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SOCIAL AND ECONOMIC EFFICIENCY OF THE DEVELOPMENT OF RAILWAY NETWORK IN SIBERIA AND THE FAR EAST: MATHEMATICAL MODELING AND FORECAST [1]

The aim of the work is to quantify the long-term macroeconomic, social, geopolitical effects from the implementation of the project for the development of the railway network in Siberia and the Far East, including the construction of a high-speed cargo and passenger highway. This research applies methods of mathematical modeling and forecasting. Calculations based on the developed mathematical models have shown that the implementation of this project will play a big role in the social and economic development of the country, in strengthening its geo-economic and geopolitical positions in the Asia-Pacific region and in the world as a whole.

Keywords: Trans-Siberian Railway, investment projects, mathematical modeling, multiplicative effect, socio-economic development, trade flows

Introduction

According to the Decree of the President of the Russian Federation of May 7, 2018 No. 204 "On national goals and strategic aims for the development of the Russian Federation until 2024," one of the priorities of the Russian Government is the development of the country's main infrastructure. In particular, the Decree says: "The Government of the Russian Federation, on the basis of the spatial development strategy of the Russian Federation, shall develop, with the participation of the state authorities of the constituent entities of the Russian Federation, and before October 1, 2018, approve a comprehensive plan for the modernization and expansion of the main infrastructure providing for the provision in 2024:

a) development of transport corridors "West—East" and "North—South" for cargo transportation, including:

— the decrease of the time for the transportation of containers by rail, in particular from the Far East to the western border of the Russian Federation to seven days, and increase of the volume of transit container traffic by rail four times;

— formation of cargo multimodal transport and logistics centers;

— the increase of the throughput capacity of the Baikal-Amur Mainline and Trans-Siberian railway in one and a half times to 180 million tons".[2]

This Decree moves into practical terms the provisions formulated in the Presidential Address to the Federal Assembly of the Russian Federation of March 1, 2018: "In six years the capacity of BAM (Baikal-Amur Mainline) and Transsib (Trans-Siberian railway) will grow in one and a half times up to 180 million tons. Containers will be delivered from Vladivostok to the western border of Russia in seven days. This is one of the infrastructure projects, which will give a quick economic return. There are cargos there and all investments will pay off very quickly and will contribute to the development of these territories. The volume of transit container traffic on our railways should increase almost in four times. This means that our country will be one of the world leaders in the transit of containers between Europe and Asia".[3]

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[1] © Sadovnichiy V. A., Osipov G. V., Akaev A. A., Malkov A. S., Shulgin S. G. Text. 2018.

[2] On national goals and strategic aims for the development of the Russian Federation until 2024. Decree of the President of the Russian Federation of May 7, 2018 No. 204. Retrieved from: http://www.kremlin.ru/acts/bank/43027/page/1 (date of access: June 20, 2018). (in Russ.)

[3] Presidential Address to the Federal Assembly of the Russian Federation on 01/03/2018. Retrieved from: http://www.kremlin.ru/events/president/news/56957 (date of access: June 20, 2018). (In Russ.)

At the same time, the development of Transsib and BAM is not just a transport project. In the work "Integral Eurasian Infrastructure System as a Priority for National Development of the Country" [1] it is said: "This system will become a new infrastructure matrix of Russia, including all its regions into the common national economy and giving a powerful impetus to the development and settlement of Siberia and the Far East. The zone of this matrix will become a "development belt" with a new, innovative industry and new generation cities.

The use of this infrastructure system will stabilize the geopolitical situation around Eurasia and will strengthen Russia's position in the world economy. Strengthening the coherence of our country, increasing the mobility of the population throughout its territory will make a great contribution to rallying the peoples of Russia as a multi-ethnic civil nation. This is a historical challenge that we all have to answer in the coming decades".

The importance of the development of transport infrastructure is stated in many sources (see, for example, official documents[4] and academic papers [3, 4]), but as a rule the argumentation in them is qualitative in nature. In this regard the urgent task of quantifying long-term macroeconomic, social, geopolitical effects from the implementation of the project to develop the railway network of Siberia and the Far East arises. The following materials present an attempt to make such an assessment, which will allow to plan more effectively the work on the implementation of the Presidential Decree mentioned-above.

1. Evaluation tasks

The aim of the work is to quantify the long-term macroeconomic, social, geopolitical effects from the implementation of the project on the development of the railway network in Siberia and the Far East (hereinafter referred to as the Project). In this case, it is expedient to distinguish two horizons of development:

The first horizon is the development of the Transsib (Trans-Siberian railway) and BAM (1Baikal-Amur Mainline) within the framework of existing strategies for the development of the eastern regions of Russia and federal state programs.

The second horizon is the development of the railway network of Siberia and the Far East within the framework of the creation of the prospective Integral Eurasian Infrastructural System (IEIS) [1]. This development involves a large-scale modernization of the Transsib and BAM, including the construction of a high-speed cargo and passenger highway, as well as railway branches to Sakhalin Island (and further to the Japanese islands) and to the Bering Strait (and then to Alaska).

An important advantage of the Project is that it has a complex multiplicative effect that exerts a strong influence on various spheres of society's life. The problem, however, is that a quantitative assessment of the long-term effects from the implementation of such large-scale transport projects faces great challenges. The large scale of scientific literature in our country and abroad [3–7] is devoted to the consideration of issues related to such an assessment. However, the generally accepted standardized approach does not yet exist. In this regard, the task of this paper is to propose an approach to quantifying the long-term multiplicative effects from the Project implementation based on the use of mathematical modeling of the Project's impact on socio-economic processes within the country, as well as on geo-economic and geopolitical processes. In carrying out this task, we used the experience of modeling the global and regional dynamics obtained during the implementation of the Program of the Presidium of the RAS "Economy and Sociology of Science and Education", as well as the project RSF (Russian Scientific Fund) № 14–11–00634 "Mathematical methods for forecasting world and country socio-economic development"

2. Methodology and methods of assessment

To date a large number of studies have been conducted in Russia and abroad, touching on various aspects of the evaluation of the impact of building and improving railways on the development of society. In particular, the research of the Nobel laureate R. Vogel [8] was devoted to this topic. He tried to model the history of the American economy for an imaginary case of the absence of railways in it. At present,

[4] Transport strategy of the Russian Federation until 2030. Approved by the order of the Government of the Russian Federation of 22 November, 2008 No. 1734-r [Electronic resource]. Access from the legal-consultant system Consultant Plus; Strategy for the development of rail transport in the Russian Federation until 2030. Approved by the order of the Government of the Russian Federation of June 17, 2008 No. 877-r. [Electronic resource]. Access from the legal system Consultant Plus. (in Russ.)

such studies are conducted within the framework of a direction called the new economic geography. A key contribution to the development of this direction was made by Nobel laureate Paul Krugman, who summarized the results of many predecessors [9]. With this methodology in mind, a number of mathematical models that take into account the spatial aspects of the economic systems of the regions (unlike classical economic models that did not take those aspects into account) have been developed. Calculations for such models and other actual researches show the importance of rail transport for the economies of the regions of the world. Variants of such models allow to describe the positive transport costs with the help of the "iceberg model" [10], when the cost of goods is gradually lost during transportation. We also apply a number of spatial CGE-models that are used to describe the consequences of creating specific railways [11, 12], gravity models [13], LUTI models [5], etc. are also used.

The works of Russian researchers are of special interest since they take into account the specifics of the economic situation in Russia. According to the expert in the field of regional studies, including the new economic geography, A.N. Pilyasova [14], there are large differences in the effects caused by new railway projects in regions with already developed transport infrastructure, high population density and GDP per capita and in underdeveloped areas with less favorable climatic and other geographic conditions. Therefore, the conclusions of Western researchers, based on the experience of developed countries and well-developed territories, may not always be suitable, for example, for application to the economy of Siberia and the Far East. In Russia, there are developments in the field of mathematical modeling and forecasting at the level of individual regions. Researches of RAS Academician V.L. Makarov, corresponding member of RAS A.R. Bakhtizin and their colleagues from the Central Economic and Mathematical Institute in the field of agent-based modeling [15] are used among other things to model the New Silk Road project in cooperation with colleagues from China. For example, in the work [16] one can find an overview of the construction and use of regional intersectoral models in different countries, including Russia.

Of great interest are the works of researchers who live directly in the Siberian and the Far Eastern Federal Districts. The Nobel laureate L.V. Kantorovich, who lived in the 1960s in Novosibirsk, made an outstanding contribution to the economy of transport [17]. RAS academician A.G. Granberg (1936–2010), whose approach is sometimes represented as a domestic analogue of Western concepts such as the new economic geography, has made an important contribution to the development of studies of the spatial economics of regions [18]. To conduct quantitative research, he developed optimized inter-regional intersectoral models, which allowed to model the economy of the country simultaneously in the regional and sectoral context. At present, research is continuing in Novosibirsk in the field of spatial economics (including assessments of the appropriateness and efficiency of implementing railway projects) at the Institute of Economics and Industrial Engineering of the Siberian Department of RAS [19]. In Vladivostok, economic geography (including its transport aspect) is one of the fields of research conducted at the Pacific Institute of Geography of the Far Eastern Department of RAS under the leadership of RAS Academician P. Ya. Baklanov [20], in Khabarovsk, this field is occupied by the Institute of Economic Research of the Far Eastern Department of RAS under the leadership of RAS Academician P.A. Minakir [21]. Individual studies and dissertations are devoted to the analysis of projects to modernize the railway infrastructure of the Baikal-Amur Mainline and Trans-Siberian railway and their influence on the development of the regions (see, for example, [22, 23]).

