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Development of infrastructure for conventional and high-speed railways: comparative analysis[1]

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ABSTRACT High-speed rail service turns 60 in 2024, and 2025 is the bicentennial of rail transport. In this regard, the paper provides a comparative analysis of the development trends of conventional and high-speed rail infrastructure. The main objective of the work is to study the dynamics of the development of the two types of railway infrastructure, their impact on society and the global economy. The study is based on statistical analysis of data on the length of railways and discusses examples of various countries that played a key role in the development of both conventional and high-speed rail systems.

KEYWORDS: global railway network; railway infrastructure; high-speed rail infrastructure; HSR; socio-economic effects

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Научная статья

Развитие инфраструктуры традиционных и высокоскоростных железных дорог: сравнительный анализ[1]

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АННОТАЦИЯ Высокоскоростному железнодорожному сообщению в 2024 г. исполнилось 60 лет, а 2025 — год двухсотлетия железнодорожного транспорта. В связи с этим выполнен сравнительный анализ тенденций развития традиционной и высокоскоростной железнодорожной инфраструктуры. Основной целью работы является изучение динамики развития двух типов железнодорожной инфраструктуры, их влияния на общество и мировую экономику. Исследование основано на статистическом анализе данных о протяженности железных дорог. Рассмотрены примеры различных стран, которые сыграли ключевую роль в развитии как традиционных, так и высокоскоростных железнодорожных систем.

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КЛЮЧЕВЫЕ СЛОВА: мировая сеть железных дорог; инфраструктура железных дорог; высокоскоростная железнодорожная инфраструктура; ВСМ; социально-экономические эффекты

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INTRODUCTION

The year 2025 marks the bicentennial of rail transport. The year 2024 was the 60th anniversary of high-speed rail (HSR). In view of the proximity of the two important anniversaries, it would be relevant to carry out a comparative analysis of the development of both conventional and high-speed rail infrastructures in the world.

For the purposes of the analysis, it would be appropriate to consider 60-year long periods. Given that fully operational steam-powered railways emerged in 1830 and this happened in different countries and even parts of the world [1], it would be appropriate to consider a period between 1830 and 1890 as the relevant period of the development of conventional railways. This will ensure the comparability of the basic values of the global length of conventional railways (about 400 km in 1830) and high-speed rail lines (515 km in 1964).

COMPARING THE GROWTH IN LENGTHS OF CONVENTIONAL AND HIGH-SPEED RAIL NETWORKS

Both conventional and high-speed rail networks demonstrated impressive growth over the respective 60-year periods (*Fig. 1*, *2*). Changes in the length of the global network of conventional railways are best described by a power-law trend (the coefficient of determination R^2 is close to 1). Changes in the length of the global HSR network are more precisely described by an exponential trend (the coefficient of determination is also close to 1). This suggests that the development of the infrastructure for conventional and high-speed rail lines follow different patterns. The difference has an economic interpretation.

The conventional railway infrastructure, the construction of which was commercially efficient [2, 3], began to be built quite quickly in many countries, not only in highly developed ones [4]. Being much more advanced technologically and expensive than construction of conventional railways, HSR construction is usually not commercially efficient and generates effects of social and economic nature [5–11]. Hence, high-speed rail construction requires significant public funding, which is only possible in highly developed or rather large medium-developed economies.

In the 19th and early 20th centuries, the construction of conventional railways served as a tool to accelerate the development of countries, including as part of economic catch-up strategies, even from the very low start. In the 20th and early 21st centuries, the fact that a country builds high-speed rail indicates that it has achieved quite a high level of social and economic development, where, on the one hand, it can afford having high-speed rail service, and on the other hand, it has to do so for the sake of further development of its society and economy, as many other development tools have been already utilized and largely exhausted.

Japan is a vivid example of this. It started building railways as late as 1868 [4], when dozens of other

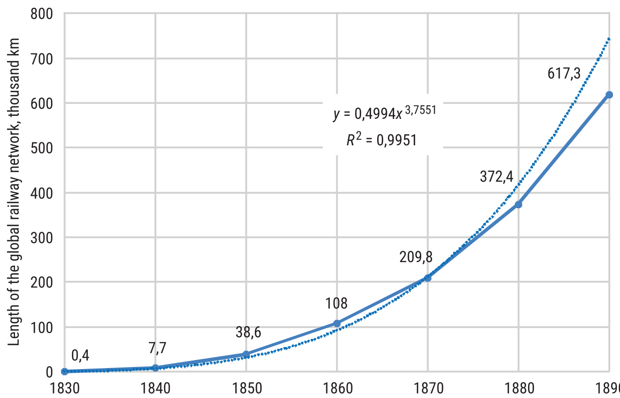

Fig. 1. Changes in the length of the global conventional railway network, 1830–1890

