Decision support system for sustainable economic development of the Far Eastern Federal District

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Abstract

In this paper we present a decision support system for the sustainable economic growth of the Far Eastern Federal District (FEFD) of the Russian Federation that consists of several regions. Using system dynamics and agent-based modeling methods, a simulation model of the FEFD economy is developed. The model is implemented in the AnyLogic system; it makes it possible to investigate the influence of multiple factors influencing the FEFD economy, for example, increasing rates of investment in fixed assets, average wages rates, subsidies from the federal budget, the forecasted price trends of oil, gas, carbon, diamonds and fishing industry products. One feature of the model is the possibility to analyze the dynamics of development of all regions of the FEFD, as well as taking into account the influence of external macroeconomic factors.

The decision support system we designed allows us to visualize important characteristics of the FEFD subjects using the map of Russia (GIS) and to save the results of the simulation modelling to the system database. At the same time, we have the possibility of forecasting the dynamics of the Gross Regional Product (a geographic information system) of the Federal District depending on values of the control parameters.

Different scenarios of the FEFD development are investigated. The realistic scenario assumes stabilization of prices for the main energy resources (oil, gas, coal) and minerals with simultaneous growth of investments in fixed assets. The pessimistic scenario assumes falling prices for energy, diamonds, fishing products, etc., as well as the reduction in the numbers of the economically active population in the Far Eastern Federal district. The optimistic scenario assumes stable increasing demand and prices for the products of all main sectors of the economy of the Federal District, maintaining current growth rates in industry and agriculture.

Key words: decision support system; regional economy; Far Eastern Federal District; simulation modeling; AnyLogic.

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Introduction

At present, the task of developing scenarios for sustainable economic growth of the Russian Federation regions is becoming very topical. The difficulty of the problem arises from the need to take into account internal feedback relations between the main characteristics of the economies of regions. For example, it is difficult to provide sustainable economic growth under conditions of a shortfall in the economically active population, such as occurs, in particular, in the regions of the Far Eastern Federal District (FEFD). Nevertheless, the important feature of the regional economic system is the possibility to implement a compensatory strategy that assumes the growth of the Gross Regional Product (GRP). It may be implemented by developing asset-intensive fields of the economy, attracting external labor, as well as by effective use of geographic advantages and natural resources.

The research topic of this paper is the economic system of the FEFD of Russia. The total size of the FEFD is 6 952 555 sq km, which is 40.6% of the total area of the country (it is the largest Federal District in Russia). However, the population density in the FEFD is only 1.18 person/sq km.

The FEFD consists of the following regions: Republic of Sakha (Yakutia), Primorsky Krai, Khabarovsk Krai, Amur Region, Kamchatka Krai, Magadan Region, Sakhalin Region, Jewish Autonomous Region and Chukotka Autonomous Region. The leading industries in the FEFD are nonferrous metallurgy, mining of precious metals and stones, coal mining, fishing, timber and woodworking industries, oil and gas production and mechanical engineering. The basis of the economy of the FEFD is natural resources. Here are the largest deposits of hydrocarbons, gold, diamonds, ferrous, non-ferrous and rare metals, tin, coal and other metallic and non-metallic minerals. In the FEFD are mined of 100% of Russian tin, almost 100% of diamonds, more than 50% of gold and silver. The fishing industry of the FEFD is the largest in Russia. It produces about 70% of all aquatic and biological resources of the country and 56% of the total Russian production of fish products[1].

Thus, there are all preconditions for the economic development of the FEFD. However, there are certain problems related primarily with a shortage of the economically active population (only 3.5 million people), the unsatisfactory condition of the transport infrastructure (the length of roads is only 36 971 thousand km), as well as inflated prices for consumer goods and services against a background of low average wages. Therefore, the development of a new approach to finding the best scenarios for the development of the Federal District is required. This entails forming an effective strategy for control of key production and investment characteristics [1].

Such key characteristics, in particular, include growth rates of investments in fixed assets (including transport infrastructure), reducing interest rates on loans, raising wages, reducing the rate of inflation, etc. Implementation of such an approach requires the development of a decision support system (DSS) [2] based on simulation methods [3].

The noteworthy feature of the suggested approach is use of system dynamics methods first advanced in the works of J. Forrester [4; 5] and D. Meadows [6; 7], and later developed by V.N. Sidorenko [8], A.S. Akopov [9–12] and others. Additionally, methods of agent-based modeling are applied within the suggested approach. Such methods were proposed by T. Schelling [13] and R. Axelord [14] and then improved in works of Russian scientists [15–17].