The most difficult are the assessments of the long-term socio-economic effects of large-scale investment projects. As a rule, the general scheme for conducting such assessments is as follows:

— assessment of the magnitude of direct economic effects on the basis of available data on the project under consideration;

— assessment of the associated social and economic effects (for example, on the basis of analysis of interbranch relations and balances, use of specialized socio-economic models, etc.);

— assessment of the magnitude of the total effects and determine the value of the multiplicative effect.

In our case, the task of evaluating multiplicative effects is complicated due to the fact that transport projects and the quality of transport services have an extremely diverse indirect impact on all aspects of economic and social life in the country.

In connection with the complexity of the task and the presence of a variety of uncertainties, it is advisable to assess the socio-economic efficiency in parallel by several methods using both macroeconomic and microeconomic approaches. The microeconomic approach involves taking

into account the effects of the implementation of each particular investment project with a further analysis of their cumulative impact on the development of the region (the so-called bottom-up analysis). Macroeconomic approach (analysis from above) involves the use of macroeconomic models describing the interaction of economic sectors, households, financial and government institutions, etc. Implementation of investment projects with this approach influences the change in modeling conditions, which, in turn, leads to a change in the calculated macroeconomic characteristics. Each of these approaches has its advantages and disadvantages, so their joint use makes it possible to make the assessment more objective.

In this paper, the assessment of long-term socio-economic effects was carried out separately for each horizon of the development of the railway network in Siberia and the Far East.

1. For the first horizon of the Project development, the evaluations were carried out according to the following scheme.

Within the framework of the microeconomic approach, it was considered that the main direct social and economic effect of the development of the Transsib (Trans-Siberian railway) and BAM (Baikal-Amur Mainline) is the economic development of the spaces of Siberia and the Far East through prospective investment projects that are envisaged by regional development strategies, but the implementation of which is impossible without the construction of new railway branches and (or) without improvement of the railway infrastructure. In accordance with this, investment projects of this type were selected, and the economic and social efficiency of their implementation was assessed using standard methods of economic analysis. Essentially, this is a bottom-down estimate that takes into account only direct effects from the selected projects.

Macroeconomic modeling based on a specialized general equilibrium model and a specialized dynamic model describing the country's economy as a whole was applied to assess long-term complex (direct and indirect) effects from the implementation of projects on the Russian economy. This approach takes into account the impact of the investment projects on the socio-economic development of the country, on changing its macroeconomic parameters.

2. For the second development horizon of the Project, the main effect is to ensure the high-speed movement of goods and passengers from East Asian countries to and from Europe, which makes Russia a key transit country and the most important element of the global trading network. At the same time, the connectivity of the country, the degree of unification of its national economic complex into a single organism increases.

To forecast global trade flows until 2030 and to estimate the share of these flows that can pass through the territory of Russia, macroeconomic modeling was used. The microeconomic approach was used to assess the necessary costs for upgrading the railroad to provide high-speed (with the maximum speed of trains on the line from 200 km/h and above) moving intensive cargo and passenger traffic.

3. Evaluation

The procedure for assessing long-term socio-economic effects separately for each development horizon of the railway network in Siberia and the Far East is described below and the results are given.

3.1 Assessment of the socio-economic effects of the first development horizon of the railway network in Siberia and the Far East

In accordance with the methodology outlined above, the assessment of the socio-economic effects of the first horizon of the development of the railway network in Siberia and the Far East was carried out according to the following algorithm.

At first, direct effects were evaluated on the basis of analysis of specific large-scale investment projects in the Siberian and Far Eastern Federal Districts (which are envisaged by regional development strategies, etc.[5]), but implementation of which is impossible without investments in the development of the transport network. Selection of investment projects for the analysis was carried out according to the following criteria:

— Projects are implemented or planned in the Siberian or Far Eastern Federal District;

[5] Strategy of social and economic development of the Far East and the Baikal region until 2025. Approved by the order of the Government of the Russian Federation of February 28, 2009 No. 2094-r [Electronic resource]. Access from the legal system "Consultant Plus"; Strategy of social and economic development of Siberia until 2020. Approved by the order of the Government of the Russian Federation of July 5, 2010 No. 1120-r [Electronic resource]. Access from the legal system "Consultant Plus". (In Russ.)

