A. A. Akaev [a], O. I. Davydova [b], A. S. Malkov [b], S. G. Shulgin [c]

[a] Lomonosov Moscow State University (Moscow, Russian Federation; e-mail: askarakaev@mail.ru)

[b] iDecide Consulting Ltd. (Korolyov, Russian Federation)

[c] Institute of Applied Economic Research (Moscow, Russian Federation)

SIMULATION OF THE PROSPECTIVE TRADE AND TRANSPORT CORRIDORS WITHIN THE FRAMEWORK OF THE "ONE BELT, ONE ROAD" PROJECT [1]

The rapid growth of trade between Asia and Europe facilitated the revival of the Great Silk Road that used to be one of the main trade routes. The new Silk Road can pass through the territory of several states, contributing to their economic growth. The exact route of the new Silk Road is yet to be defined, as there are several alternative options. We developed a mathematical model based on the thermal conductivity equation, which is widely used in physics. Our model assesses how Trans-Eurasian transport flows will change in case of implementing a particular route variant of the Chinese project "One belt, One road" (taking into account the modernisation of the Russian railway network). Based on the spatial distribution of the goods' supply and demand, this spatial model simulates and predicts the flow of goods in a particular geographical area. The model uses correlations linking the characteristics of commodity flows and the spatial distribution of prices in the considered territory. We have presented results of calculations for several scenarios of modernisation, including the inertial scenario, which maintains the current scheme of transportation of goods. Moreover, we have examined a scenario, involving construction of the high- speed Northern corridor of the Trans-Asian railway, including the high-speed line Moscow—Kazan—Ekaterinburg—Kazakhstan—Urumqi, as well as a scenario in which the Silk Road passes through Kazakhstan. The simulations have shown that creation of a high-speed highway from Vladivostok to the country's Western border is the most favourable scenario for implementing Russia's transit opportunities and accelerating its economic growth. The simulations' results can be used for assessing the effectiveness of infrastructure projects aimed at modernisation of the Russian transport network.

Keywords: trade flows, transport corridors, spatial simulation, world trade, High-Speed Railways

Introduction

Currently, dramatic changes are taking place in the world. Centres of economic growth are moving from west to east. Accordingly, the geography of global trade flows is changing, too. A striking example of such changes is China's "One Belt, One Road" project, launched in 2013 by Xi Jinping, Chairman of the People's Republic of China. The project aims to create a modern transport infrastructure: a network of roads and railways, sea routes and pipelines connecting China and Europe. The constructed routes will enable intensification of trade flows between various parts of the world, and reduction of the costs of transporting goods. Raw materials will be delivered to China, and goods will be exported from China.

Recent decades have witnessed a rapid increase in trade between China and Europe (see Figure 1).

At the same time, trade between Europe and Asia is mainly served by sea transport. Only a small part of China's total volume of imports is delivered to Europe by land (Figure 2).

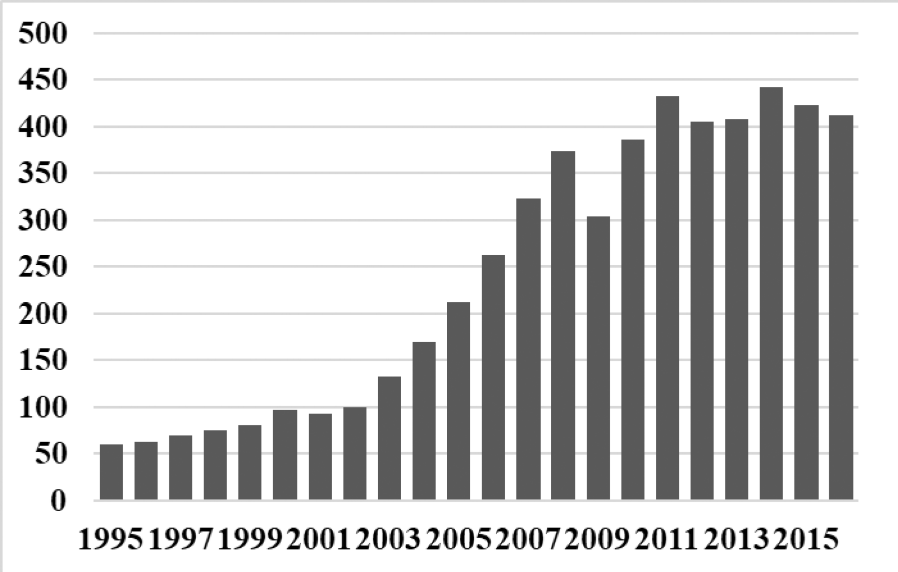
Despite this, railway transport claims a part of the flow of goods, having advantages in speed of delivery. Volumes of railway traffic increase rapidly. In 2016 alone, a twofold increase in railway container transportation in the direction of China-European Union-China (PRC-EU-PRC) was achieved[2], going from 47 thousand TEU in 2015 to 105 thousand TEU in 2016. This figure is almost 100 times higher than the one in 2011[3]. In 2017, the volume of container traffic in transit through the territory of the Eurasian Economic Union amounted to 262 thousand TEU[4] (Figure 3).

By 2020, transit can grow up to 450–500 thousand TEU, and the number of departures will increase three times and reach 100 trains per week. By 2025, the United Transport and Logistics Company (JSC

[2] TEU (twenty-foot equivalent unit) — a standard container for transporting goods.

[3] Simonova, T. (2017). Obem perevozok mezhdu KNR-ES-KNR po territorii Kazakhstana uvelichilsya v dva raza [The volume of traffic between the PRC — EU — PRC on the territory of Kazakhstan doubled]. Retrieved from: http://www.rzd-partner.ru/zhd-transport/news/obem-perevozok-mezhdu-knr-es-knr-po-territorii-kazakhstana-uvelichilsya-v-dva-raza/ (Date of access: 10/15/2018).

[4] Pletnev, S. (2018). Obem tranzitnyh konteynernykh perevozok cherez Rossiyu rastet do 500 tys. TEU [The volume of transit container traffic through Russia is growing to 500 thousand TEU]. Retrieved from: http://www.gudok.ru/freighttrans/?ID=1410287 (Date of access: 10.16.2018).



