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Typification of Projects for Development of High-Speed Rail

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ABSTRACT

The emerging demand for improving consumer parameters of rail passenger transport leads to the need to build a dedicated railway infrastructure for passenger trains with speeds exceeding in some sections 250 km/h. The high capital intensity of dedicated infrastructure development projects imposes significant restrictions on their scope and financial feasibility. The geographically determined location of urban agglomerations in European and Asian countries has led to formation of many approaches to the routing of lines for high-speed passenger transportation.

The projects for development of dedicated high-speed railways being developed in various countries differ in their technical, technological, and operational characteristics. The use of different approaches has led to different efficiency of the passenger traffic, expressed in the demand of passengers for transportation.

A structural analysis of existing high-speed transportation projects allowed revealing general patterns of their development. By the number of operational tasks arising with regard to movement of trains, the phases of traffic development were divided into linear, tree-like and network stages. Thus, when moving from the linear structure of a high-speed rail, an additional problem arises of trains passing from the main track to the secondary one. The transition to the network stage can result in emergence of parallel passages rail tracks between urban agglomerations.

To generalise the experience of operating high-speed systems in the world, the article describes the developed method that allows comparing different projects for organising high-speed rail with each other. The comparison is made according to the main characteristics of traffic: travel time between separation points, the traffic speed, the total length of the railway line. Identification of the patterns inherent in various projects for development of high-speed rail will make it possible to compare their technological parameters, to identify the scope of rational use of high-speed lines and areas of competition with other core types of transport.

Keywords: *railways, passenger transportation, high-speed traffic, higher-speed traffic, dedicated passenger railway.*

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INTRODUCTION

Railway lines intended for high-speed transportation of passengers differ in their operational characteristics from other types of railway transportation [1; 2]. The implementation of high-speed traffic requires the construction of a new infrastructure, which is characterised by increased requirements for the profile and structure of the track superstructure, which enables passenger trains to develop a route speed between the main destinations above 180 km/h, which corresponds to the concept of modern passenger high-speed, interregional transport system. The existing infrastructure does not allow the movement of passenger trains in speed or high-speed mode due to the presence of infrastructural constraints, such as small radius curves. World practices testify to the following fundamental ways of organising high-speed transportation and its interaction with the existing railway transportation network:

- Separation of the infrastructure under construction and the formed routes of higher- or high-speed transportation from the rest of the railway network due to the need for physical isolation of rail tracks that have different permissible axle loads and different gauges, as well as of lines with different infrastructure affiliation [3]. Examples of the process of separating the network of high-speed lines from other railway sections can be observed in Japan and Saudi Arabia [4].
- Creation of a dedicated infrastructure for higher-speed passenger transportation with exits to the existing non-higher-speed railway infrastructure, with consistent modernisation of those lines but a significant reduction in speed of high-speed rolling stock when following them [4; 5].
- Inclusion of newly created railway sections for higher- and high-speed passenger transportation into a single route network with existing lines, while providing the possibility of high-speed rolling stock to use sections not intended for higher-speed traffic. The most prominent examples of implementation of such solutions can be found in Germany and France.

In all the cases, development of concepts and plans for creation of a HSR route network is based on topology and expertise drawn from operation of the existing network of mainline railways. Consequently, there is a difference in scale and volume of investment in creation and upgrading HSR infrastructure [7].

The development of the railway infrastructure of the main cargo and passenger railway lines in Russia resulted in a question of creation of dedicated tracks, with allocation of specialised infrastructure for high-speed passenger trains[1] [8]. The formation of a route network for circulation of passenger trains in long-distance traffic requires continuous improvement of methodological approaches and technical means of ensuring traffic with the ultimate goal to develop the backbone of high-speed railways to satisfy the demand for interregional passenger transportation, while ensuring a quality level that allows effectively competing with other types of mainline transport [9; 10].

The analysis of projects for development of dedicated passenger infrastructure in the world, as it was highlighted in our previous works, makes it possible to identify a certain regularity in the stage-by-stage development of high-speed railways from single reconstructed sections to an extensive network covering all major agglomerations that generate passenger flow [3].

The *objective* of the article, that reflects the advancement of the study on the typification of HSR, is to update the types of stages previously revealed but regarding implementation of development projects and to further develop the method to compare them while specifying main features.

RESULTS

Let us consider the stages of evolutionary development of HSR in more detail.