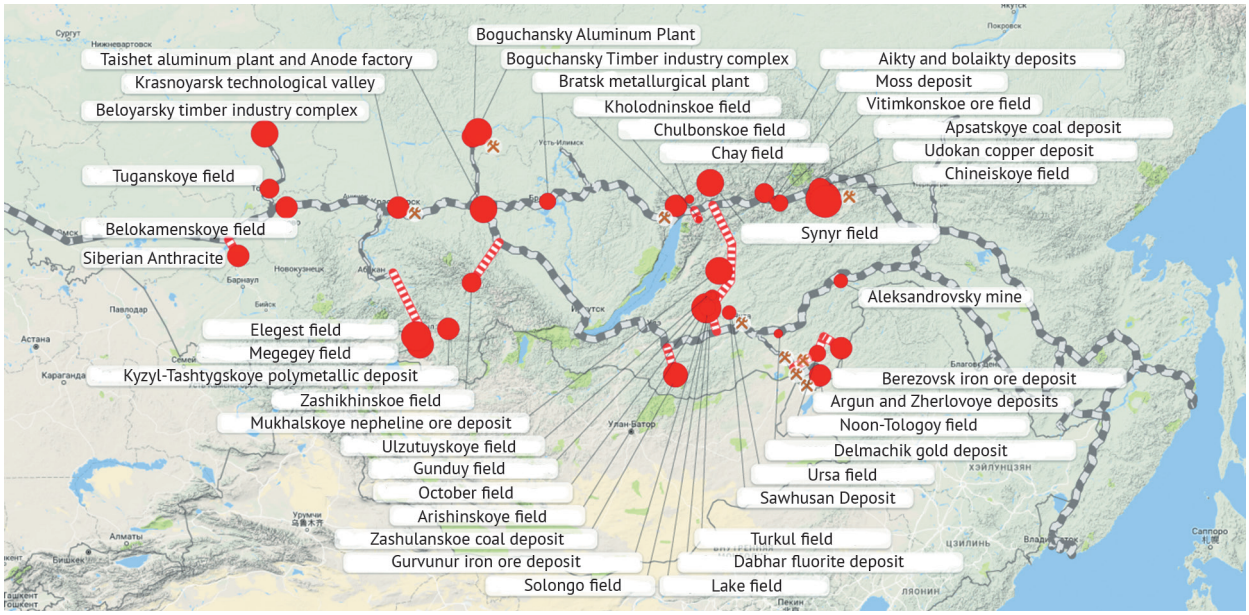

Fig. 1. *Analyzed investment projects in the Siberian Federal District*

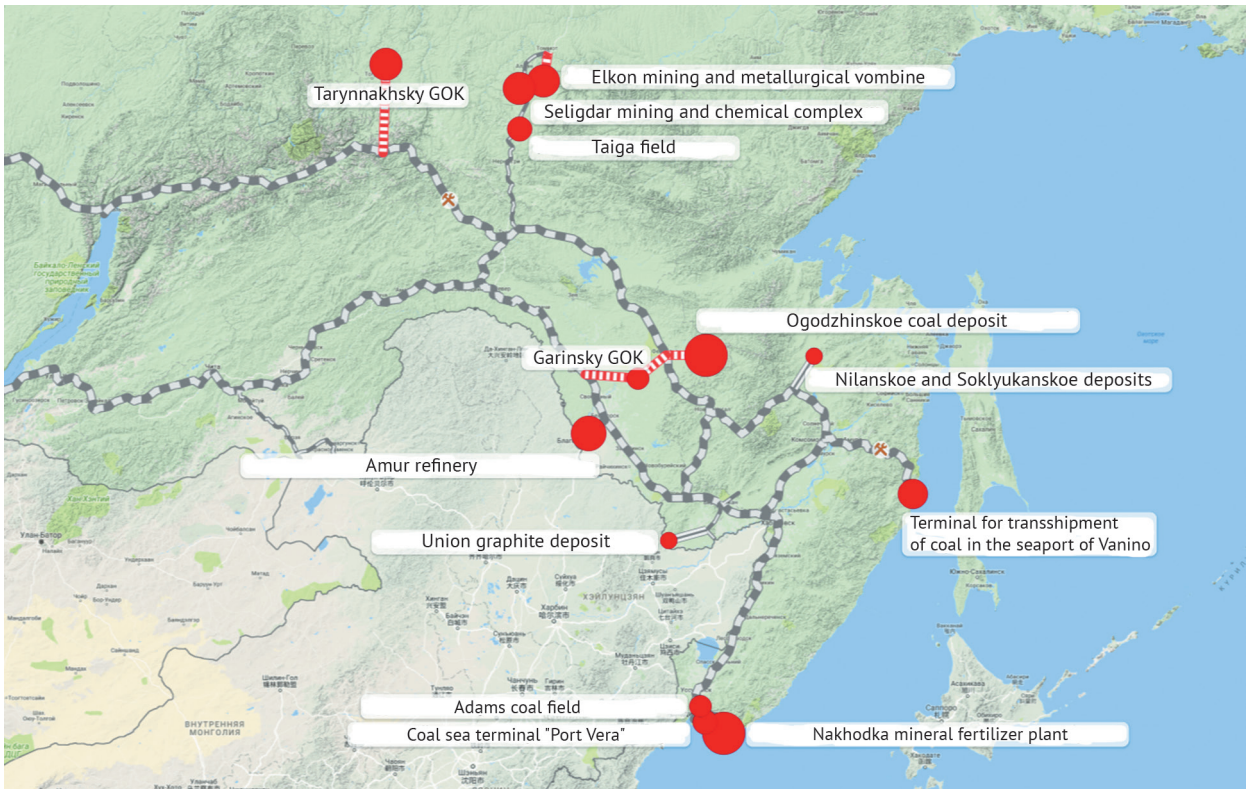

Fig. 2. *Analyzed investment projects in the Far Eastern Federal District*

— Projects can be implemented or additional profit within the framework of projects can be obtained only on condition that new railway lines are built or modernized;

— The implementation of projects or individual stages of projects is planned for 2018–2030;

— The projects imply a large amount of investments (over or about 5 billion rubles);

— Projects are included in regional or federal development strategies and government programs.

In total, there were 55 such projects, including the creation of 12 large-scale production facilities, the development of 40 deposits, and the implementation of 3 large-scale infrastructure projects. The list and review of these projects is given in the report "Assessment of the social and economic efficiency of the project for the development of the railway network in Siberia and the Far East" prepared by the Center for Long-range Forecasting and Strategic Planning of Moscow State University[6], their spatial arrangement of which is shown in Figures 1 and 2.

[6] Assessment of the social and economic efficiency of the project on the development of the railway network in Siberia and the Far East. (2018). Moscow: MSU. (In Russ.)

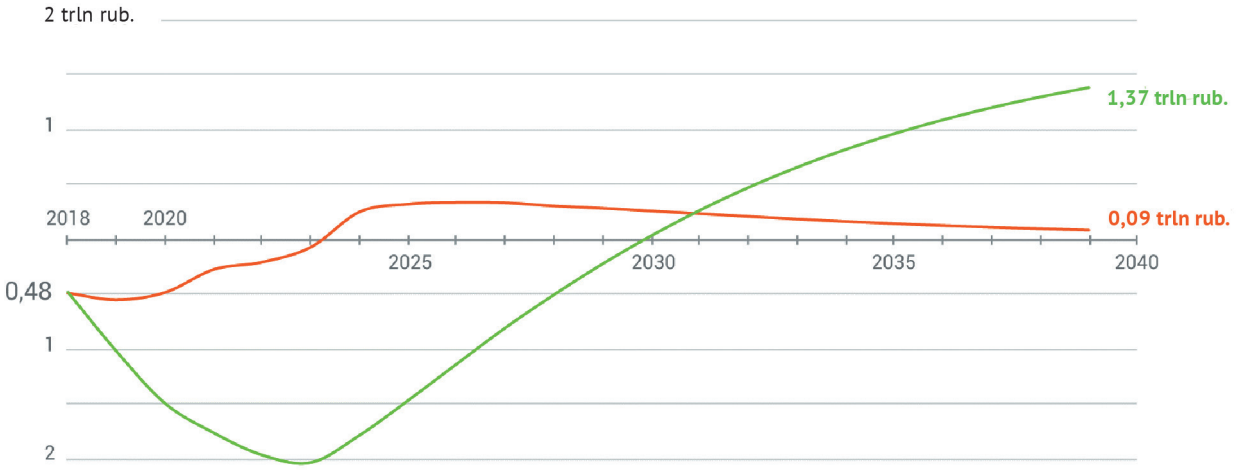

Fig. 3. *Forecast of total discounted cash flow (orange line) and accumulated discounted cash flow (green line) for the investment projects considered*

At the figures the size of the circles corresponds to the scale of the projected investment in projects, dashed lines are the branches of the railways that need to be built.

The methodology for assessing the socio-economic effects from the implementation of each of these projects and related projects on the modernization of the Trans-Siberian railway and the Baikal-Amur Mainline was as follows.

For each project or cluster of projects the main economic indicators were assessed: the volume of capital investments for the development of deposits or the construction of enterprises, the volume of capital investments for the construction of railways and infrastructure, the number of jobs on the railway and in enterprises created both for the construction period and the period of further operation, the annual volume of operating expenses for deposits or enterprises, including the labor compensation fund of employees, annual volume of costs on operating railways and infrastructure, including the labor compensation fund employees engaged in the work, the cost of depreciation, income from mining or operation of enterprises, the payback period of the project or a cluster of projects.

Cash flow (CF) and discounted cash flow (DCF), accumulated discounted cash flow, payback period (PP) were used as the main indicators of the economic effect; the indicator "the number of new jobs" was used as the main social effect.

The results of the combined assessments (for all the projects considered) are given below:

— the total amount of investment in the projects reviewed — 3.7 trillion rubles (of which 1.2 trillion rubles — in the development of the railway infrastructure);

— the average payback period of projects — 13 years;

— the length of the new railway tracks — 2,5 thousand km;

— the number of new jobs — 110 thousand (of which about half — high-tech jobs).

The graphs of the total discounted cash flow and the accumulated discounted cash flow for all the projects considered are shown in Figure 3.

Figures 4 and 5 give a predictive assessment of the direct contribution of the investment projects considered to the gross regional product (GRP) of the Siberian Federal District and the Far Eastern Federal District respectively.

It is assumed that 61 thousand new jobs will appear in the Siberian Federal District, and 49 thousand new jobs will in the Far Eastern Federal District. At the same time, it is important that, as shown by the assessments, this is predominantly (by 40–55 %) highly paid high-tech jobs.

Estimates show that the implementation of the investment projects considered, even without taking into account the indirect effects, will ensure the country's GDP growth in 2030 (in contrast to the inertial scenario without the implementation of these projects) by 1 %.

To assess the long-term complex (direct and indirect) effects from the implementation of projects on the scale of the Russian economy, on the basis of the approach outlined in the work [24], a specialized multi-branch dynamic general equilibrium model (CGE model) including several dozen equations was developed. As the economic agents in the model, firms, households, the state, foreign countries, which interact in labor, capital markets, intermediate goods, final goods, foreign exchange are considered. Producers maximize profits, households maximize consumption. Equilibrium in the

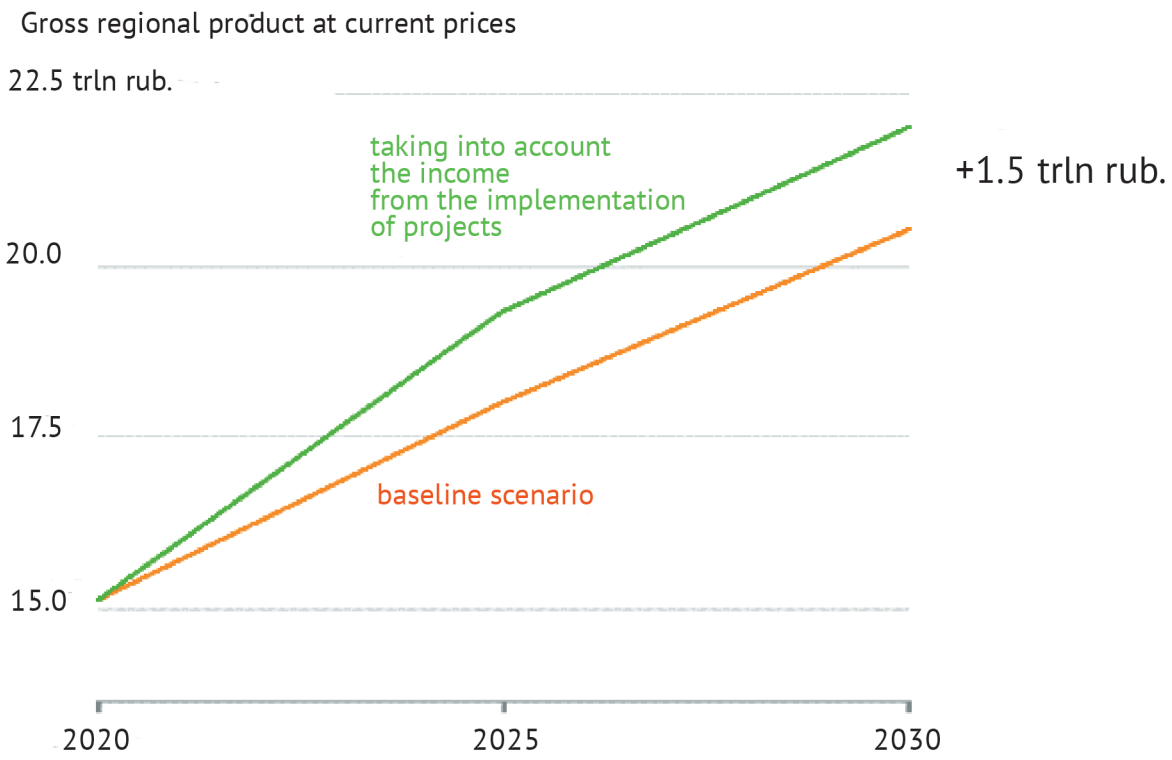

Fig. 4. *Predictive assessment of the contribution of the considered investment projects to the GRP of the Siberian Federal District*