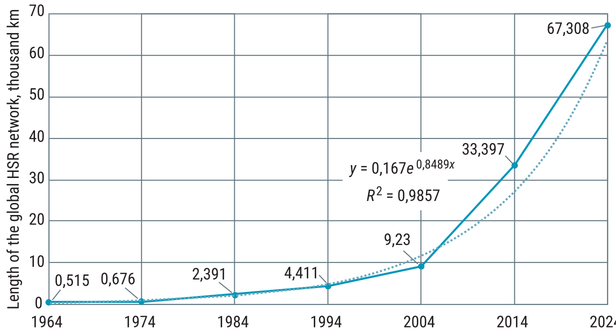

Fig. 2. Changes in the length of the global HSR network, 1964–2024 (data for 2024 are estimated values)

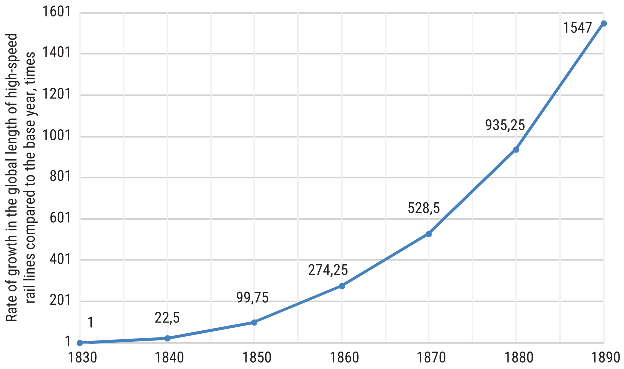

Fig. 3. Rates of growth in the length of the global conventional railway network, 1830–1890

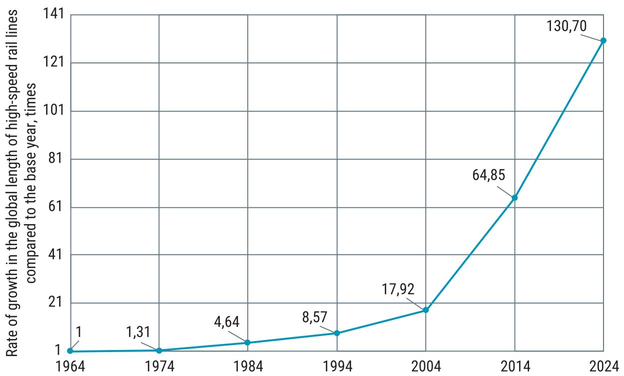

Fig. 4. Rates of growth in the length of the global high-speed rail network, 1964–2024

countries already had railways[2] and the total length of the global railway network was about 200 thousand km [13]. High rates of railway construction in Japan in the late 19th and early 20th centuries were one of the major tools of the catch-up development strategy implemented at the time. In 1870, Japan's GDP per capita was 84% of the world average, and by 1913 it was as high as 91%. Nevertheless, Japan still substantially lagged behind economic development leaders. The world's first high-speed railway line was launched in Japan less than one hundred years after the start of railway construction in the country, in 1964. It was no longer a catch-up development tool, but one of the outcomes of the country's successful post-war progress known as the "Japanese economic miracle" [15], which ultimately made Japan one of the global economic leaders.

When characterizing differences in the development of the global network of conventional and high-speed railways, it is very important to compare growth rates for each of the networks (*Fig. 3*, *4*).

While the absolute growth values for the global network of conventional railways increased from one decade to another (see *Fig. 1*), the growth rates of their network gradually decreased (see *Fig. 3*).

The dynamics of the HSR network growth rates changed nonuniformly (see *Fig. 4*). Worth mentioning are two periods when its growth accelerated: first, between 1974 and 1984, when the high-speed rail network began to develop in Europe, and second, between 2004 and 2014, when the acceleration was driven by high growth rates in HSR construction in China which currently has more than two thirds of the global high-speed rail network.

COMPARING THE CONCENTRATION OF CONVENTIONAL AND HIGH-SPEED RAIL NETWORKS

An analysis of the concentration of the global HSR network in comparison with the conventional railway network is worth a separate note.