Source: UNCTAD (See on: The United Nations Conference on Trade and Development (UNCTAD). Retrieved from: http://unctadstat.unctad.org/EN/ (Date of access: 10/15/2018))

Fig. 1. *Exports from China to Europe, billion US dollars*

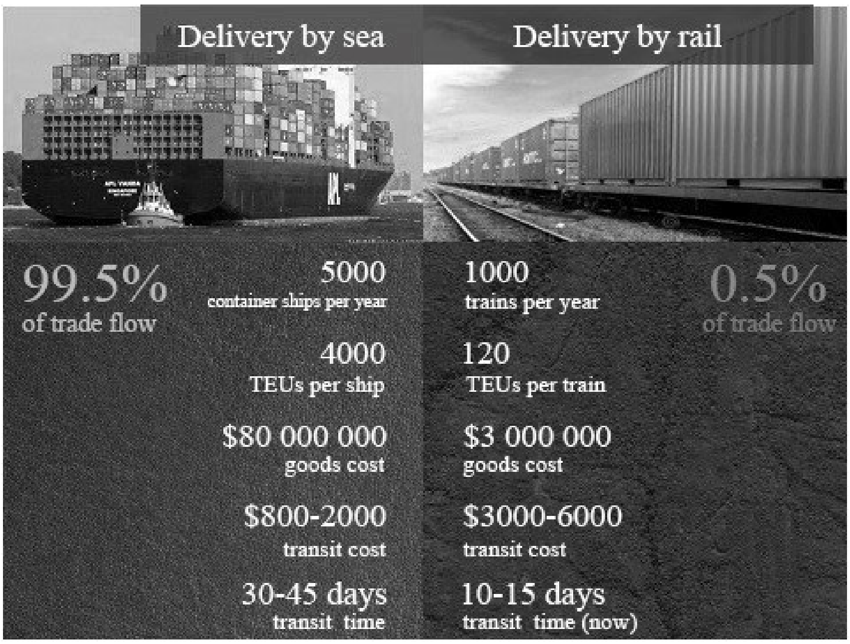


Fig. 2. *Estimates of the parameters of maritime and railway trans-Asian trade*

UTLC) intends to increase transit railway transportation of goods between China and Europe to 1 million TEU per year[5].

At the "One Belt, One Road" Summit in Beijing in May 2017, Xi Jinping announced that he was ready to invest 124 billion dollars in the creation of the New Silk Road[6]. Currently, there are two functioning institutions for financing projects: the Asian Infrastructure Investment Bank and the Silk Road Fund. Assets of the Asian Infrastructure Investment Bank amount to $ 100 billion; Silk Road Fund's assets are $ 40 billion[7].

[5] Million konteynerov na Shelkovom puti [Million containers on the Silk Road]. (2016). United Transport and Logistics Company — Eurasian Railway Alliance. Retrieved from: http://www.utlc.com/news/million-konteynerov-na-shelkovom-puti/ (Date of access: 10.17.2018).

[6] Goh, B & Chen, Y. (2017). China pledges $124 billion for new Silk Road as champion of globalization. Retrieved from: https://www.reuters.com/article/us-china-silkroad-africa/china-pledges-124-billion-for-new-silk-road-as-champion-of-globalization-idUSKBN18A02I?il=0 (Date of access: 17.10.2018).

[7] Khimshiashvili, P., Koshkin, P. & Podobedova. L. (2017). Putin v Pekine: kak Rossiya vstraivaetsya v kitayskiy Shelkovyy put [Putin in Beijing: how Russia fits into the Chinese Silk Road]. Retrieved from: https://www.rbc.ru/politics/14/05/2017/59159e0d9a7947318586f81f (Date of access: 10.17.2018).

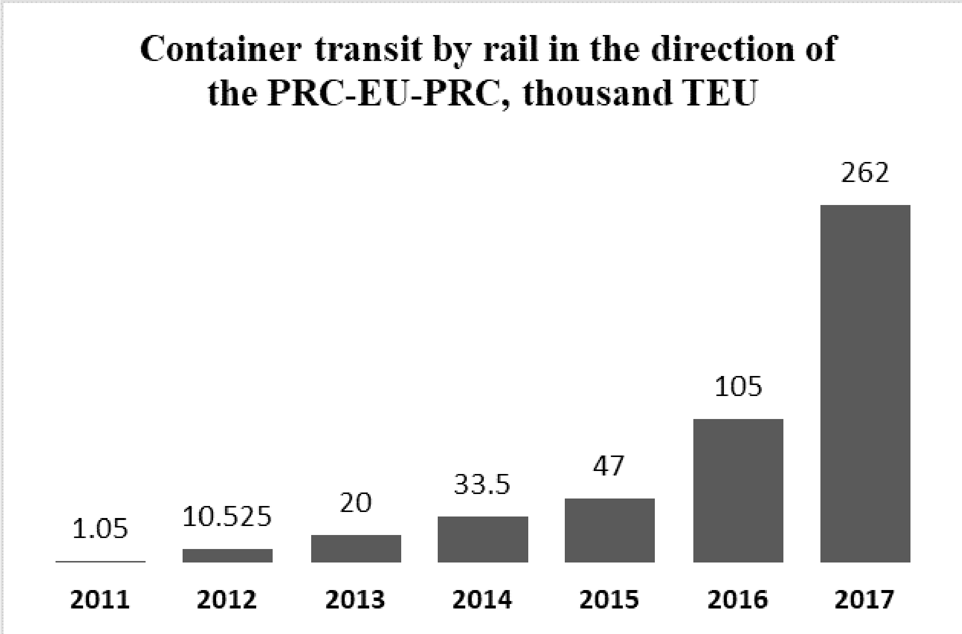


Fig. 3. *Container transit by railway in the direction of the PRC-EU-PRC*

It is extremely important for Russia to become the Trans-Eurasian transport corridor of the New Silk Road. This will require modernisation of the Baikal-Amur Mainline and Trans-Siberian highways. The stage of modernisation of the Baikal-Amur Mainline and the Trans-Siberian Railway, implemented from 2018 to 2025, is estimated to cost up at 500 billion roubles[8]. The Decree of the President of the Russian Federation of May 7, 2018 No. 204 "On National Goals and Strategic Objectives of the Russian Federation through to 2024" sets the aim to increase the throughput capacity of the Baikal-Amur and Trans-Siberian railways by one and a half times, up to 180 million tons; railway transit volume should be increased 4 times[9].

Development of high-speed railway lines plays the most important role. Beijing-Moscow-Europe High Speed Railway (HSR) can be built by 2035. The feasibility study of the project is being developed by Russian Railways together with China Railways. In Russia, the project of Moscow-Kazan high-speed railway is already being implemented; it is likely to become a part of the Moscow-Beijing high-speed railway, costing 7 trillion roubles, and the project "One belt, One Road"[10].