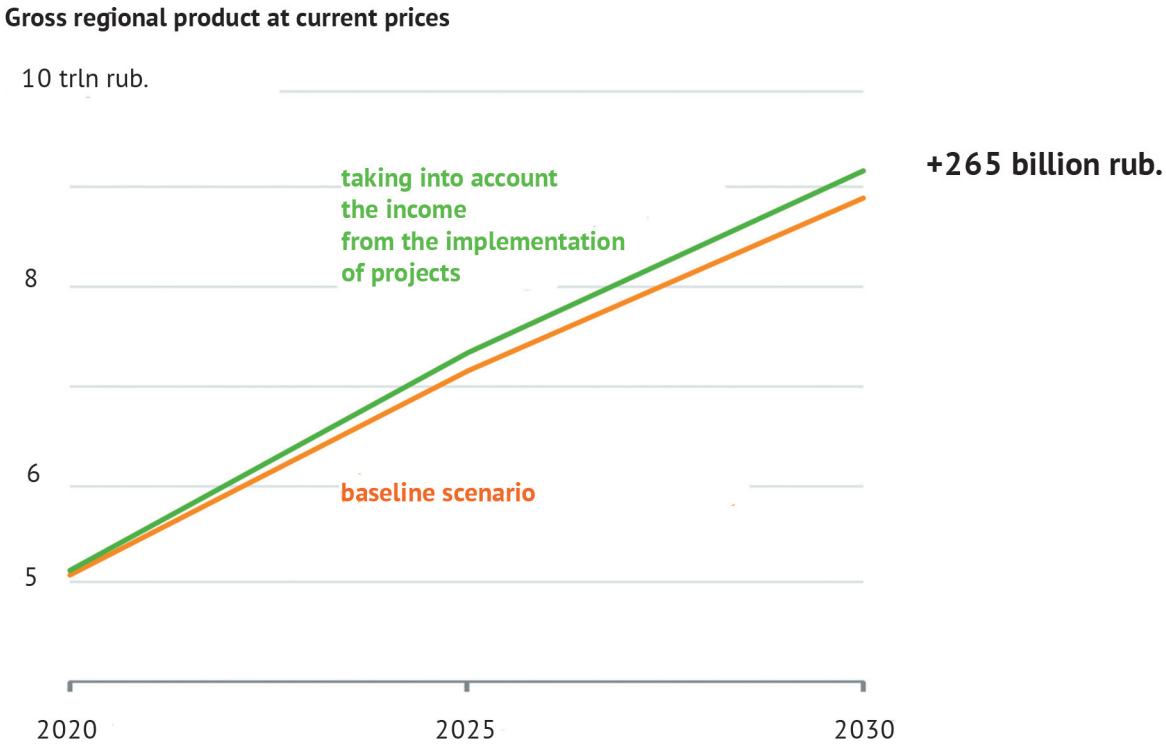

Fig. 5. *Predictive assessment of the contribution of the investment projects considered in the GRP of the Far Eastern Federal District*

currency market is determined by the floating exchange rate, which influences the switching of demand between domestic and foreign goods. The key features of the model that allow analyzing the effectiveness of the investment projects under consideration are the prerequisite for the impact of the accumulated volume of infrastructure capital on overall factor productivity and the impact of projects on export growth. For the production of intermediate goods, the Cobb-Douglas function was used:

Translation

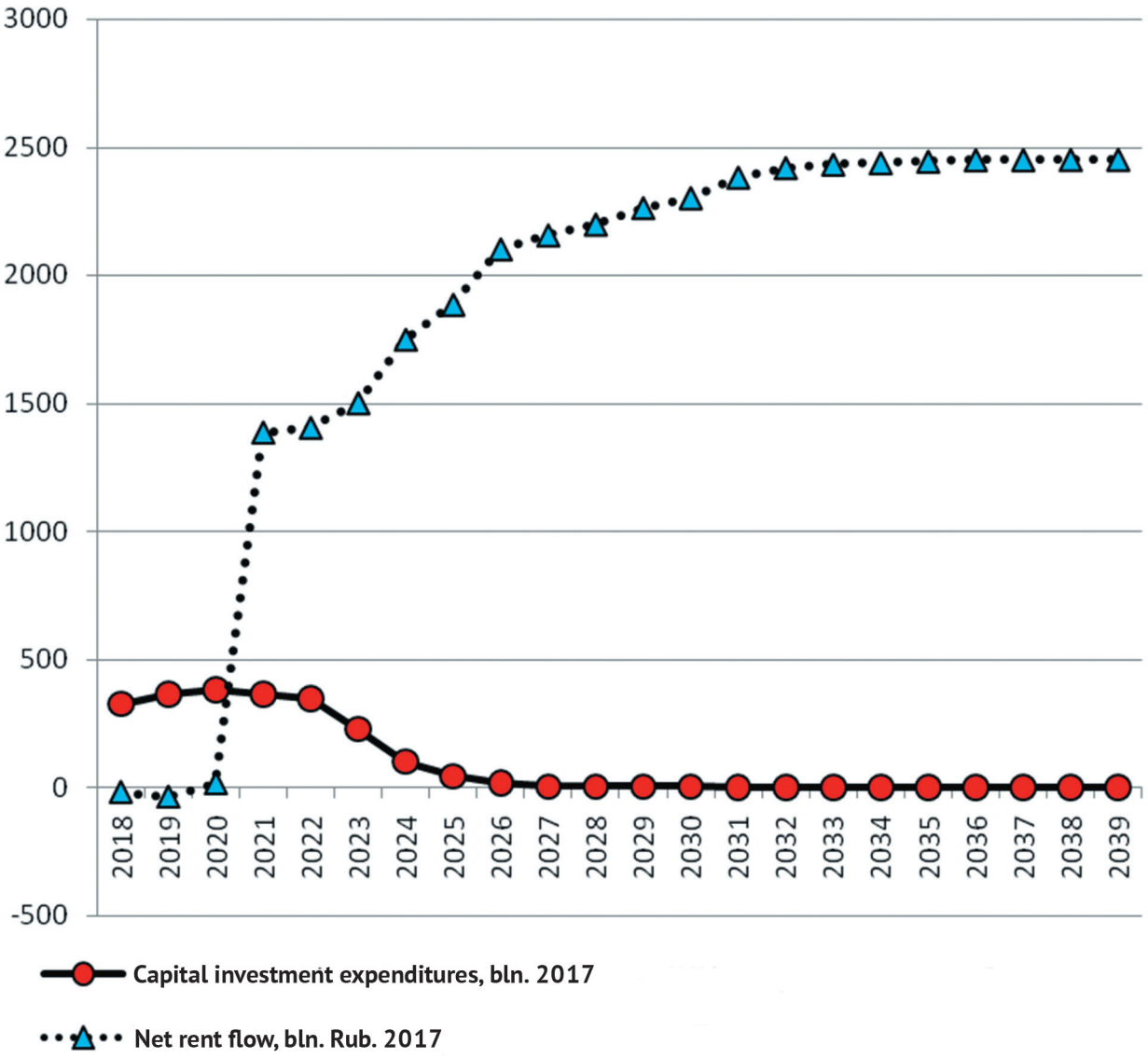

Fig. 6. *Source data for the calculation of macroeconomic effects from the implementation of the Project*

$$Y_t = A_t K_t^{\alpha} (A_L L_t)^{1-\alpha}, A_L > 0, \quad (1)$$

where $A_L L_T$ — is the factor of labor; K_t — factor of capital; A_t — total factor productivity, depending on the accumulated infrastructure:

$$A_t = A_0 \exp\left(\xi \frac{P_{TI,t} TI_t}{NGDP_t}\right), \ \xi, A_0 > 0, \quad (2)$$

where $P_{TI,t}$ — is the price of a unit of infrastructure goods; TI_t — the stock of transport infrastructure created as a result of new infrastructure projects; $NGDP_t$ — nominal GDP in the economy.