By the end of the 60-year period in question (1890), the majority (90%) of conventional railways were concentrated in the United States and Europe. At the same time, a notable portion (10%) was accounted for by other parts of the world: Asia, Africa, and Australia (*Fig. 5*).

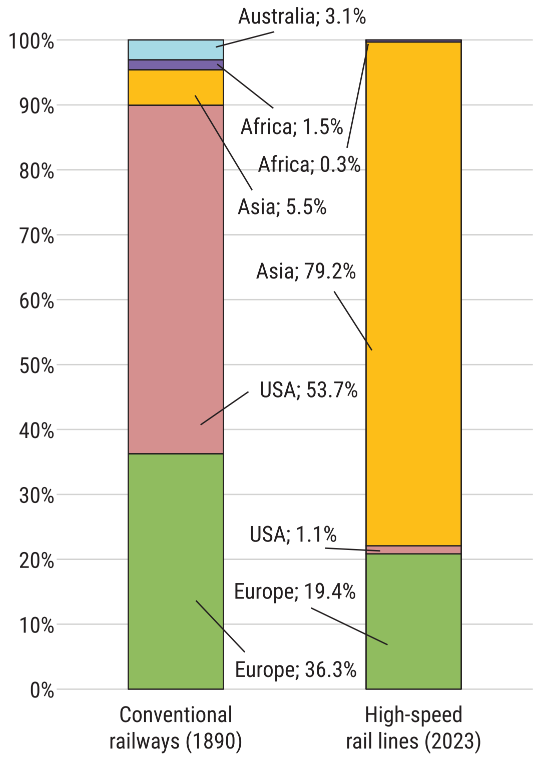

Fig. 5. Concentration of conventional railways (1890) and HSR (2023) by part of the world by the end of the respective 60-year period of development

[2] In particular, as early as 1867, the length of Russian railways exceeded 5,000 km and was growing rapidly [12].

The concentration of the HSR network (as of 2023) was even higher: it was nearly entirely (98.6%) concentrated in Eurasia, with Asia accounting for four times more than Europe.

Worth noting is that although they first appeared in Europe, by the end of the 19th century, conventional railways were the longest in the United States. On the other hand, high-speed railways first appeared in Asia and are also developing most dynamically in this part of the world. However, in both cases, the growth was related with passing the baton from the country that pioneered in the construction of railways (Great Britain for conventional railways and Japan for HSR) to the country with the longest network length (the United States and China, respectively). The diffusion of innovation in the railway sector (and in transport in general) significantly increases the efficiency of both industry and macroeconomic development [16, 17].

Representative is the data on the top ten countries in terms of the length of infrastructures for conventional railways (in 1890) and HSR (in 2023) (*Tables 1, 2*). For conventional railway infrastructure, the leading country accounted for 43.5%, the top five countries accounted for 66.9%, and the top ten countries accounted for 83.0% of the total global network length (see *Table 1*), while for high-speed rail, the figures are 70.2%, 88%, and 95.8%, respectively. In other words, the share of the HSR leader (China) exceeds that of the top five countries in terms of length of conventional railway infrastructure, and the share of the top five countries for HSR exceeds that of the top ten countries for conventional railway infrastructure.

Table 1

Top 10 countries in terms of length of conventional railways in 1890

List position	Country	Length*, thousand km	Percentage, %	Percentage (cumulative), %
1	United States	268.409	43.5	43.5
2	Germany	42.869	6.9	50.4
3	France	36.895	6.0	56.4
4	Russia and Finland	32.39	5.2	61.7
5	Great Britain and Ireland	32.297	5.2	66.9
6	Austria-Hungary	27.113	4.4	71.3
7	British East Indies	27	4.4	75.6
8	Canada	22.533	3.7	79.3
9	Italy	12.907	2.1	81.4
10	Spain	9.878	1.6	83.0
	World Total	617.285		

* Compiled by the authors on the basis of [13].

Table 2

Top 10 countries in terms of length of high-speed railways in 2023

List position	Country	Length*, thousand km	Percentage, %	Percentage (cumulative), %
1	China	45.390	70.2	70.2
2	Spain	3.993	6.2	76.3
3	Japan	3.147	4.9	81.2
4	France	2.760	4.3	85.5
5	Germany	1.631	2.5	88.0
6	Turkey	1.232	1.9	89.9
7	Finland	1.120	1.7	91.6
8	Italy	0.921	1.4	93.0
9	Sweden	0.895	1.4	94.4
10	South Korea	0.874	1.4	95.8
	World Total	64.7		

* Compiled by the authors on the basis of [18].