Russia and Japan are considering the possibility of building a bridge between Sakhalin and Hokkaido. This railway would allow Russia to significantly increase transit from Japan. According to calculations by the Ministry of Transport, the approximate cost of constructing a bridge across the Nevelskoy Strait separating Sakhalin from the mainland will be 400 billion[11]. The total cost of the project should be 8 trillion roubles; the Russian share will reach 3.6 trillion[12].

Although there are many plans for the development of the Eurasian transport infrastructure, its final appearance is not yet clear, as several options for transport corridors under the New Silk Road are being discussed. To assess the prospects for their development and to determine priorities in creating a trans-Eurasian transport infrastructure, it is necessary to carry out mathematical modelling in order to compare possible options for trade routes. This article describes the methodology of such modelling, sets out a mathematical model, and provides some results of the calculations.

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[8] RZHD otsenili vtoroy etap proekta BAM-Transsib pochti v 500 mlrd rubley [Russian Railways estimated the second stage of the BAM-Transsib project at almost 500 billion rubles]. (2017). Retrieved from: http://tass.ru/transport/4662797 (Date of access: 10/19/2018).

[9] The Decree of the President of the Russian Federation of May 7, 2018 No. 204 "On National Goals and Strategic Objectives of the Russian Federation through to 2024"

[10] Mintrans: proekt VSM Pekin — Moskva — Evropa budet realizovan k 2035 g. [Ministry of Transport: Beijing-Moscow-Europe high-speed railway project will be implemented by 2035[. (2017). Retrieved from: http://tass.ru/ekonomika/4431364 (Date of access date: 10/19/2018).

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Theory

Global trade flows are shaped as a result of economic interactions between different countries and regions of the world. The works [1–24] and others are devoted to the modelling of international trade. In our research, we used an advanced model [24] to analyse and model trade flows. [24] assesses the role and mutual influence of demographic, economic, technological and spatial-geographical factors on international trade in the pre-industrial era. New spatial and geographical characteristics were introduced: transport conductivity and product conductivity. A model is proposed for calculating transport conductivity for various geographical areas. This model can be used for both historical and modern data for calculating the time of transportation of goods along a specific route. In addition to the intensity of trade flows, the proposed methodology allows us to assess the spatial distribution of prices, production and consumption densities. Using the existing spatial distribution of production and consumption, the model presented in [24] enables analysis of flows of goods in a specific geographical area. Moreover, the location of flows of goods (products) in space is calculated, taking into account the differences of geographical areas. The problem can be formulated as follows: there exists geographic area U in which a piecewise smooth boundary is defined. For all points $(x, y) \in U$ are given: $p(x, y, t)$ — product cost; $\mathbf{w}(x, y, t)$ — product flow density; $q(x, y, t)$ — the density difference between the production and consumption of product; $T(x, y, t)$ — product density; $\{K_i(x, y)\}$ — territory parameters affecting the transportation of product. $\mathbf{w}_{\partial U}(x, y, t)$ represents product flow defined on the border of the region ∂U, where x and y are coordinates of the boundary: $(x, y) \in \partial U$. We need to calculate values $T(x, y, t)$, $w(x, y, t)$, and value of $p(x, y, t)$, given that $q(x, y, t)$, $\{K_i(x, y)\}$ and $\mathbf{w}_{\partial U}(x, y, t)$.

A similar problem was solved by M. Beckmann [22, 23]. He selected the cost of transportation and the speed of transportation of goods at a specific point ss the main parameters of the territory. M. Beckmann proposed an equation for determining optimal flows. The equation assumes that the flow of goods follows the direction of the price gradient. In this case, the gradient modulus is equal to the cost of transportation.

$$k\frac{w}{|w|} = \operatorname{grad} p \text{ anywhere, when } w \neq 0. \tag{1}$$

In [24], rigidity (coarseness) and non-stationarity were added to the M. Beckmann's model. Rigidity (coarseness) implies a slight change in flows with a small change in the cost of transportation. Non-stationarity implies evolution in time. The final equation:

$$\frac{\partial p}{\partial t} = \zeta(\operatorname{div}(k(x,y)\operatorname{grad} p) - q). \tag{2}$$

This equation implies that the flow of goods is proportional to the price gradient and follows in the direction of the price gradient. The paper [24] provides clear justifications for these assumptions. The resulting equation does not require information on the cost of transportation, and includes the coefficient of product conductivity $k(x, y)$, which we can assess.

In [24], formula (2) shows the model of historical the Great Silk Road (GSR), which for centuries connected medieval Europe and China. The coefficient of product conductivity was considered as a function of the taxes and duties forced on traders, the likelihood of robbery attacks on trade caravans, the costs of maintaining vehicles, their carrying capacity and power, landscape features, and energy consumption for movement. Modelling was carried out using finite-difference methods on a spatial grid constructed taking into account the shape of the Earth.

As a result of the simulation, we determined the most probable routes for transporting goods for different historical eras, provided that the source of the product was in China and the stock was in Europe. It appeared that geopolitical factors were important for the formation of routes and their stable functioning: in the era of the rise of large empires, the terms of trade (including transportation safety) improved. It led to an increase in the coefficient of product conductivity and an increase in product flows. A comparison of historical routes, and routes calculated according to the model showed their good correspondence.

For simulation of modern "the New Silk Road" we modified the model in a way described below.

Data and Methods

To implement the aforementioned approach to spatial modelling of trade flows, it is necessary to set the spatial distribution of sources and stocks of goods, that is, the spatial location of producers and consumers of products (exporters and importers), as well as predicted volumes of exports and imports. The forecast and visualization of world trade interactions between countries until 2025 were based on the macromodel described in [25]. The modelling was based on statistical data: current UN COMTRADE trade statistics, UN demographic forecast, WorldBank macroeconomic data. Moreover, we used J. Tinbergen's gravity model, Barro and Sala-i-Martin, Mankyu, Romer and Vale, Evans models of long-term economic growth. According to the inertial scenario (assuming that the world economic growth rates are maintained at the current level), by 2025 China will become the undisputed leader in world trade and the main trading partner of Germany, the economic leader of the European Union.

For the task in the model of the spatial distribution of production and consumption in 2025, we selected 30 of the largest world economies. We regarded China, South Korea and Japan as manufactures. The remaining countries were considered as importers of products manufactured in the aforementioned countries. To determine the volume of transportation based on the calculated inertial forecast for 2025, we assessed exports from China, South Korea and Japan to the largest economies in the world. Export is represented by 10 product categories: 1) textiles and furniture; 2) vegetables, food and wood; 3) precious stones and glass products; 4) minerals; 5) metals; 6) chemicals and plastic; 7) vehicles; 8) machinery; 9) electronics; 10) other. The results for product groups and countries (in constant 2015 US dollars) are presented in Table 1.

