center, since a number of factors limit the possibility of their formation and expansion here.

For the external zone, of course, the residential function, and the placement of infrastructure and logistics facilities, and industrial production, the requirements for the level of automation, robotization, environmental friendliness and humanization of which are increasing, remain core.

It should be noted that the external zone is more extensive in comparison with the central part of the city, therefore, uniform saturation of the territory with various functions is impossible here, and a certain intra-sectoral polarization must be considered as an inevitable phenomenon. The poles of the external zones are comparatively small territories, the saturation of which with various functions in many respects exceeds that of the immediate environment. World urban planning experience shows that it is optimal to tie such poles to the main highways of off-street transport. The development of railway transport is the most realistic option for a radical improvement of the transport situation in the external zones of Russian millionaire cities in the short term, especially since the necessary infrastructure already exists and was formed in the 20th century.

To assess the level of development of railway communication in the external zones of the compared cities, two groups of indicators were proposed: the first included those that characterize intra-city connections ("city-city"), the second - connections between the external zones and the agglomeration ("city-suburb"). First, the values of all indicators were calculated for each sector of the external zone.

Let's consider the indicators of the first group.

\[
c_i^j = \frac{1}{2} \times \left( \text{total number of runs per week between the sector and a large center} + \text{number of runs per week on routes covering a significant section of the railway track within the inhabited part of the sector} \right)
\]
of runs that also connect the center with this sector, but completely cover the sectoral segment of the railway network, units;

\[ q_{ij}^{-j} \] – average number of suburban and city train runs per week on routes connecting the j-th sector of the external zone of the i-th urban district with other sectors of the external zones (formula 1), units.

\[
\Delta q_i^j = (\sum q_{ij}^{-j})/3
\]  

(1)

where \( q_{ij}^{-j} \) – the number of suburban and city train runs per week on routes connecting the j-th sector with another j-th sector of the external zone of the i-th urban district, by analogy with the previous indicator, the problem of incomplete coverage of some railway network runs in some sectors was solved by calculating the arithmetic mean.

\( q_i^j \) – number of suburban and city train runs per week on routes connecting the j-th sector of the external zone of the i-th urban district with the main city airport, units.

\( p_i^j \) – the number of transfer combinations at the main railway station (railway station, stopping point) of the j-th sector of the external zone of the i-th urban district per week, which fit into the standard of 20 minutes, and allow the formation of new directions of passenger movement (formula 2), units.

\[
p_i^j = \sum((f_i^n + b_i^n)/2)
\]  

(2)

where \( f_i^n \) – the number of trips of suburban and urban electric trains, from which, within 20 minutes, it is possible to transfer at the main railway station (railway station, stopping point) of the j-th sector of the i-th urban district to other trips of suburban and urban electric trains or subway on the n-th direction of travel passengers, units; \( b_i^n \) – the number of commuter and urban electric trains that can be transferred within 20 minutes at the main railway station (railway station, stopping point) of the j-th sector of the i-th urban district from other commuter and urban electric trains or the subway to n-th direction of movement of passengers, units.

The values of all indicators were normalized relative to the average value according to formula 3 (considered using the example of the first indicator):

\[
c(n)_i^j = \frac{c_i^j}{c_{med}}
\]  

(3)

where \( c(n)_i^j \) – normalized number of suburban and city train runs connecting the j-th sector of the external zone of the i-th urban district with a large center, units.; \( c(n)_i^j \) – the arithmetic mean among the sectors of all cities under consideration \( c(n)_i^j \).

By analogy, indicators were calculated that characterize the connection between the external zones of the city and the suburbs.

1) the number of commuter train trips in the j-th sector of the external zone of the i-th urban district per week along routes connecting the external zone of the city center and the adjacent suburban zone \( (m_i^j) \), units;

2) the number of commuter train trips in the j-th sector of the external zone of the i-th urban district per week along routes that ensure the connection of this sector with suburban zones not adjacent to it \( (d_i^j) \), units;

3) the number of transfer combinations at the main railway station (railway station, stopping point) of the j-th sector of the external zone of the i-th urban district per week, which fit into the standard of
20 minutes and allow the formation of new directions of passenger movement, including the suburban area \((d_i^j)\), units.

At the next stage, the values of the normalized indicators were summed up within each sector, each group, and the integral indicator of the level of development of railway communication in the external zones of cities \((R_i)\), presented in formula 4, was determined.

\[
R_i = RG_i + RM_i
\]  

where \(RG_i\) – an integral indicator characterizing the level of development of railway communication in external zones, providing communications in the "city-city" system, and calculated as the sum of all normalized values of indicators of the first group, units; \(RM_i\) – an integral indicator characterizing the level of development of railway communication in the external zones, providing communications in the "city - suburb" system (calculated as the sum of all normalized values of indicators of the second group), units.