Thus, it was believed that the existing infrastructure assets are already included in the capital, and new infrastructure projects create an additional infrastructure stock that increases the productivity of existing factors of production through a function of overall factor productivity (2).

In the model, the positive effect of new investment projects is associated with an increase in the export of natural resources and overall factor productivity, while a negative effect arises from the diversion of available resources from other alternative uses: private and public consumption and investment.

The model was calibrated according to the data of Federal State Statistic Service, the Ministry of Finance, the Central Bank of Russia, UN Comtrade. The input data for the calculations of the socio-economic effects of the Project at the macroeconomic level on a national scale were the data on investment projects obtained as a result of microeconomic analysis (see above) and reflected in Figure 6.

Translation

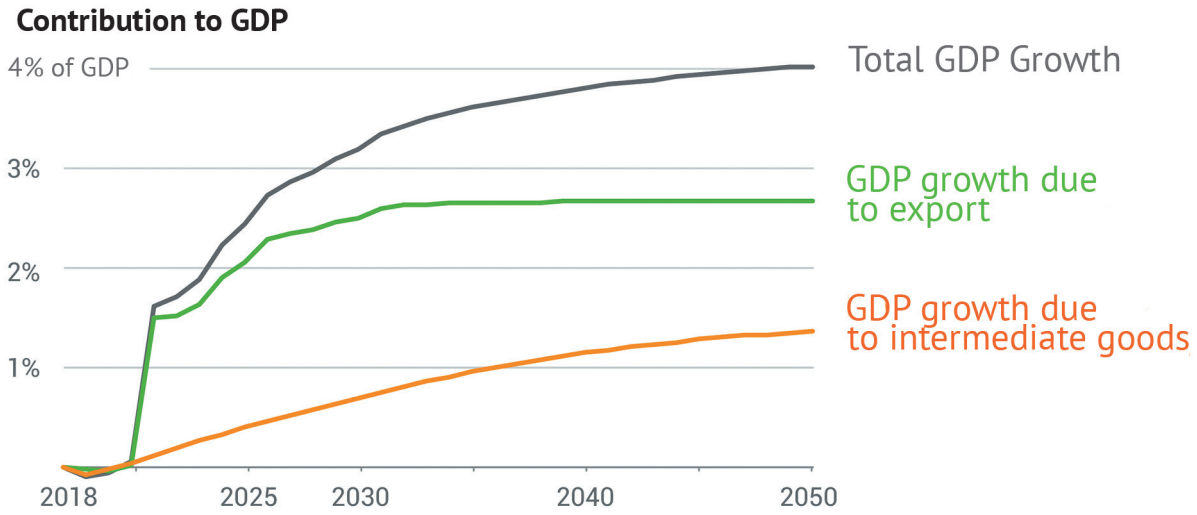

Fig. 7. *The additional increase in the GDP of Russia (in comparison with the baseline scenario of the Russian economy development) in the case of the implementation of the Project (taking into account direct and indirect effects)*

Table

Assessment of the additional change in macroeconomic parameters (in relation to the basic scenario of the development of the Russian economy) in the case of the implementation of the Project

Effect	by 2030, %	by 2050, %
Growth in household consumption	5.2	7.2
Real wage growth	2.9	4.2
Strengthening of the long-term real exchange rate of the ruble	4.7	5.4
The increase in GDP (in % to the baseline scenario)	3.2	4.2

The results of the calculations are shown in Figure 7 and in the table.

In order to increase the reliability of the conducted assessments, some parallel calculations were carried out with the use of the dynamic macroeconomic model of Russia. The basic dynamic model (described in the work [25]) is a system of differential and algebraic equations. The country's economy is represented by two main sectors: the manufacturing sector (MS), which produces goods and services for final consumption and export, and households (HH), which consume goods and services that were produced by MS or were imported, and which participate in production, providing the MS with workforce at the same time.

Other sectors are taken into account indirectly. Also, there is an external world considered in the model, interaction with which is carried out through international trade. The external world is seen as a single unit without splitting into separate foreign countries.

The model describes the cash flows dynamics in the economic system as follows.

Ruble funds dynamics $M_Y(t)$ of production sector (legal entities):

$$\frac{dM_Y(t)}{dt} = \text{(revenues from selling goods and services to households within the country)} - \text{(transfers to households)} + \text{(export revenues)} - \text{(import expenses)} + \text{(foreign direct investment)} + \text{(other cash flows)}. \quad (3)$$

Other cash flows refer to the funds exchange with economic actors considered indirectly (state, financial sector, etc.).

Ruble funds dynamics $M_H(t)$ of households (individuals):

$$\frac{dM_H(t)}{dt} = \text{(households revenues)} - \text{(households expenses on the purchase of domestic goods and services)} - \text{(households expenses on the purchase of imported goods and services)} + \text{(other revenues and expenses)}. \quad (4)$$

Other revenues and expenses refer to the funds exchange with economic actors considered indirectly (state, financial sector, etc.).

Goods and services produced by the MS were represented as a single unit — the aggregate product (so-called single-product model). The dynamics of the price level $p(t)$ for that aggregate product was determined on the basis of the ratio of demand and supply of goods and services in the domestic market:

$$\frac{dp}{dt} = a_p \times (\text{effective demand} - \text{supply of goods and services}). \quad (5)$$

This equation (5) means that if the demand exceeds the supply, it leads to the inflation (price level $p(t)$ increases), and if the supply exceeds the demand, it leads to the deflation (price level $p(t)$ decreases). The ap index describes the rate of setting the equilibrium value of $p(t)$.

The model (3)–(5) was specified with regard to the conditions of the Russian economy, the identification of the model options was carried out with the use of some Russian economic statistics for 2001–2017. The input data for the calculations, as in the previous case, included the data on investment projects obtained through the microeconomic analysis (see above). The modeling resulted in the conclusion that additional GDP growth (provided the implementation of The Project) could reach 3.4 % by 2030, and that additional average wage growth could reach 3.0 %. Comparison of these values with the data included in the table shows a good approximation of the results obtained by independent methods, which indicates a sufficiently high reliability of these results.

The assessment of direct and indirect long-term socio-demographic effects from the implementation of investment projects associated with the development of the Trans-Siberian railway and the Baikal-Amur Mainline was carried out according to the following algorithm:

— the number of jobs created was assessed for each project (using the microeconomic approach, see above);

— the share of jobs that can be provided by the local labor market was estimated, as well as the number of employees which has to be involved from other regions;

— the expenses on the involvement employees from other regions (compensation of costs associated with the relocation of employees and their families, assistance in housing, etc.) were assessed;

— the expenses on the creation and maintenance of social infrastructure (housing, trade, transport, education, health, culture, sports and recreation, etc.) were assessed.

In fact, these expenses are not production costs but the investment in human capital that will increase the demographic potential of Siberia and the Far East, will improve the population's quality of life there.

The assessments on the considered investment projects reveal the necessity of jobs for 110 thousand people (see above). They also show that if these projects are implemented, it is possible to increase the demographic potential of Siberia and the Far East by at least 600–700 thousand people (taking into account their family members and employees in related areas).

3.2 The assessment of socio-economic effects of the second development prospect of the railway network in Siberia and the Far East

The main goal of the second development prospect of the railway network in Siberia and the Far East is to provide high-speed (with a maximum speed of trains on the line from 200 km/h and above) movement of goods and passengers from the Far East to its Western border and back. It will be useful for tackling both internal and external problems — these measures lead to the increasing the connectivity of the territory of Russia, to the shift of its economy from commodity specialization to a new industrial model of development, and as well as to the use of the unique transport and transit potential of Russia, to the upgrading its role in the world economic space. Geographically Russia is located between the world's largest economic clusters in Europe and Asia (Fig. 8) and it should benefit from such a strategic position.

In order to implement the second development prospect of the railway network in Siberia and the Far East, it is necessary to modernize a significant part of the railways, to create new ones, to replace the vehicle fleet and to build some terminals and other transport infrastructure.