Among the studies of rational regional systems management, we should mention the

[1] Regions of Russia. Socio-economic indicators 2017. Statistical compilation

works by S.A. Aivazian [1], V.L. Makarov [18], A.R. Bakhtizin [19], G.L. Beklaryan [20], as well as the works [21–23], in which special attention is focused on comparative analysis of production and investment characteristics of Russian regions by the fields of the oil and energy industries.

For implementing the simulation model of the FEFD economy, the AnyLogic system is used. In the papers [24; 25] AnyLogic is also used to simulate activities of the interregional underwriting center, as well as the behavior of the human crowd in emergencies. The distinctive feature of AnyLogic is the possibility to support system dynamics and agent-based modeling within one model [3].

The purpose of this research is to develop a decision support system for the sustainable economic development of the FEFD using simulation methods, so as to later develop optimal strategies to control the internal characteristics of the regions considered.

1. Simulation model of the socio-economic system of the FEFD

The conceptual model of the socio-economic system of the FEFD is shown in *Figure 1.*

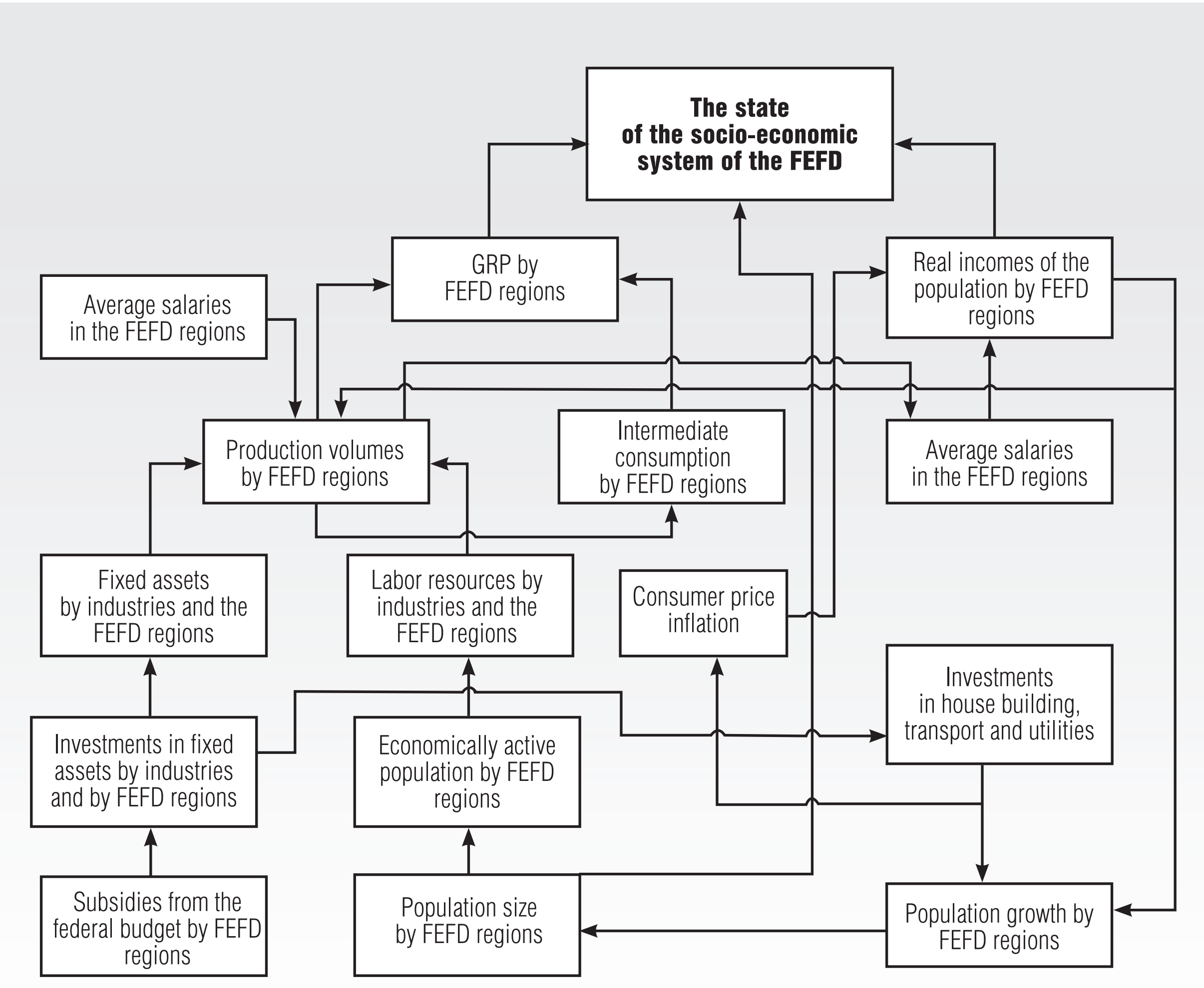

Fig. 1. Conceptual model of the socio–economic system of the FEFD

The most important characteristic of the proposed model is the state of the socio-economic system of the FEFD. It is estimated by classifying the regions into three groups, depending on the value of an integrated indicator. This indicator takes into account the GRP growth rate, population size and real incomes of the population. For each region of the FEFD, we will assign one of three possible states: favorable, satisfactory and unfavorable. It should be noted that the relationship between GRP and real incomes of the population is not sustainable, because real incomes of the population are formed under the influence of inflation, which, in turn, depends on the accessibility of goods and services for people. The unfavorable state of transport and social infrastructure in the FEFD leads to unreasonable overpricing and, as a result, significantly reduces real incomes of the population. Let us to remember that according to the Federal State Statistics Service[2] the rate of decline of real incomes of the population in the FEFD was 0.989 in 2015, and 0.935 in 2016. At the same time, the consumer price index was 112.0 and 105.4 respectively.

The distinctive feature of the proposed model is considering important feedbacks in the socio-economic systems of the FEFD. Such feedbacks include relationships between investments (in housing construction, transport and housing utilities), real incomes and population growth by region of the Federal District. The low population density is one of the important problems of the FEFD, which is explained, first of all, by the unfavorable state of transport and housing infrastructure.