Such spatial distribution of production and consumption serves as an input data to model product flows.

Model

The modelling of promising trade and transport corridors was carried out based on the model of spatial trade flows described above and in [24]. The model was improved in order to ensure the possibility of taking into account the entire global (and not just the Eurasian) haulage network, including the Northern Sea Route and intercontinental trade. Figure 4 presents trade flows and transportation corridors analysed in the model.

Our model defines global transport network as the graph $G = (V, E)$, where V are the vertices of the graph, E are the edges of the graph. The vertices of column V are the main cities that are connected by the railways (Astana, Warsaw, Vladivostok, Hamburg, Hong Kong, Irkutsk, Kazan, Moscow, Paris, Beijing, Petersburg, Rotterdam, Istanbul, Tehran, Shanghai, etc.), and cities located along the sea routes (Kaohsiung, Jakarta, Djibouti, Cairo, Karachi, Manila, Marseille, Mumbai, Busan, Singapore, Qingdao, etc.). Edges (E) of the graph represent railway and sea routes between cities (vertices of the graph). For each vertex of graph V_i, exists net production qi, which is the difference between production and consumption in the i-th node of the graph (in this way the spatial distribution of demand and supply of goods is set). Also, for all the vertices, the price of the product pi is determined. For each edge E_{ij} connecting the vertices i and j, the coefficient k_{ij} is determined (where k_{ij} is the conductivity between the nodes i and j of the graph) and the category of the road is indicated (0—motor road, 1—railway, 2—high-speed railway, 3—sea route). For each category of road, the average speed of movement along it and its throughput are set. During the simulation, the spatial distribution of product flows j and price p was determined for a given spatial distribution of production and consumption of goods q.

Equation (2) is the model's most important equation. It is a kind of a thermal conductivity equation, in which the price p acts as temperature, the sources are consumers of goods, and the stocks are producers of goods. The coefficient of product conductivity k plays the role of the coefficient of thermal conductivity; it is calculated based on the length of the edge of the graph and the category of road. As a result, flows are defined in the system when the following condition is satisfied for each node i:

$$\sum_{j=i} k_{ij}(p_i - p_j) = q_i. \quad (3)$$

Therefore, prices p can be calculated by the formula $p = K^{-1}q$, where K^{-1} is inverse matrix in relation to matrix K of coefficients k_{ij}.

Table 1

Forecast of exports from China (CHN), South Korea (KOR) and Japan (JPN) to the largest countries in the world in 2025 by product groups, in US dollars 2015

Exporter	Importer	Textiles and furniture	Vegetables, food-stuffs and wood	Stone and glass	Minerals	Metals	Chemicals and plastics	Transport vehicles	Machinery	Electronics	Other	total, $
CHN	USA	1.27E+11	3.57E+10	1.43E+10	1.37E+09	3.53E+10	4.86E+10	1.92E+10	2.02E+11	1.78E+11	5.67E+09	6.67E+11
CHN	JPN	1.14E+11	5.65E+10	8.59E+09	7.02E+09	3.01E+10	4.46E+10	1.6E+10	1.24E+11	1.30E+11	1.13E+09	5.33E+11
CHN	DEU	7.66E+10	1.8E+10	6.32E+09	1.75E+09	1.78E+10	2.31E+10	1.11E+10	9.05E+10	6.3E+10	17692731	3.08E+11
CHN	GBR	1.76E+10	5.09E+09	1.74E+09	83915900	4.51E+09	5.35E+09	1.77E+09	1.79E+10	1.39E+10	2.89E+08	6.83E+10
CHN	FRA	1.75E+10	4.1E+09	1.3E+09	96523054	3.38E+09	4.72E+09	1.31E+09	1.96E+10	1.81E+10	33739471	7.02E+10
CHN	BRA	2.09E+10	6.6E+09	3.04E+09	9.49E+08	1.37E+10	2.29E+10	8.62E+09	3.56E+10	3.94E+10	6411561	1.52E+11
CHN	ITA	1.19E+10	3.3E+09	1.1E+09	1.1E+08	4.52E+09	4.43E+09	1.25E+09	1.18E+10	8.15E+09	74419746	4.66E+10
CHN	RUS	2.67E+10	1.1E+10	2.29E+09	4.28E+08	6.93E+09	7.42E+09	4.33E+09	1.78E+10	1.42E+10	305460	9.12E+10
CHN	IND	1.13E+10	3.32E+09	6.2E+09	2.49E+09	1.43E+10	3.4E+10	6.18E+09	3.12E+10	3.66E+10	3.05E+09	1.49E+11
CHN	CAN	1.71E+10	5.85E+09	2.22E+09	3.57E+08	7.86E+09	6.13E+09	3.19E+09	1.92E+10	1.59E+10	21275326	7.79E+10
CHN	AUS	6.83E+10	2.17E+10	8.11E+09	5.39E+09	2.87E+10	3.48E+10	1.4E+10	7.54E+10	5.49E+10	3288277	3.11E+11
CHN	KOR	1.04E+11	6.47E+10	2.62E+10	2.18E+10	1.32E+11	8.55E+10	1.97E+10	1.37E+11	3.29E+11	89780867	9.21E+11
CHN	ESP	5.41E+09	1.52E+09	4.11E+08	48583827	1.56E+09	1.97E+09	3.62E+08	4.19E+09	3.62E+09	14092207	1.91E+10
CHN	MEX	4.76E+09	1.41E+09	5.52E+08	1.52E+08	2.13E+09	3.14E+09	2.17E+09	1.11E+10	8.29E+09	542840.9	3.37E+10
CHN	TUR	3.84E+09	8.68E+08	7.13E+08	61008795	1.86E+09	2.6E+09	7.3E+08	6.11E+09	5.59E+09	19949324	2.24E+10
CHN	IDN	3.02E+10	1.25E+10	4.94E+09	9.55E+09	2.47E+10	2.4E+10	6.59E+09	3.8E+10	2.91E+10	4400797	1.79E+11
CHN	NLD	3.94E+09	1.44E+09	3.22E+08	1.11E+08	1.26E+09	2.14E+09	5.1E+08	1.25E+10	8.22E+09	1.82E+08	3.07E+10
CHN	SAU	6.28E+10	1.53E+10	1.38E+10	8.55E+08	3.41E+10	2.29E+10	1.34E+10	4.08E+10	2.73E+10	7963277	2.31E+11
CHN	CHE	3.83E+10	1.2E+10	6.06E+09	1.15E+09	9.73E+09	3.18E+10	3.33E+09	5.55E+10	4.83E+10	46404010	2.06E+11
CHN	SWE	7.27E+09	1.77E+09	5.35E+08	46082291	1.97E+09	1.48E+09	7.33E+08	4.7E+09	5.51E+09	8432502	2.4E+10
CHN	NGA	1.9E+09	5.1E+08	3.61E+08	52533139	9.93E+08	9.95E+08	6.96E+08	9.87E+08	1.27E+09	2634223	7.77E+09
CHN	POL	1.92E+09	4.28E+08	2.18E+08	32434118	6.82E+08	6.2E+08	3.17E+08	3E+09	2.01E+09	403408.2	9.23E+09
CHN	BEL	7.6E+09	2.26E+09	1.95E+09	1.1E+08	4.25E+09	4.7E+09	7.35E+08	5.5E+09	4.34E+09	2.64E+08	3.17E+10
CHN	ARG	2.48E+09	6.52E+08	3.15E+08	2.44E+08	1.2E+09	5.02E+09	3.12E+09	7.39E+09	8.23E+09	1755222	2.87E+10
CHN	NOR	2.71E+09	7.54E+08	2.7E+08	76948783	9.27E+08	5.92E+08	5.37E+08	1.44E+09	1.26E+09	1773978	8.58E+09
CHN	VEN	5.59E+08	1.39E+08	87091128	9244093	7.07E+08	4.41E+08	8.82E+08	1.86E+09	9.71E+08	0	5.66E+09
CHN	AUT	2.72E+09	8.37E+08	5.45E+08	1.46E+08	1.38E+09	1.14E+09	3.5E+08	3.16E+09	5.92E+09	15756365	1.62E+10
CHN	IRN	4.01E+09	1.68E+09	1.68E+09	4.95E+08	3.6E+09	2.81E+09	2.09E+09	4.82E+09	3.14E+09	458952	2.43E+10
CHN	THA	1.85E+10	1.68E+10	6.37E+09	2E+09	2.42E+10	2.44E+10	7E+09	3.93E+10	3.65E+10	5044498	1.75E+11