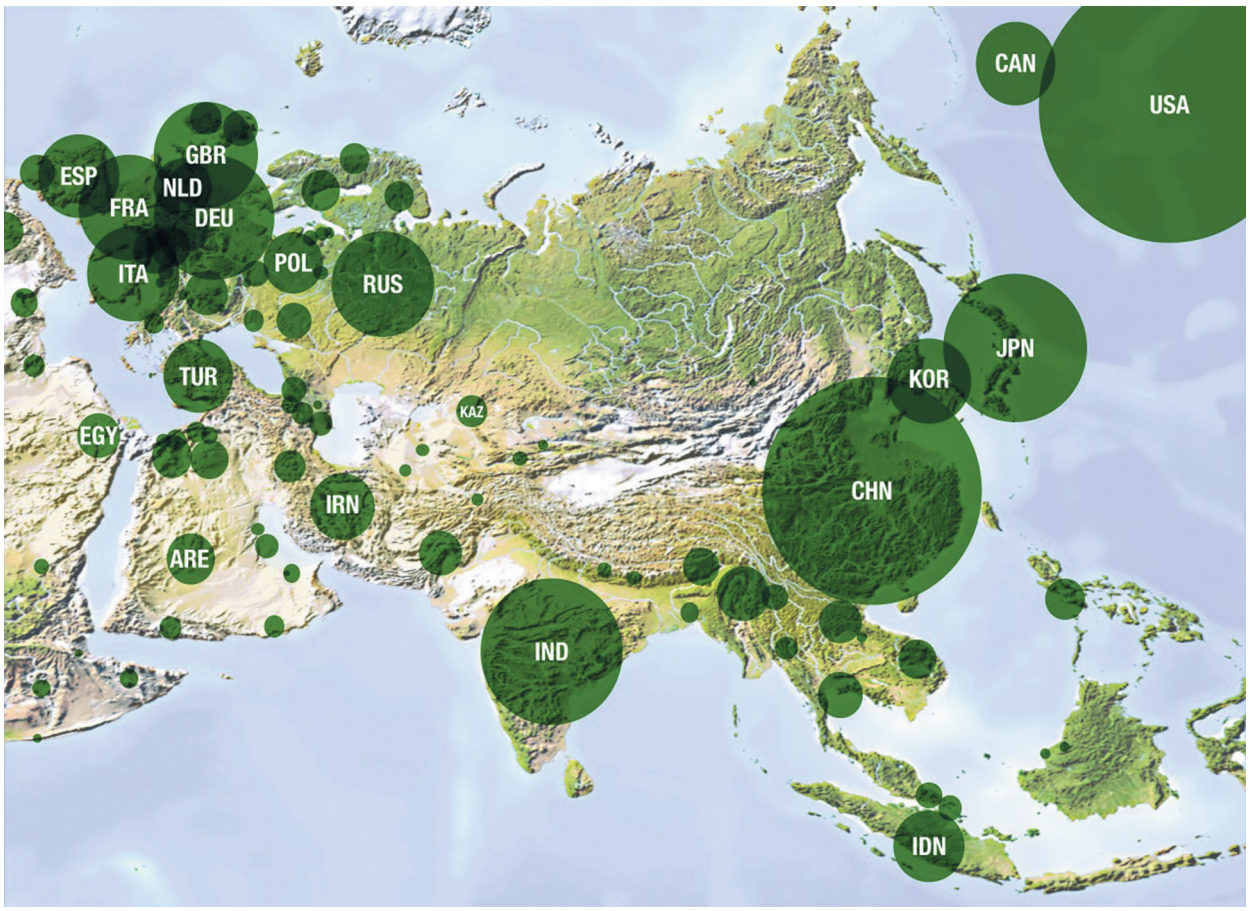

Fig. 8. *The spatial arrangement of global economic clusters in Eurasia (the area of a circle corresponds to the GDP of the respective country in 2017 at purchasing power parity)*

In accordance with the above methodology, the assessment of socio-economic effects of the second development prospect of the railway network in Siberia and the Far East was carried out according to the following algorithm.

Firstly, the forecast of world trade flows up to 2030 was made on the basis of macroeconomic modeling, and the share of these flows that can cross the territory of Russia in the case of modernization of the main roads in Siberia and the Far East was fully estimated. Secondly, it was necessary to assess the expenses on modernization and the socio-economic efficiency of The Project.

At the first stage, the study focuses on determining possible transit flows of goods transported by the railway system of the Russian Federation. It should consider several factors: existing volumes of maritime trade, potential projects under the Chinese Belt and Road initiative, potential trade flows from Japan and South Korea.

The analysis of world trade interactions between countries was carried out by means of a specialized mathematical modeling that allows to identify and visualize the structure of international trade relations. Due to the statistical data (current trade statistics UN Comtrade), the directed graph was built, and each vertex of it corresponded to a particular country, while the edge indicated the direction of the main trading partner of that country. For the convenience of visualization force-directed graph drawing algorithm was used, and it successfully demonstrated communication between the main trade partners by “bringing different tops close together”, while naturally, tops are repelling each other.

Figure 9 shows a chart displaying the current pattern of interaction among the main partners in a world trade (each country is depicted in a circle proportional to its foreign trade; the thickness of the lines corresponds to the intensity of trade flows between the countries concerned).

It is clear that nowadays there are three main trade clusters formed, headed by China, Germany and the United States.

To forecast the structure of trade interactions for the period up to 2030, the gravitational model of Jan Tinbergen was used in the following modification:

$$\log(T_{ij}) = a_0 + a_1 \times \log(GDP_i \times GDP_j) + a_2 \times \log(N_i \times N_j) + a_3 \times \log(D_{ij}) + \ldots + e_{ij}, \quad (6)$$

Translation

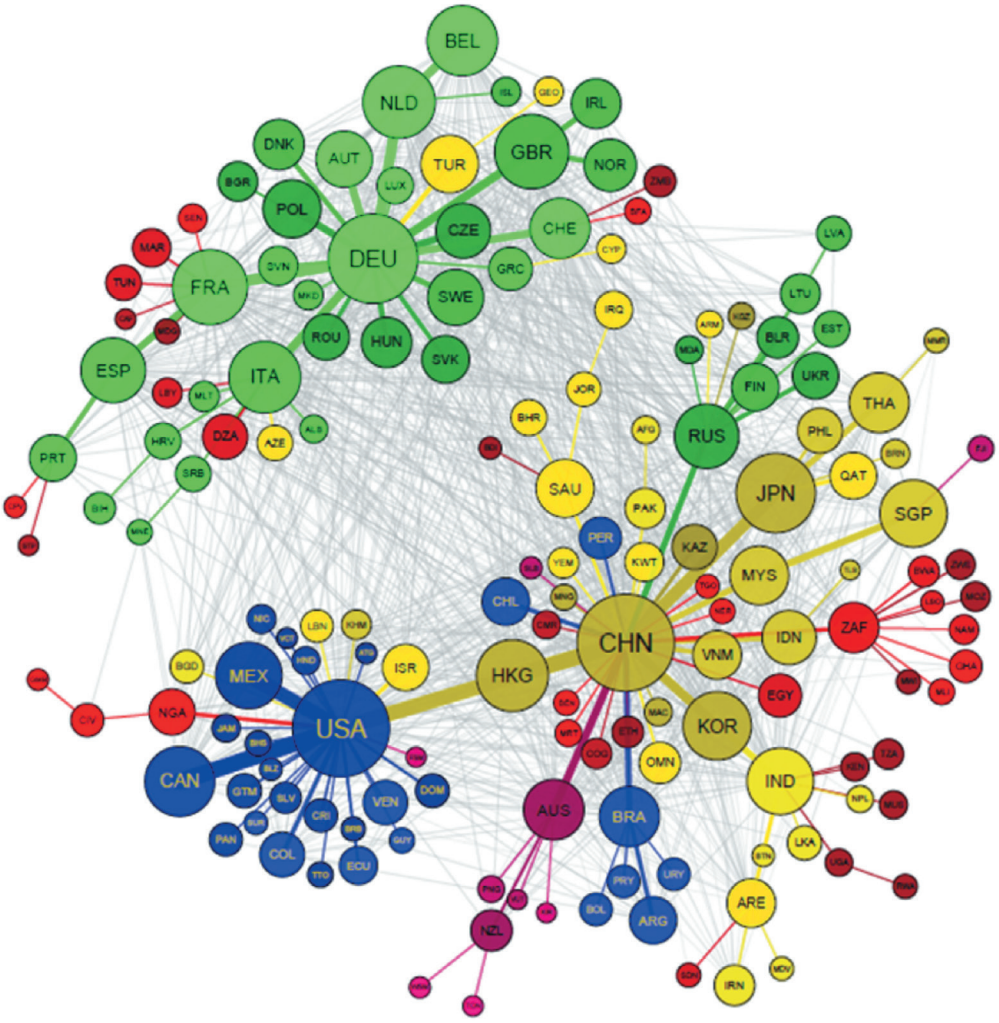

Fig. 9. *A chart reflecting the intensity of trade interactions between the countries in 2017*

where T_{ij} is a volume of trade between the countries i and j; $GDP_{i/j}$ is a real gross domestic product of the country i; $N_{i/j}$ is population; D_{ij} is a distance between the countries i and j; e_{ij} is model biases.

Using the data on mutual trade between countries in the current period and considering expectation of change in the variables used in the model (6) (in accordance with data from the UN, World Bank, with the model of long-term economic growth Barro and Sala-i-Martin; Mankiw–Romer–Weil model, as well as Evans model), it is possible (assuming the stationarity of the gravitational constants ai) to calculate the values of T_{ij} and by the algorithm mentioned above to construct schemes similar to the chart in Figure 9 for the foreseeable period of time (Figure 10).