The first stage in development of HSR is *the stage of development of the linear infrastructure* [3]. At this stage, a direction or section with the greatest prospective demand for speed and high-speed traffic is identified, a dedicated main section of HSR is built or existing infrastructure undergoes a significant modernisation. This section, as a rule, solves the task of connecting the capital city of the country with one of the major agglomerations.

Let us demonstrate a developed schematic representation of HSR line topology (Pic. 1), which indicates the main section connecting the starting point *a* and the end point *A* passing

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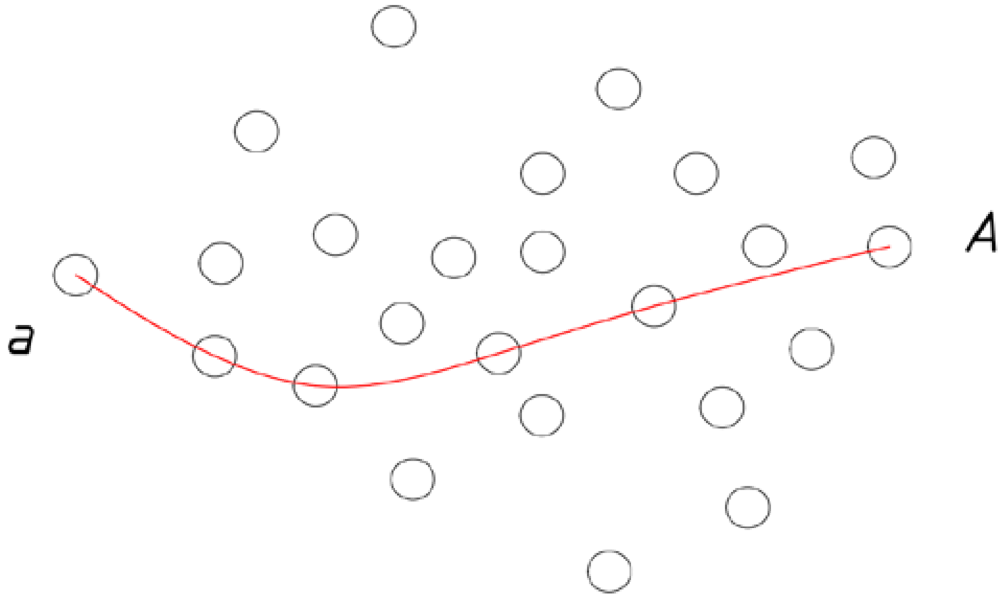

Pic. 1. Linear structure of HSR development [[3], performed by the authors].

through a certain number of intermediate populated areas that form an ordered set. This requires modernisation of the track development of all the passenger stations, of terminal and intermediate ones as well, for circulation of high-speed passenger trains, depending on the intensity of passenger work and technological features of rolling stock maintenance [3]. Relevant target schemes were developed by the domestic scientific school[2,3] [11].

Such a linear structure is most characteristic of the beginnings of development of HSR networks in the pioneer countries of high-speed traffic which are France and Japan, and of new lines of passenger infrastructure in Morocco and Turkey (Pic. 2). After formation of a stable demand for transportation on the constructed linear high-speed infrastructure, there is a further development of high-speed infrastructure.

The second stage of HSR development is *the stage of tree infrastructure topology* [3]. As it follows from the name itself, at this stage initial line is extended, a construction of HSR from the capital city to other megapolises beyond the boundaries of the initial route starts followed by the construction of feeder lines, providing transportation of passengers from other sites towards HSR [3].

The difference between the feeder sections and the main ones is their lower provision in equipment, lower requirements for the track profile. They are designed to carry a much smaller number of passengers compared to the volume of traffic on the main lines. Less demand for transportation is accompanied by smaller traffic on the section, and, as a result, increased time intervals between trains. When developing projects for feeder sections, the problem arises of minimising investments in development or reconstruction of the railway infrastructure. Therefore, existing reconstructed railway lines, updated to enable passage of trains with speeds above 140 km/h, can serve as feeder sections. A separate issue for consideration is the prospect of using single-track sections on such segments with low-intensity traffic, by analogy with the technical solutions used on high-speed lines in Spain [12–14].