Translation

Exporter	Importer	Textiles and furniture	Vegetables, food-stuffs and wood	Stone and glass	Minerals	Metals	Chemicals and plastics	Transport vehicles	Machinery	Electronics	Other	total, $
CHN	ARE	1.67E+10	3.14E+09	2.36E+09	8.21E+08	5.42E+09	3.96E+09	1.71E+09	1.15E+10	1.07E+10	150553.9	5.63E+10
KOR	USA	2.3E+09	1.87E+09	1.05E+09	4E+09	9.17E+09	7.94E+09	2.74E+10	1.71E+10	1.94E+10	1.26E+09	9.15E+10
KOR	CHN	6.57E+09	4.31E+09	2.15E+10	2.18E+10	2.17E+10	7.22E+10	1.5E+10	8.96E+10	1.65E+11	2.88E+08	4.18E+11
KOR	JPN	3.12E+09	7.2E+09	4.61E+09	2.07E+10	1.5E+10	1.34E+10	3.19E+09	1.21E+10	1.84E+10	1.64E+09	9.93E+10
KOR	DEU	1.26E+09	2.69E+08	2.64E+08	34250753	1.66E+09	4.98E+09	9.5E+09	6.45E+09	7.46E+09	7051047	3.19E+10
KOR	GBR	3.96E+08	1.36E+08	6.01E+08	1.27E+09	4.29E+08	1E+09	3.73E+09	1.5E+09	1.81E+09	2.96E+08	1.12E+10
KOR	FRA	5.27E+08	1.35E+08	76870003	6.55E+08	3.54E+08	1E+09	1.99E+09	1.58E+09	2.87E+09	6430544	9.2E+09
KOR	BRA	1.89E+08	37349182	22137632	47598601	5.26E+08	8.42E+08	1.35E+09	1.19E+09	3.64E+09	428453.9	7.85E+09
KOR	ITA	5.41E+08	1.53E+08	84572856	49647708	1.27E+09	1.91E+09	1.4E+09	9.39E+08	8.38E+08	8979453	7.19E+09
KOR	RUS	3.94E+08	4.19E+08	71806689	1.8E+08	7.69E+08	1.52E+09	6.27E+09	2.29E+09	1.39E+09	670547.6	1.33E+10
KOR	IND	3.74E+08	6.11E+08	7.82E+08	1.96E+09	5.38E+09	6.73E+09	2.13E+09	3.99E+09	4.82E+09	5.03E+08	2.73E+10
KOR	CAN	1.89E+08	1.61E+08	1.88E+08	1.61E+08	7.6E+08	6.14E+08	3.11E+09	1.16E+09	9.8E+08	9727594	7.33E+09
KOR	AUS	4.13E+08	7.8E+08	1.21E+08	1.31E+10	2.69E+09	2.03E+09	6.82E+09	5.08E+09	1.87E+09	6025399	3.3E+10
KOR	ESP	1.87E+08	63119729	20808353	5167608	2.88E+08	5.95E+08	6.82E+08	3.16E+08	4.12E+08	5455861	2.57E+09
KOR	MEX	64742432	21143112	14383726	15125360	4.96E+08	3.01E+08	8.04E+08	1.17E+09	9.12E+08	14349629	3.81E+09
KOR	TUR	78514207	23410909	5025010	6604132	2.05E+08	5.08E+08	1.63E+08	3.32E+08	4.15E+08	2168434	1.74E+09
KOR	IDN	4.72E+09	1.23E+09	1.62E+08	1.3E+10	5.68E+09	5.37E+09	1.62E+09	3.63E+09	2.52E+09	2265431	3.8E+10
KOR	NLD	1.03E+08	60369737	16667050	1.79E+09	3.86E+08	7.64E+08	3.01E+08	1.67E+09	1.52E+09	12107162	6.63E+09
KOR	SAU	2.89E+09	9.07E+08	2.62E+08	3.65E+08	9.16E+09	7.76E+09	3.18E+10	1.64E+10	1.26E+10	2401679	8.22E+10
KOR	CHE	1.45E+08	82927813	2.95E+08	7584509	2.88E+08	1.12E+09	1.37E+09	1.03E+09	6.86E+08	2113217	5.04E+09
KOR	SWE	1.22E+08	40392362	21667410	1867811	2.32E+08	3.27E+08	6.71E+08	4.66E+08	9.31E+08	669068.5	2.81E+09
KOR	NGA	2.61E+08	1.18E+08	8794117	1.07E+08	1.27E+09	1.32E+09	2.03E+09	3.96E+08	3.31E+08	131842.5	5.84E+09
KOR	POL	71329468	11655321	4684230	266181.3	1.33E+08	1.61E+08	1.09E+08	5.35E+08	5.91E+08	180350.9	1.62E+09
KOR	BEL	78280253	11882129	13378759	1.76E+08	2.89E+08	5.54E+08	8.9E+08	4.96E+08	58315530	5990369	2.57E+09
KOR	ARG	1.15E+08	22570862	8341623	89491970	2.17E+08	5.47E+08	3.99E+08	5E+08	9.38E+08	32809.13	2.84E+09
KOR	NOR	37801664	29699487	7649445	7436080	52587385	79913192	3.73E+09	2.87E+08	3.23E+08	2102610	4.56E+09
KOR	VEN	4674846	1635129	576334	4704	39759233	35935495	52329922	50311231	50616305	14430	2.36E+08
KOR	AUT	35412410	28168872	14377207	378349.2	88297389	1.04E+08	2.92E+08	8.74E+08	8.05E+08	90988.03	2.24E+09
KOR	IRN	86016478	2.6E+08	7901437	9717957	5.81E+08	9.31E+08	3.03E+08	1.24E+09	7.5E+08	65677	4.17E+09
KOR	THA	3.11E+08	4.29E+08	3.35E+08	4.09E+08	3.63E+09	2.52E+09	4.11E+08	2.02E+09	1.91E+09	1073773	1.2E+10