3. Results and discussions

Three cities with a population of one million - Yekaterinburg, Kazan, Perm - were considered as a territorial object in the study. Having similarities as an economic profile with the serious development of the industrial industry, the formation and active development of the postindustry and relatively similar characteristics of the physical-geographical plan.

The results of assessing the level of development of intracity transport links of external zones of the cities under consideration, provided by rail, are presented in Table 1.

**Table 1.** The level of development of intracity transport links of the external zones of Yekaterinburg, Kazan and Perm, provided by rail, as of January 2019.

| City         | Sector number | \(c(n)_i^j\) | \(\Delta q(n)_i^j\) | \(a(n)_i^j\) | \(p(n)_i^j\) | \(RG_i (RG_i^j)\) |
|--------------|---------------|---------------|----------------------|---------------|---------------|------------------|
| Yekaterinburg| 1             | 0.3           | 0.4                  | 0.0           | 0.3           | 0.7              |
|              | 2             | 2.3           | 1.5                  | 1.9           | 0.3           | 6.1              |
|              | 3             | 0.7           | 1.6                  | 0.0           | 0.0           | 2.3              |
|              | 4             | 2.7           | 1.2                  | 1.0           | 7.3           | 12.2             |
|              | Total         | 6.0           | 4.8                  | 2.9           | 7.6           | **21.3**         |
| Kazan        | 1             | 1.2           | 1.7                  | 0.0           | 2.8           | 5.6              |
|              | 2             | 0.7           | 1.2                  | 7.2           | 0.0           | 9.1              |
|              | 3             | 1.3           | 1.1                  | 1.9           | 0.1           | 4.4              |
|              | 4             | 0.0           | 1.7                  | 0.0           | 1.2           | 2.9              |
|              | Total         | 3.1           | 5.8                  | 9.1           | 4.1           | **22.1**         |
| Perm         | 1             | 1.4           | 0.7                  | 0.0           | 0.0           | 2.1              |
|              | 2             | 0.0           | 0.0                  | 0.0           | 0.0           | 0.0              |
|              | 3             | 0.6           | 0.0                  | 0.0           | 0.0           | 0.6              |
|              | 4             | 0.9           | 0.7                  | 0.0           | 0.3           | 1.9              |
|              | Total         | 2.9           | 1.4                  | 0.0           | 0.3           | **4.6**          |

A low level of development of intracity railway transport links of external zones is typical for Perm, the positions of Yekaterinburg and Kazan are much better and comparable, although they differ markedly in the context of individual components.
The railway connection between the external zone and the center is most developed in Yekaterinburg. All four Yekaterinburg sectors have it (with varying degrees of intensity), while in Kazan it is impossible to get from the center to the northern (fourth) sector by rail, and in Perm there is no railway at all within the second sector. Yekaterinburg is also distinguished by the presence of very intensive link between the center and the second and fourth sectors. Their infrastructure basis is formed by the railway corridor, within which suburban and urban routes of five directions are consolidated in the second sector, and three in the fourth.

The best situation with railway communication between the sectors of the external zones, the development of which is very important in the context of an ever-increasing sectoral specialization in certain types of attractiveness, is associated with the specifics of the configuration of the railway network. Along the southern part of the fourth sector of the external zone through the Vosstanie-Pass station. there is a line served by routes directly connecting not only the third, fourth and first sectors, but also the north-western and north-eastern Kazan suburbs. Some of the electric trains following a relatively recently built line from the airport pass through the second sector and through the Kazan-Passenger station to the third sector and further to the adjacent suburb. The fairly high value of the indicator under consideration in Yekaterinburg is also due to the network and routing configuration features. The center is connected with the first and third sectors through the second sector, and between the third, part of the second and fourth sectors, city electric trains run through the main railway station of the city. However, there is no complete connectivity between the sectors of the external zones in Yekaterinburg and Kazan. In Perm, at the beginning of 2019, there was a direct railway connection only between the first and fourth sectors. With the closure of the Perm-1 - Perm-2 section in 2020, it was liquidated. In the short term, the transfer alternative proposed by the city authorities involves the use of street transport and, therefore, is associated with significant time losses [2], which will not be overcome in the medium term if tram traffic is organized along the Kama embankment.

Kazan is distinguished by the most intensive traffic between the center and the airport. The leading positions of Yekaterinburg in terms of the number of interchange combinations per week within the transport and interchange hubs of the external zones are due to the presence of the Uralskaya metro station near the main railway station, located on the border of the fourth sector of the external zone and the center and characterized by heavy electric train traffic. In Kazan, a very intensive interaction between the railway and the metro is provided by transport interchange hubs located in the fourth sector (railway station Vosstanie-Passazhirskaya - metro station "Severny Vokzal") and on the border of the first sector and a large center (halting point Ametyevo - Ametyevo metro station).