A schematic representation of the tree topology of HSR is shown in Pic. 3, it consists of a main section similar to a linear scheme, as well as four feeder sections that connect individual stations of the set *a* and of

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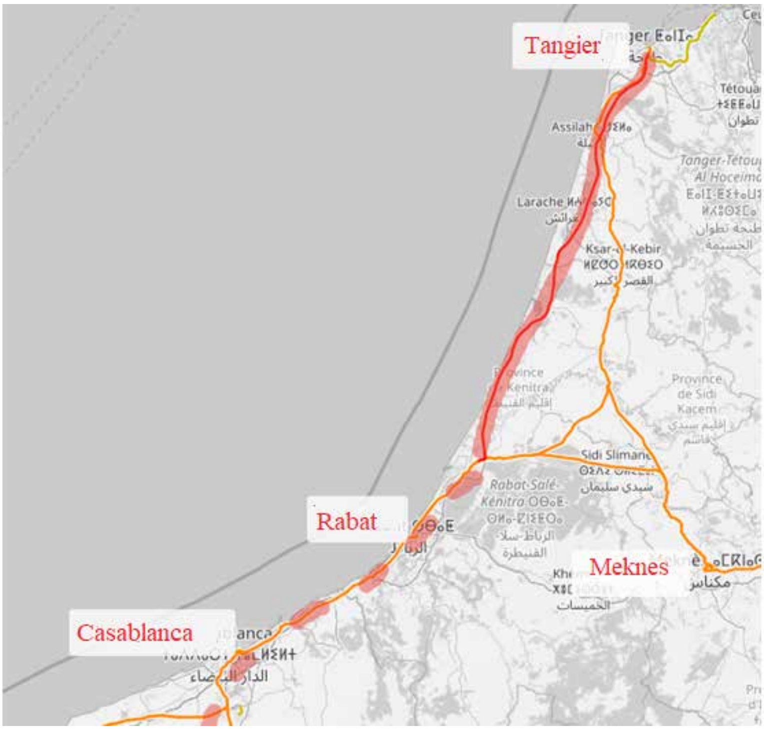
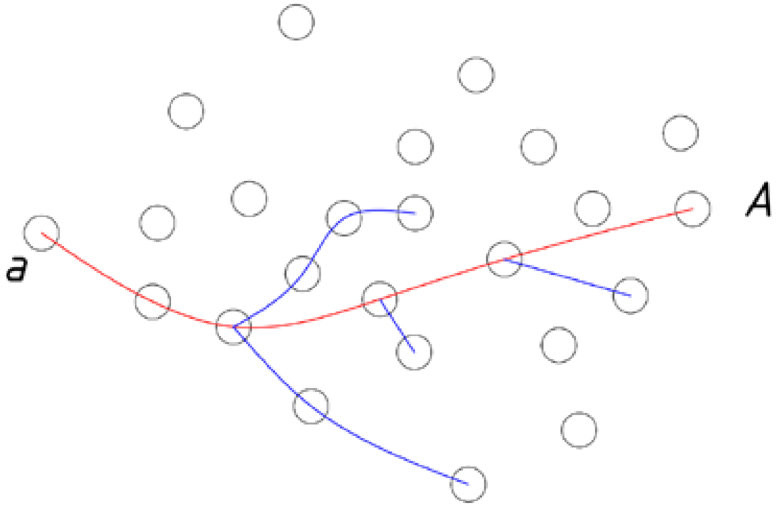


Pic. 2. Topology of Morocco's first high-speed railway, showing existing non-high-speed railway lines [[3], performed by the authors using an open-source topographical survey at the openrailwaymap].

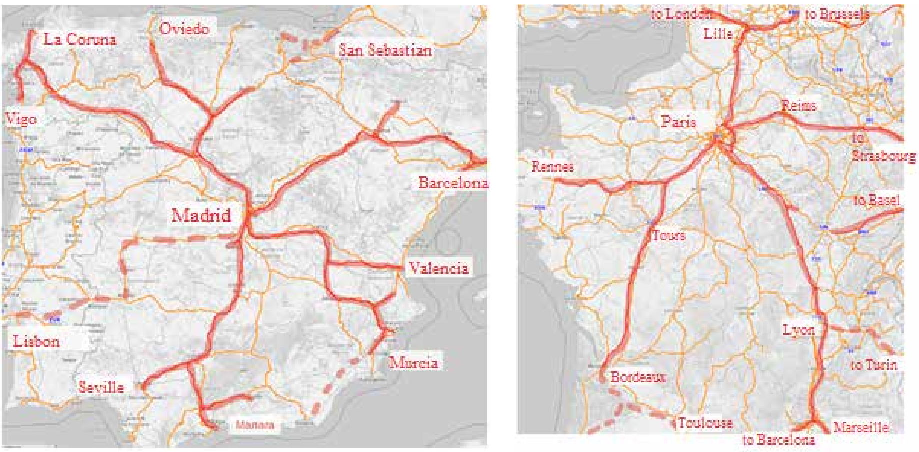


Pic. 3. Tree structure of HSR development [performed by the authors].