Translation

Exporter	Importer	Textiles and furniture	Vegetables, food-stuffs and wood	Stone and glass	Minerals	Metals	Chemicals and plastics	Transport vehicles	Machinery	Electronics	Other	total, $
KOR	ARE	2.76E+09	1.97E+09	2.11E+08	7.03E+08	5.44E+09	4.16E+09	7.24E+09	8.59E+09	9E+09	5100521	4.01E+10
JPN	USA	9.63E+08	9.82E+08	1.22E+09	4.77E+08	4.6E+09	1.01E+10	3.85E+10	3.01E+10	1.31E+10	2.87E+09	1.03E+11
JPN	CHN	1.3E+10	1.02E+10	1.36E+10	7.36E+09	6.1E+10	1.05E+11	6.07E+10	1.75E+11	1.45E+11	3.34E+09	5.94E+11
JPN	DEU	2.76E+08	1.47E+08	4.67E+08	26428277	7.43E+08	2.64E+09	4E+09	9.29E+09	6.05E+09	2.01E+09	2.57E+10
JPN	GBR	1.13E+08	66773216	4.16E+08	2.24E+08	3.48E+08	8.68E+08	2.12E+09	2.36E+09	1.1E+09	1.2E+08	7.74E+09
JPN	FRA	2.5E+08	1.29E+08	1.27E+08	17290908	2.83E+08	2.17E+09	2.76E+09	4.39E+09	1.51E+09	14914941	1.17E+10
JPN	BRA	85897230	81795411	47414907	12046408	8.55E+08	1.62E+09	2.37E+09	3.87E+09	1.25E+09	30711415	1.02E+10
JPN	ITA	4.66E+08	91755871	2.45E+08	39227825	3.79E+08	1.78E+09	1.78E+09	2.83E+09	6.93E+08	17284991	8.32E+09
JPN	RUS	2.13E+08	4.62E+08	1.08E+08	1.1E+08	5.49E+08	1.49E+09	1.07E+10	3.33E+09	7.9E+08	1.4E+08	1.79E+10
JPN	IND	3.38E+08	1.04E+08	2.26E+08	4.61E+08	4.17E+09	3.26E+09	2.93E+09	6.37E+09	1.93E+09	5.91E+08	2.04E+10
JPN	CAN	1.01E+08	1.33E+08	63643390	44162709	6.98E+08	9.52E+08	4.97E+09	3.74E+09	1.35E+09	88341094	1.21E+10
JPN	AUS	1.75E+08	5.99E+08	9.11E+08	8.31E+09	4.03E+09	3.69E+09	2.43E+10	7.92E+09	1.96E+09	9.56E+08	5.28E+10
JPN	KOR	5.26E+08	9.74E+08	1.84E+09	3.47E+09	1.07E+10	1.54E+10	1.83E+09	1.46E+10	8.68E+09	1.21E+09	5.93E+10
JPN	ESP	34984840	23133064	20146625	34407251	1.03E+08	4.58E+08	1.59E+09	1.19E+09	4.91E+08	1823037	3.94E+09
JPN	MEX	30739240	9232658	21493877	22481902	7.53E+08	2.78E+08	1.28E+09	1.35E+09	7.36E+08	1.01E+08	4.58E+09
JPN	TUR	19146464	4739007	4304489	764803.8	91738659	1.51E+08	1.36E+08	4.88E+08	86131285	572952.6	9.83E+08
JPN	IDN	1.35E+09	6.32E+08	4.11E+08	4.04E+08	1.05E+10	7.78E+09	7.68E+09	1.8E+10	5.45E+09	1.99E+09	5.43E+10
JPN	NLD	26608649	68809062	27109987	6749065	1.51E+08	6.67E+08	3.51E+08	2.34E+09	9.44E+08	44326410	4.63E+09
JPN	SAU	1.16E+09	3.12E+08	4.7E+08	1.63E+08	1.06E+10	4.84E+09	3.47E+10	1.45E+10	3.76E+09	5.16E+08	7.1E+10
JPN	CHE	73162499	56700941	2.78E+09	4744839	1.77E+08	1.81E+09	1.47E+09	1.21E+09	4.44E+08	7.87E+08	8.81E+09
JPN	SWE	17457740	14572119	14792851	3509562	1.9E+08	1.88E+08	1.23E+09	6.03E+08	3.66E+08	1482526	2.63E+09
JPN	NGA	5.83E+08	27525427	21987093	39294.71	1.44E+09	3.84E+08	1.17E+09	1.97E+09	2.34E+08	19565222	5.85E+09
JPN	POL	25119677	7196304	10654885	2852564	61196607	1.67E+08	3.33E+08	5.93E+08	1.74E+08	20081893	1.4E+09
JPN	BEL	27184323	9458968	37934361	5426498	57862374	6.95E+08	7.46E+08	7.58E+08	2.86E+08	9347077	2.63E+09
JPN	ARG	7609918	5848025	6993858	2988088	1.09E+08	4.55E+08	7.24E+08	1.3E+09	2.53E+08	1755252	2.86E+09
JPN	NOR	6041387	7901849	7148012	495857.8	4.18E+08	1.08E+08	5.46E+08	4.27E+08	60995923	32968039	1.61E+09
JPN	VEN	356747	818426	821484	73816	11638549	40456539	1.92E+08	64417081	8918601	5614657	3.25E+08
JPN	AUT	23638245	10806131	33970548	11093847	86783253	2.8E+08	6.05E+08	5.41E+08	2E+08	40593227	1.83E+09
JPN	IRN	5821383	2158991	1396205	559252	2641055	29606728	1.07E+08	62932987	32825199	5951866	2.51E+08
JPN	THA	4.18E+08	6.7E+08	1.13E+09	1.63E+08	7.41E+09	3.98E+09	3.22E+09	9.15E+09	5.64E+09	1.15E+09	3.29E+10
JPN	ARE	1.43E+09	4.81E+08	4.57E+08	2.26E+08	6.15E+09	4.68E+09	3.18E+10	1.1E+10	3.85E+09	1.34E+09	6.14E+10