The effect of combining the two off-street transport systems, obvious for Yekaterinburg and Kazan, is not yet available in Perm.

In Yekaterinburg, the intensity of connections in the “external zone - suburb” direction (Table 2) was lower than in the “external zone - center” direction.

The revealed asymmetry is manifested in three sectors, but it is most pronounced in the third: urban electric trains end their routes here. The railway in this direction, which concentrates significant flows of passengers, is much inferior to road transport. In the fourth sector, the decrease in runs is also associated with the completion of urban electric train routes, but here their share in the total volume of traffic due to intensive commuter traffic is much smaller. In Kazan, there were more runs to the nearest suburbs from the second and fourth sectors than to the center, since here electric trains are added to the routes in the center-suburb direction, following through the Vosstanie-Passenger station. In Perm, there were fewer runs in the "external zone - suburb" direction than in the "external zone - center" direction only in the first sector (here the routes of urban electric trains are not completed).
Table 2. The level of development of suburban and intracity transport links of the external zones of Yekaterinburg, Kazan and Perm, provided by rail, as of January 2019.

| City          | Sector number | Indicators characterizing the "city-suburb" links, units. | | | | | |
|---------------|---------------|------------------------------------------------------|---|---|---|---|---|---|
|               |               | $R^i \left( R_i^j \right)$ | $m(n)_i^j$ | $d(n)_i^j$ | $w(n)_i^j$ | $R^i \left( R_i^j \right)$ | | |
| Yekaterinburg | 1             | 0.7 | 0.4 | 0.0 | 0.0 | 0.4 | 1.0 | | |
|               | 2             | 6.1 | 1.8 | 0.5 | 0.3 | 2.6 | 8.7 | | |
|               | 3             | 2.3 | 0.2 | 0.5 | 0.0 | 0.7 | 3.0 | | |
|               | 4             | 12.2 | 2.6 | 0.0 | 6.8 | 9.4 | 21.6 | | |
|               | Total         | **21.3** | 5.0 | 1.0 | 7.1 | **13.1** | **34.4** | | |
| Kazan         | 1             | 5.6 | 1.6 | 1.8 | 3.1 | 6.5 | 12.2 | | |
|               | 2             | 9.1 | 0.8 | 1.3 | 0.0 | 2.1 | 11.2 | | |
|               | 3             | 4.4 | 1.7 | 3.2 | 0.1 | 5.0 | 9.4 | | |
|               | 4             | 2.9 | 0.0 | 0.0 | 1.4 | 1.4 | 4.3 | | |
|               | Total         | **22.1** | 4.1 | 6.3 | 4.6 | **15.0** | **37.1** | | |
| Perm          | 1             | 2.1 | 1.2 | 2.3 | 0.0 | 3.5 | 5.6 | | |
|               | 2             | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
|               | 3             | 0.6 | 0.7 | 0.0 | 0.0 | 0.7 | 1.3 | | |
|               | 4             | 1.9 | 1.1 | 2.3 | 0.3 | 3.7 | 5.6 | | |
|               | Total         | **4.6** | 3.0 | 4.7 | 0.3 | **7.9** | **12.5** | | |

The intensity of connections between sectors of external zones and suburbs, which are not adjacent to them, sharply decreases in Yekaterinburg in comparison with intracity connections of sectors. This does not happen in Kazan, since here the electric trains crossing several sectors at once must go to the suburbs. A similar situation was typical for Perm, but only in conditions of full-fledged functioning of the Gornozavodsky direction.

The presence of a metro in Yekaterinburg and a transport interchange hub at the main station capable of redistributing large-scale flows allows the city to maintain a leading position in terms of the number of interchange combinations per week, which are within the 20-minute standard and allow the formation of new directions of passenger movement, including the suburban area. In Kazan, with a more even and logical distribution of transport interchange hubs in the external zones, the value of the indicator under consideration turned out to be lower due to the smaller number of electric train trips passing through these nodes.

4. Conclusion

On the whole, according to the final indicator characterizing the links between the external zones of cities in the “city-suburb” system, the described cities turned out to be closer to each other. The deterioration of the relative position of Yekaterinburg indicates that the railway transport in this city, despite a good level of development and integration with the metro, is weakly involved in increasing the freedom of choice of residents of the suburbs in places of employment and recreation by increasing the accessibility of external urban zones.

The integral indicator of the level of development of suburban and intracity transport links of external zones demonstrates a strong Perm lag behind Yekaterinburg and Kazan, in which, as mentioned above, these links are highly differentiated between sectors. This gap, even without taking into account the integration of electric trains with the metro, when taking into account the interaction of the two off-street transport systems, is even more widespread.
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