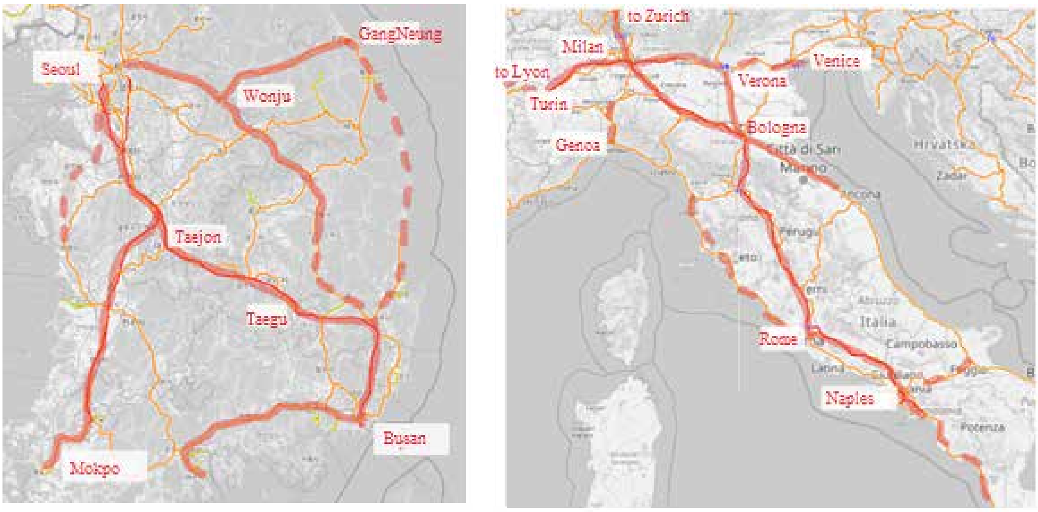
agglomerations that are not included in the service area of the main section. The route network is represented both by a route connecting the start and end points, and by routes following to branch lines (to feeder lines).

An extensive HSR network can be observed on the railways of countries that have been improving and developing their high-speed passenger transportation network for decades, Japan, France, Spain, Italy, Turkey and South Korea can be good examples of such countries (Pics. 4–5).

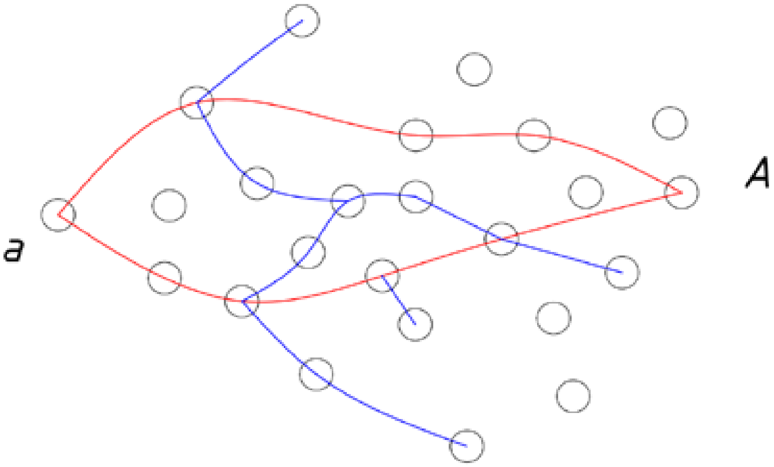
After formation of a stable demand for transportation through the constructed tree-like high-speed infrastructure, there is a further development of high-speed infrastructure.



Pic. 4. The topology of the HSR network of Spain (left) and France (right) with the designation of existing non-high-speed railway lines [performed by the authors using an open-source topographical survey at the openrailwaymap].



Pic. 5. High-speed railway network topology of South Korea (left) and Italy (right) showing existing non-high-speed rail lines [performed by the authors using an open-source topographical survey at the openrailwaymap].



Pic. 6. Network development structure of HSR [performed by the authors].

The third stage in development of HSR is *the stage of the infrastructure network topology* [3]. It supposes construction of high-speed railway lines, which can form parallel tracks where trains can run parallel to each other, i. e., ensure the connection of two points with each other by more than one option for a passenger train traffic. Construction is performed in new areas not covered by high-speed rail during the tree-like development of the network; new routes, feeder sections, and new main tracks are being added, creating the task of controlling traffic on parallel tracks.