Source: author's assessments.

Translation

Fig. 4. *Model of trade flows and transport corridors (indicated by solid lines in the figure)*

Translation

To calculate the inverse matrix, we used the Python library NumPy. This library contains the linalg section, which is a set of standard matrix operations of linear algebra. The linalg.inv (K) method returns the inverse of the matrix K.

To calculate the coefficients of product conductivity k_{ij}, it is necessary to determine the throughput of the edges of the graph, the speed of movement along the edges of the graph and the length of the edges of the graph. For this purpose, we collected data on sea and railway routes: main cities included in the route, travel time on sections of the route, their capacity, and cost of transportation. Example of the obtained table is presented below in Table 2:

Table 2

Throughput and transportation costs by sea and rail routes

Route name	Countries	City A	City B	Distance (length)	Travel time	Throughput	Transportation cost ($/kg)
North – South	Northern Europe — Gulf countries through Russia and Iran, with the participation of Kazakhstan	Helsinki	St. Petersburg	389 km	1 day	788270 ton/ day	0.01
...	...	...	...	...	...	...	...

Source: author's assessments.

Each line of the table indicates the time of the goods' delivery from city A to city B. Using the Dijkstra algorithm, the graph finds the shortest path from vertex A to vertex B. The path is a sequence of edges of the graph that you need to go through to get from city A to city B. For each edge, the category of road (railway, high-speed railway, sea route) and its length l are known. Therefore, for the entire path from city A to city B, you can find the total distances travelled on the roads of category 1, category 2 and category 3. The speeds on the roads belonging to different categories are an unknown vector $V = (v_1, v_2, v_3)$. Freight delivery time, on the one hand, is found by dividing the distance by speed; on the other hand, it is known from the table described above. We created the following Table 3:

Table 3

Freight transit time by sea and rail routes

The total transit time on all edges category 1	The total transit time on all edges category 2	The total transit time on all edges category 2	Empirical time (statistics)
$\tau_{11} = l_{11} / v_1$	$\tau_{12} = l_{12} / v_2$	$\tau_{13} = l_{13} / v_3$	T_1
$\tau_{21} = l_{21} / v_1$	$\tau_{22} = l_{22} / v_2$	$\tau_{23} = l_{23} / v_3$	T_2
…	…	…	…
$\tau_{n1} = l_{n1} / v_1$	$\tau_{n2} = l_{n2} / v_2$	$\tau_{n3} = l_{33} / v_3$	T_n

Source: author's assessments.

Using linear regression (Figure 5), we assessed the velocity vector $V = (v_1, v_2, v_3)$:

— average speed by railway — 27,8 km/h;

— average speed by high-speed railway — 108,16 km/h;

— average speed by sea — 18,7 km/h.

To calculate the coefficients of product conductivity, it is also necessary to assess the throughput of the edges of the graph. For the sea route, estimates are made based on the carrying capacity of the Strait of Malacca as the bottleneck of the sea route (source: Malaysian Marine Department[13]). For railways, parameters are estimated using statistics from the Trans-Siberian Railway. Thus, based on the

[13] Numbers of ships reporting under straitrep for 2017. Retrieved from: https://drive.google.com/file/d/1_afnUbJW5O8B5pF3VvPV859i5kgfCyVA/view (Date of access: 23.10.2018); Marine Department Malaysia. Retrieved from: http://www.marine.gov.my/jlmeng/Contentdetail.asp?article_id=245&category_id=4&subcategory_id=42&subcategory2_id=0#.Wg8u8TclGUk (Date of access: 23.10.2018).

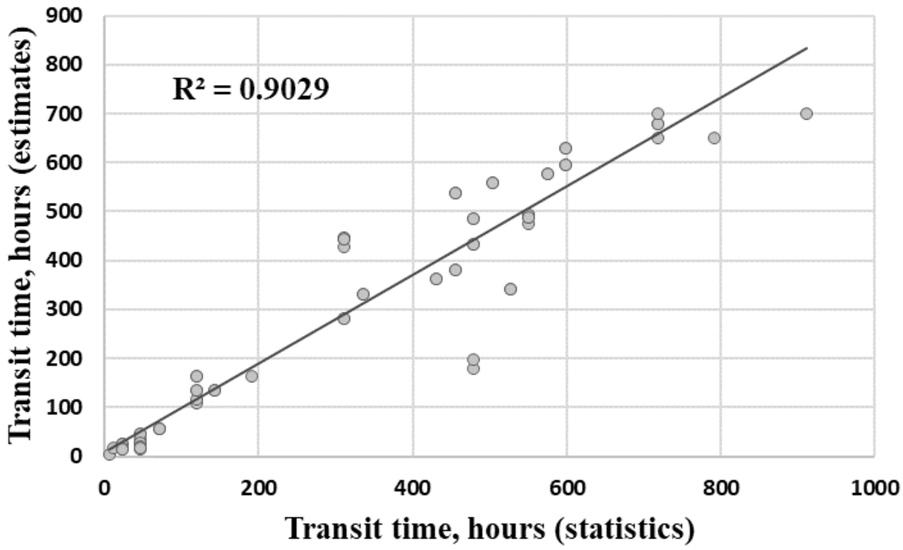

Fig. 5. *Relationship between estimated transit times and empirical data (statistics)*

obtained parameters of carrying capacity m and speed V for each edge, the coefficients of commodity distribution are calculated by the formula:

$$k = V \times m / l, \qquad (4)$$

where V—speed on given edge; m—edge throughput; l—edge length.