Thus, the above analysis shows that concentration is significantly higher for HSR than for conventional railways (after an equivalently long period of development), both by country and by part of the world.

MACROECONOMIC PERSPECTIVE

The development of conventional railway infrastructure promoted economic growth. Paper [4] found a positive correlation between the level of economic development of countries and the level of development of conventional railway infrastructure.

In the modern context, there is a positive correlation between the level of economic development and the level of development of high-speed rail infrastructure: there is a direct correlation between the countries' share of global Gross Domestic Product at Purchasing Power Parity (GDP PPP) and their share of the global HSR network (*Fig. 6*). The coefficient of determination $R^2 = 0.5886$ suggests a rather high quality of the regression line and shows, based on [19, 20], that 59% of the cumulative variation in the countries' share of global GDP is described by their share of the global HSR network. The corresponding linear correlation coefficient (0.7672) enables us to conclude, on the basis of the Chaddock scale, that there is not just a direct, but a *strong* direct correlation between a country's share of the global GDP and its share of the global HSR network.

A comparison of changes in economic growth and the length of HSR lines in countries with the largest high-speed rail networks (China, Spain, and Japan) shows that the fact that a country starts HSR construc-

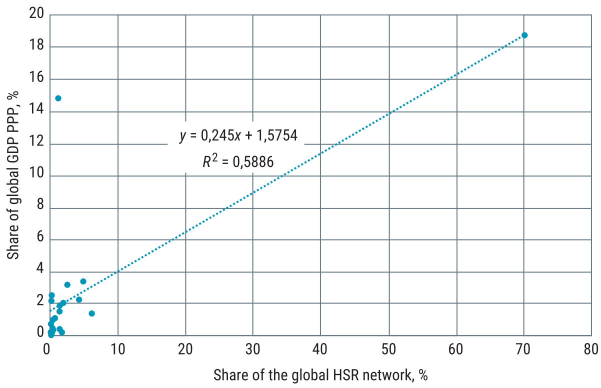

Fig. 6. Dependence of countries' share of the global GDP PPP on their share of the global HSR network

tion is indicative of its significant progress in economic growth and subsequent development of high-speed rail service adds impetus to the economic growth.

Thus, economic growth and development of high-speed rail infrastructure are mutually supportive processes with a positive inverse correlation between them.

In this context, the launch of the project for building Russia's first HSR line between Moscow and St. Petersburg is a landmark event [8, 21, 22]. First, it demonstrates that the Russian economy has reached an appropriate level of development and second, it paves the way for the acceleration of economic growth in Russia.

While the total length of the global HSR network is more than nine times shorter than that of the global conventional railway network built during the first 60 years of its development, given the significantly higher cost of HSR construction, the estimated investment in the high-speed rail infrastructure can be approximately as high as five times the investment in the conventional railway infrastructure over the equivalent period. This is a good illustration of the current "renaissance" of rail transport as one of the innovative leaders among sectors of the world economy [23].

At the same time, it is the high cost of building HSR lines that provides an economic basis for the concentration of the network of HSR lines identified in countries with rather large economies.

CONCLUSION

Our analysis enables us to draw meaningful conclusions on the development of high-speed rail infrastructure in comparison with conventional railways.

The nature of railway infrastructure development is determined by economic factors, such as its cost and specific features of the effects it generates [24]. With relatively low costs and significant commercial effects (conventional railways), the construction and expansion of railway infrastructure across countries and continents is much more dynamic than when costs are high and effects are mainly social and macroeconomic (HSR). This conclusion is important in view of the proposed construction of maglev and vacuum levitation lines in the future [5, 25].

Compared to conventional railways, HSR is not only a more expensive mode of transport, but it is also more specialized. While in the 19th century, railway construction had virtually no alternatives as a general-purpose tool to promote modernization of economies, in the 21st century, HSR should fit into a much more developed transport system featuring versatile capabilities and compete with other modern modes of transport, first of all, air transport. Therefore, for the HSR network to develop, it is quite essential to competently implement the social, economic and environmental benefits it offers and position them in society.

Finally, an important methodological conclusion as to the long-term analysis of transport infrastructure development is that a comparative analysis of the development of various types of transport infrastructure in different periods of history can be meaningful, provided the relevant time periods are comparable.

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