As it is seen in Figure 10, the inertial scenario (on the left) corresponds to a situation in which the growth rates of the world's economies are maintained at the current level, and the convergent scenario (on the right) corresponds to a situation in which the growth rates of the economies are gradually equalizing. It is clear that in case of the inertial scenario, China by 2030 becomes the undisputed world leader. Though, in the case of the convergent scenario, China's positions are also strengthening, but not so fast. In any case, it follows from the calculations that by 2030 China will become the main trading partner of Germany. At this point, the role of Russia as a transit country in this trade is sharply increasing and these opportunities should be seized.

It is necessary for the determination of the development prospects of transit routes from China to Europe passing through the territory of Russia, to compare them with alternative routes, especially with the sea route through the Indian Ocean and the Mediterranean Sea, which is the main one. Quantitative assessment was conducted by using mathematical models of trade flows, allowing to address problems of spatial economics. A detailed description of the model is given in [26]. It covers a geographical space in which each point (x, y) defined by the following quantities: $T(x, y, t)$ is the density of the product, $Q(x, y, t)$ is the density difference between the volumes of production and consumption of goods, $j(x, y, t)$ — a flow of goods, $p(x, y, t)$ is the price of the goods, $\{K_i(x, y)\}$ is a set of conditions of the

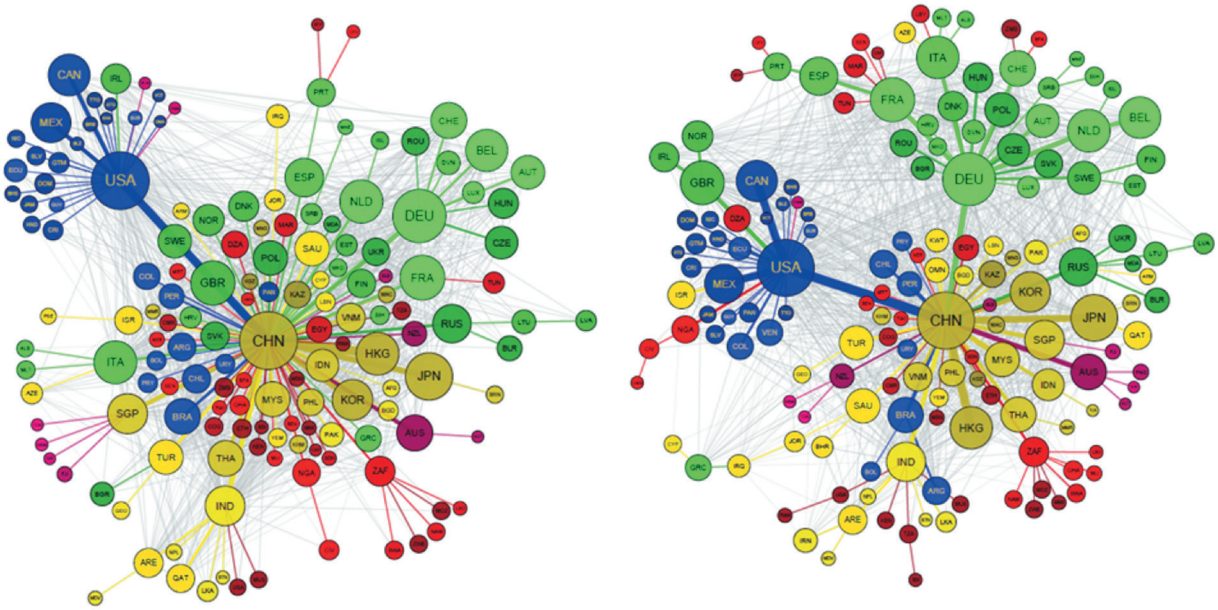

Fig. 10. *The forecast of trade relations structure in 2030 (a scenario of inertial development on the left, a scenario of convergent development on the right)*

area that affect the transportation of goods. The issue is to determine $T(x, y, t)$, $j(x, y, t)$ and $p(x, y, t)$ for given $Q(x, y, t)$, $\{K_i(x, y)\}$. The model assumes that the flow of goods j is proportional to the price lapse rate with some aspect ratio k:

$$j = k \cdot \text{grad}p. \tag{7}$$

In other words, the goods are transported from the points where the price is lower to the point where the price is higher, and the more active this transportation goes, the bigger the price difference. The ratio k can be treated as the ratio of the commodity conductivity. The dynamics of prices change is described by the equation:

$$\frac{\partial p}{\partial t} = div(k \cdot \text{grad}p) - Q, \tag{8}$$

which is the counterpart for the heat equation, where the price p plays the role of temperature, the ratio of commodity conductivity k is similar to the ratio of thermal conductivity, consumers of goods play the role of sources (Q with negative), and producers play the role of drains (they lower the price).

To simulate the transport issues associated with the transit of goods from China to Europe, we used a graph representation of the model in which the global transport network is represented by a graph:

$$G = (V, E),$$

where V is network nodes (vertexes); E is network arcs (edges of the graph). The vertexes V represent the key cities connected by rail network (Hong Kong, Shanghai, Beijing, Vladivostok, Irkutsk, Astana, Tehran, Istanbul, Kazan, Moscow, St. Petersburg, Warsaw, Hamburg, Rotterdam, Paris, etc.), and also cities located along the sea route (Marseille, Cairo, Djibouti, Karachi, Mumbai, Singapore, Jakarta, Manila, Busan, Qingdao, Kaohsiung, etc.). The edges of the graph E are the available rail or sea routes that link the vertexes of the graph (city). The spatial distribution of production and consumption of goods was given. It means that for each vertex of graph V_i, the value Q_i was determined, which is the difference between production and consumption in the i node of the graph. For each edge E_{ij} linking vertexes i and j, the road category was specified (0—road, 1—railway, 2—high-speed railway, 3—sea route). For each road category, the average movement speed and its traffic capacity were known, which made it possible to determine the values of the coefficients of k_{ij} that reflects commodity conductivity between nodes i and j of the graph.

With discretized equations(7) and (8) the problem of identification space traffic accommodation j and price p at pre-assigned space allocation of production and consumption of good Qwas resolved.

Figure 11 shows visualized results of modeling the current situation with transit of Chinese export to Europe.

Translation

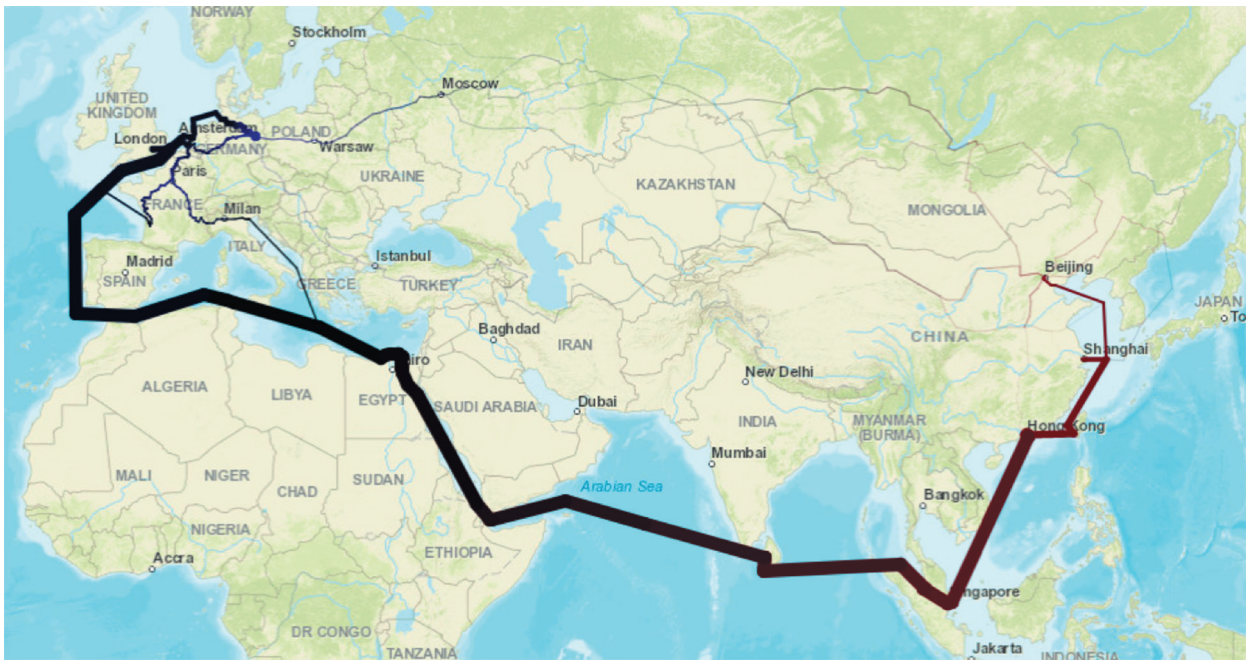

Fig. 11. *Spatial good traffic distribution without considering of modernized Trans-Siberian railway (a linewidth is proportionally associated to the size of commodity flow)*

Fig. 12. *Spatial disposition of goods traffics in case of creating high-speedTrans-Siberian railway (a linewidth is proportionally associated to the size of commodity flow)*

Currently, accordant with trade scheme, 22 million TEU (twenty-foot equivalent unit, typical cargo transporter) are transported by sea, which is 99.5 % of the whole commodity flow, and 105 thousand TEU or 0.5 % of the total are transported by railroads. The reasons are higher rail cargo transportation costs (3000–6000$ per a cargo transporter facing 800–2000$ for sea transportation) and low modern railway lines capacity, which do not compensate delivery time differences (30–45 days of sea transportation versus 10–15 days of rail transportation).