The network topology of HSR is shown in Pic. 6, the diagram shows two main tracks connecting the starting point *a* and the end point *A*, which form a parallel connection of two points, as well as feeder lines that make up an extensive HSR network. Departure and destination in such a route network can be scheduled from any node or backbone passenger station that provides a stable passenger flow from the largest agglomerations within the considered transport corridor [15; 16].

Such type of development of dedicated passenger infrastructure can be found in Germany and China (Pics. 7–8).

To compare HSR networks in different regions of the world, it is important to assess technological mapping of the lines.

To evaluate the mapping parameters of HSR and identify the features of the project on the considered set of agglomerations through which the HSR line passes (hereinafter, the set $a=[1,2,\ldots,A]$), let us mark the points of departure and destination with coordinates x_a and y_a, while the reference point on the ground can be taken arbitrarily. The HSR line, passing through the cities [17] of the considered set *a*, forms an ordered subset $s=[1,2,\ldots,S]$, i. e., $a \supseteq s$. The number of settlements and passenger stations through which the HSR line passes affects the number of generated origin-destination routes [18; 19].

In turn, the increase in the number of origin-destination routes Tr_{ij} occurs non-linearly, the dependence of the total number of origin-destination routes on the number of separation points involved in the circulation of high-speed trains is shown in Pic. 9, and is determined by the formula:

$$Tr_{sum} = 0{,}5 \cdot S^2 - 0{,}5 \cdot S\ . \qquad (1)$$

Since networks of different countries differ in their length and structure, different technological mapping, it is necessary to normalise the parameters of the networks under consideration.

A proposed algorithm, based on structural alignment method for technological mapping of dedicated passenger infrastructure, has been described by us previously [3]. Its main steps are as follow.

At the initial stage, for the considered network, *the directive origin-destination link* of the route is identified, which is a straight line connecting the main point of origin (denoted by *I*) and the main destination (denoted by *J*). This straight line can be described by the canonical equation of the line:

$$\frac{x_a - x_1}{x_A - x_1} = \frac{y_a - y_1}{y_A - y_1}, \qquad (2)$$

where x_1 and y_1 –coordinates of the point of departure *I* relative to an arbitrarily accepted reference point;

x_A and y_A are respectively the coordinates of the main destination *J*.

«After that, it is necessary to eliminate the free coefficient of the linear equation, for this it is necessary to shift the origin of the coordinate axis to the starting point of directive correspondence» [3]:

$$\left[\begin{array}{l} x'_a = x_a - x_1 \\ y'_a = y_a - y_{1.} \end{array}\right. \qquad (3)$$

After adjusting the position of all considered points characterising the position of individual points on the plane, the function describing the defining correspondence (2) will take the form:

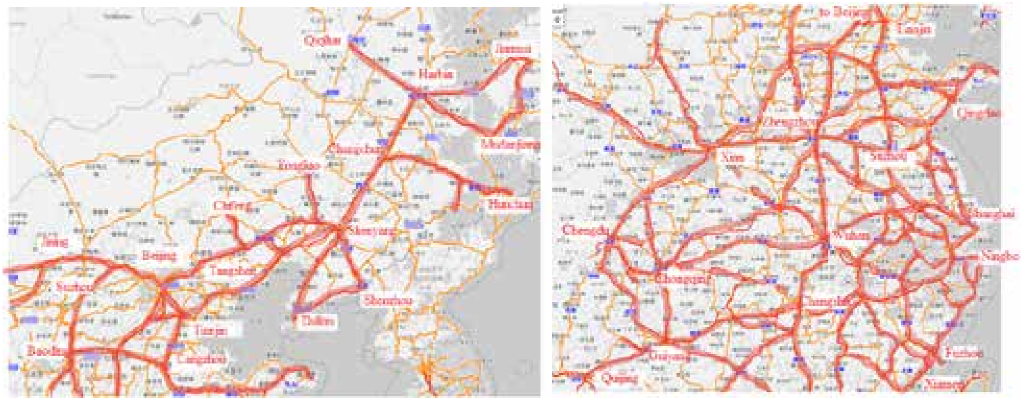
$$y = \frac{y_A}{x_A} x\ , \qquad (4)$$

where component $\frac{y_A}{x_A}$ characterises the tangent of the angle of deviation of the directive origin-destination function from the abscissa axis, then, to determine the angle of inclination in radians:

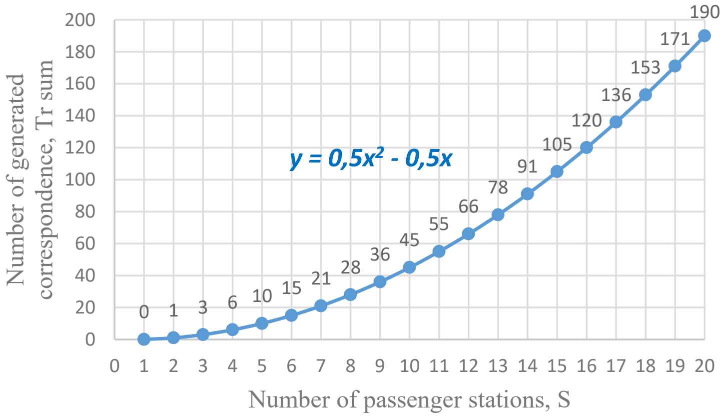
$$\alpha = arctg \frac{y_A}{x_{A}.}\ . \qquad (5)$$

«To obtain the final coordinates of the points of the considered array of potential-forming points, it is necessary to eliminate the angular component of the directive origin-destination link. For this, if the end point of the directive origin-destination link is in the 1st $(x'_A > 0; y'_A > 0)$, or 4th $(x'_A > 0; y'_A < 0)$ quarter of the coordinate

Pic. 7. The topology of the German HSR network [performed by the authors using an open-source topographical survey at the openrailwaymap].



Pic. 8. Topology of the HSR network of northern China (left) and central China (right) [performed by the authors using an open-source topographical survey at the openrailwaymap].



Pic. 9. Number of generated passenger origin-destination routes, depending on the total number of passenger stations on the HSR line [[9], performed by the authors].

Pic. 10. Alignment of coordinates of a single HSR network [performed by the authors].

plane, the final coordinates of the points will be determined as:

$$\left[\begin{array}{l} x''_a = x'_a * (\cos(-\alpha)) - y'_a(\sin(-\alpha)) \\ y''_a = x'_a(\sin(-\alpha)) + y'_a(\cos(-\alpha)). \end{array}\right. \qquad (6)$$

If the end point of the directive correspondence is in 2nd $(x'_A \langle 0; y'_A \rangle 0)$ or 3rd $(x'_A < 0; y'_A < 0)$ quarter of the coordinate plane, the final coordinates of the received points must be inverted» [3] (7).

$$\left[\begin{array}{l} x''_a = -(x'_a * (\cos(-\alpha)) - y'_a(sin(-\alpha))) \\ y''_a = -(x'_a(sin(-\alpha)) + y'_a(cos(-\alpha))). \end{array}\right. \qquad (7)$$

Structural alignment for a single HSR network is shown in Pic. 10. Scheme 10a shows the initial set of points that reflect the position of individual points on the map. In Pic.10b, the coordinates of these points are shifted relative to the reference point (3), and Pic. 10c shows the result of the structural alignment of the set of points.

When analysing several HSR systems (each system will be an element of the set $f = [1, 2, \ldots, F]$) the position coordinates of separation points on the HSR network of different *f* should be considered as $x_{f,a}$ and $y_{f,a}$. The application of the described algorithm for the elements F of the set *f* will allow using the methods of statistical analysis to identify patterns in development of HSR systems and the influence of mapping features on the overall competitiveness of a high-speed traffic. An example of using the developed

Pic. 11. Alignment of the coordinates of the set of HSR networks [performed by the authors].

method for $F = 3$ is shown in Pic. 11, which presents three abstract point sets of HSR networks, $f1, f2, f3$.

BRIEF CONCLUSIONS

Identification of the patterns inherent in various projects for development of high-speed railways will allow comparing the technological parameters of these lines, as well as to study the role of HSR in a country's transport system, the scope of rational use of HSR and areas of competition with other modes of mainline transport. The described research method allows identifying the general patterns of passage of sections of dedicated passenger infrastructure through the settlements of the set *a* generating passenger flow for main modes of transport. The obtained values clearly demonstrate the differences in projects for development of high-speed traffic of railway networks of the set *f*, aimed at ensuring the stable connection of each pair of points of departure *i* and destination *j*, all provided origin-destination links Tr_{ij}. Based on the results obtained, it is possible to build predictive models for determining the demand for high-speed transportation in Russia.

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