Results

During the simulation, we assessed predicted effects of trade flows' structure by 2025 in case of implementation of "One Belt, One Road" project (Table 1 shows parameters of world trade flows that we used). We focused on changes that might occur in trade flows through Russia as a result of the construction of high-speed railways. We considered a few different scenarios (including inertial one):

— Inertial scenario: the same scheme of transportation of goods as it was at year 2016;

— Scenario #1: construction of a high-speed Northern Corridor of the Trans-Asian Railway (includes the high-speed section Moscow-Kazan-Ekaterinburg-Kazakhstan-Urumqi);

— Scenario #2: construction of a high-speed highway through Kazan-Ekaterinburg-Novosibirsk-Mongolia-PRC (without high-speed section Ekaterinburg-Kazakhstan-Urumqi);

— Scenario #3: construction of high-speed highways both through Kazan-Ekaterinburg-Kazakhstan-Urumqi and through Kazan-Ekaterinburg-Novosibirsk-Mongolia-PRC.

The Northern Sea Route was also taken into account in all scenarios (in 2016, about 7.5 million tons of freight (360 thousand TEU) were delivered via the Northern Sea Route, in 2017 it amounted to10.7 million tons[14]).

Inertia scenario reflects the current trading pattern[15], in which 99.5 % of the total flow of goods are transported by sea, and 0.5 % of the flow are transported by railway.

Scenario #1 involves the creation of a high-speed Northern Corridor of the Trans-Asian Railway, including the high-speed section Moscow-Kazan-Ekaterinburg-Kazakhstan-Urumqi. According to preliminary calculations, our model predicts that 95.8 % of the total flow of goods will be transported by sea and 4.2 % by railways. In this scenario, flows of goods passing through Moscow will grow by 92 %, and by 1023 % through Kazan, while flows passing through Irkutsk will decrease by 56 % compared to the inertial scenario. The decrease in the flow through Irkutsk is caused by the passing through

[14] Samofalova, O. (2018). Severnyy morskoy put stanovitsya dorogoy s dvustoronnim dvizheniem [The Northern Sea Route becomes a two-way road]. Retrieved from: https://vz.ru/economy/2018/9/13/940866.html (Date of access: 24.10.2018).

[15] Currently, 22 million TEU (99.5 % of the total flow of goods) is transported by sea and 105 thousand TEU (0.5 % of the total flow of goods) by railway. This is the result of the fact that the cost of transporting goods by railway is quite high. Delivery of one container from China to Europe by sea costs $ 800–2000, while by railway it costs $ 3000–6000. The low throughput capacity of existing railways also has negative effects, despite the fact that the container can be transported from China to Europe by rail for 10–15 days, compared to 30–45 days for shipping by sea.

Kazakhstan High Speed Railway (HSR) that will pull a part of the flow. The flow of goods passing through the Strait of Malacca will decrease by 3.3 % compared to the inertial scenario.

The simulation shows that the implementation of scenario #2 (the construction of the high-speed rail through Kazan-Ekaterinburg-Novosibirsk-Mongolia-China in the absence of a high-speed section Ekaterinburg-Kazakhstan-Urumqi) will lead to an increase in the flow of goods passing through various cities: by 98 % through Moscow, by 588 % through Kazan, by 340 % through Irkutsk. The flow of goods through the Strait of Malacca will decrease by 3.25 % compared to the inertial scenario.

And finally, the implementation of scenario #3 (the creation and use of high speed railway, both through Kazan-Ekaterinburg-Kazakhstan-Urumqi and through Kazan-Ekaterinburg-Novosibirsk-Mongolia-PRC) will result in a 242 % increase in the flow of goods passing through Moscow. The flow will grow by 1430 % passing through Kazan, and by 268 % passing through Irkutsk. In this case, the flow of goods through the Strait of Malacca will decrease by 6.1 % compared to the inertial scenario.

Thus, the third scenario is the most favourable for Russia. It is important to note here that the construction of the HSR of such scale will be a powerful driver for the economic growth of all regions through which the railway passes. Moreover, it will provide demand for various processing industries, increase transport connectivity of the eastern and central regions of Russia, and improve cross country economic ties.

In case of connecting the Trans-Siberian Railway with Japan (via Sakhalin Island) and with South Korea (via the Democratic People's Republic of Korea), transit trade flows passing through the Russian territory will increase even more.

Conclusion

The development prospects of world trade are largely related to the implementation of the Chinese project "One Belt, One Road", which will significantly change modern trans-Eurasian transport flows. Russia needs to use the presented opportunities and its transit potential to increase the country's role in world trade and to accelerate its own economic growth.

The spatial mathematical model proposed in the work allows to assess how trans-Eurasian traffic flows will change in case of implementation of large-scale projects aimed at modernizing the Russian railway network. Modelling shows that the most favourable scenario for the implementation of transit opportunities and for economic growth is the scenario of creating a high-speed railway (HSR) from Vladivostok to the western border of Russia.

With the implementation of the HSR, due to an increase in the throughput capacity of the Trans-Siberian Railway, as well as a reduction in the time of transportation of goods to 3–5 days, the situation for Russia will change for the better. According to preliminary estimates, the cost of such project will amount to 18 trillion roubles, including the cost of high-speed rolling stock [26]. The project's payback period will be eight years since the start of operation of the railway tracks. In more than 20 Russian regions, there will be positive effect for different processing industries. In particular, this project will result in an increase in gross regional product and the creation of additional jobs [25].

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Authors

Askar Akaevich Akaev — Foreign Member of RAS, Doctor of Engineering, Professor, Chief Research Associate, Lomonosov Moscow State University (1, Leninskie Gory, Moscow, 119991, Russian Federation; e-mail: askarakaev@mail.ru).

Olga Igorevna Davydova — Analyst-programmer, iDecide Consulting Ltd. (6B, Kalinina St., Korolyov, Moscow Region, 141070, Russian Federation; e-mail: davydova.olga.msk@gmail.com).

Artemy Sergeevich Malkov — PhD in Physics and Mathematics, Director General, iDecide Consulting Ltd. (6B, Kalinina St., Korolyov, 141070, Russian Federation; e-mail: as@malkov.org).

Sergey Georgievich Shulgin — PhD in Economics, Deputy Chief of Laboratory, Russian Presidential Academy of National Economy and Public Administration, Institute of Applied Economic Research (82, Vernandskogo St., Moscow, 119571, Russian Federation; e-mail: sergey@shulgin.ru).