A creation of high-speed Trans-Siberian railway network, in spite of inevitable cargo transit tariff raising, may improve the situation for Russia by means of Trans-Siberian railway network capacity rising and reduction of delivery time to 3–5 days. Figure 12 shows the results of modeling the situation with transit of Chinese export to Europe in case of creating high-speed Trans-Siberian railway.

Modeling shows that in case of high-speedTrans-Siberian railway usage, 21.5 million TEU (twenty-foot equivalent unit, typical cargo transporter) are transported by sea, which is 97.3 % of the whole commodity flow, and 600 thousand TEU or 2.7 % of the total are transported by railroads. In other

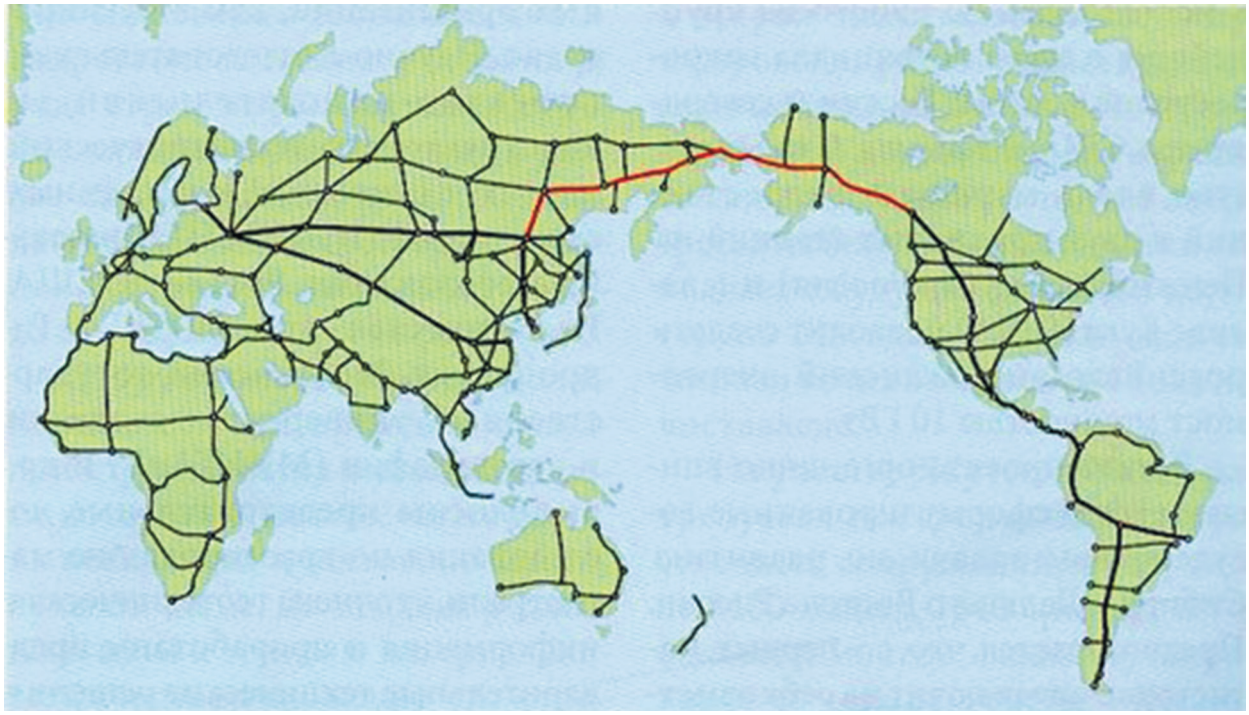

Fig. 13. *Perspective transcontinental railroad and world transit system (Retrieved from: http://mostsakhalin.ru/publications/detail.php?ID=2309 (date of access: 20.06.2018). (In Russ.))*

words, the volume of sea transportations in comparison with the existed scenario, would reduce by 2.2 % (in favor of rail transportation), and rail transportations would increase by 474 %. For individual groups of goods (for which delivery speed plays an important role) replacement of sea transportation by rail would be much higher.

Creating costs of high-speed railway from Vladivostok to the western border of Russia in advance are estimated at 18 trillion rubles, including vehicle stock costs[7]. The project is expected to become profitable after starting of high-speed railway operation in 8 years.

Transit potential of Russia would increase, if the scenario of extending Russian railways beyond the borders of the continent: to Sakhalin island and further — to Hokkaido island (Japan), and also to Bering Strait and further to the Alaska Peninsula (USA) will be realized. In the case, Russia will become the main unit of the global transit system, will connect main world economic centers. (Figure 13).

Herewith the project will become the stimulus for developing of Russian engineering industry. The project realization will have a positive impact on economies of 23 regions (including an increase of GRP and creating new workspaces) and on many branches of processing industries. Herewith the project realization will simultaneously essentially increase connections between Russian regions, will improve economic interactions between regions, will create opportunities for greater population mobility.

The important social effect of the project (including railway branch and related industries) consists in the creation of a huge amount of various qualification jobs. Personnel in total will include 600–700 thousands of people. According to new infrastructure project development experience, we know that creating one workplace in new transport and logistics system leads to creating up to 9 workplaces in related industries of the national economy, therefore the total amount of new workspaces as a result of the second horizon of the Siberia and Far East railways development project realizing may reach up to several million people.

Generally, after the second horizon of the Siberia and Far East railways development project will be realized, there will be some effects:

— ensuring the quality growth of connection between Russian regions (intensification of internal economic and social exchanges);

— creating of powerful incentives for Siberian and Far East regions (macroregions) integration in single economic and social space in modern Russia;

[7] Starikov, I. V. (2016). *Edinaya Evraziya — Novyy Transsib [United Eurasia — New Transsib (Trans-Siberian railway)]*. Moscow. (In Russ.)

— revival and bringing several non-primary industries (particularly engineering industry) of Russian national economy to a quality new technological level. In this way, the project will become the locomotive for the Russian integrated re-industrialization;

— creating of various real incentives for development of economically weak regions of the Russian Federation and overcoming regional imbalances;

— opportunity to attract during the foreseeable period an unprecedented volume of foreign investment in Russia and open new possibilities for an import into Russia of really modern technologies, technologies of the future;

— due to the involvement of European investors increase interest degree of the European Union in Russia as a key geopolitical and geo-economic partner and creating incentives for the transition of Russian-European economic and political cooperation to a qualitatively new level;

— the possibility of strengthening Russia's geopolitical position in the Asia-Pacific region and reaching a certain balance of geopolitical and geo-economic ambitions for the PRC, Japan, South Korea, the ASEAN countries;

— a qualitative increase Russia's role as a geopolitical, political, economic, cultural bridge between Western, Central Europe and East Asia.

Conclusion

The most important task facing modern Russia is the improvement of its spatial development, the accelerated integrated development of the vast expanses of Siberia and the Far East. This implies the creation of modern high-performance industries in the east of the country, covering the full cycle of industrial production, from mining to manufacturing high-value-added products, including Siberia and the Far East into chains of world economic ties and trade flows, the transformation of this region from the world economic outskirts in important element of a global trading network, linking key economic centers.

All this is impossible without a serious modernization of the Siberia and the Far East transport infrastructure, which is not just a means of reducing transportation costs, but a necessary condition for the spatial development of modern Russia.

As a result of the carried out research with using the developed mathematical models, long-term macroeconomic, social, geopolitical effects from the implementation of the project on the development of the railway network in Siberia and the Far East have been estimated. It is shown that the project has a complex multiplicative effect that exerts a strong influence on various spheres of society's life.

In the economic sphere, the effect is expressed in accelerating the GDP growth rate of the Russian economy to the world average, in restructuring the structure of the economy from raw to industrial and post-industrial, in the development of high-tech industries, in reducing the unbalanced development between regions of the country.

In the sociopolitical sphere, the effect is expressed in the appearance of new high-tech workspaces, in raising the incomes of the population, improving the demographic situation in the east of the country, in enhancing the coherence and integrity of the Russian social space.

In the geo-economic sphere, the effect is expressed in Russia's involvement in global trade networks and distribution chains, in increasing the interest of foreign partners to invest in Russian projects and in the development of the Russian economy.

In the geopolitical sphere, the effect is expressed in the interest of European and Asian countries in cooperation with Russia as a bridge between Asia and Europe, in strengthening Russia's significance in international relations, in a new multipolar world order.

In the military sphere, the effect is expressed, in particular, in increasing the mobility and mobilization capabilities of the country's armed forces.

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