Limited transport communications and geographical remoteness of the FEFD from the central and western parts of Russia lead to high cost of a fixed set of consumer products, which, according to data for 2016, amounted to 17,650 rubles (for comparison: in Moscow the cost of the consumer basket in 2016 was 20,714 rubles, and in St. Petersburg – 15,577.9 rubles). Therefore, for the FEFD regions, it is essential to increase investments in the fixed assets of all main industries, including manufacturing, construction, agriculture, transport, etc. At the same time, the economy of the FEFD regions significantly depends on the average export prices for its final products, in particular, oil, coal, iron ore, fishery products, etc. Under conditions of obvious deficit of labor resources, the regions of the FEFD need to develop capital-intensive enterprises with a high degree of automation of the main production processes. This is possible only if there are significant subsidies from the federal budget and relatively low costs of borrowed capital (low interest rates on loans).

Let us present a formal description of the simulation model of the FEFD regions which we developed. For this purpose, we introduce the following notations:

✦ $\tilde{T} \in \{t_1, t_2, ..., t_T\}$ is the set of model time indices by years, where T is the number of years within the strategic planning period (10 years);

✦ $\tilde{I} \in \{i_1, i_2, ..., i_I\}$ is the set of indices of the FEFD regions, where I is the number of regions (equals to 9);

✦ $\tilde{J}_i \in \{j_1, j_2, ..., j_{J_i}\}$ is the set of industries of the FEFD, where J_i is the number of industries in each i-th region;

✦ $\tilde{Z}_i$ is the set of indices of sub-industries of the FEFD related to housing construction, transport and housing utilities;

✦ $\{K_{j_i}(t), L_{j_i}(t)\}$ are fixed assets and labor resources in j_i-th industries of the FEFD at the time t, $j_i \in \tilde{J}_i$, $i \in \tilde{I}$, $t \in \tilde{T}$;

✦ $\{\alpha_{j_i}, \beta_{j_i}\}$ are production factors (elasticities of output by fixed assets and labor resources) in ji-th industries of the FEFD, $\alpha_{j_i} + \beta_{j_i} = 1$, $j_i \in \tilde{J}_i$, $i \in \tilde{I}$;

[2] Regions of Russia. Socio-economic indicators 2017. Statistical compilation

✦ A_{j_i} is the factor of scientific and technological progress in j_i-th industries of the FEFD, $j_i \in \tilde{J}_i, i \in \tilde{I}$;

✦ $\{\mathrm{Inv}_{j_i}(t),\ \delta\,\mathrm{Inv}_{j_i}(t),\ \delta B_{j_i}(t),\ \delta r_i(t)\}$ are investments in fixed assets of j_i-th industries, growth rate of investments (funding from local resources), rate of subsidies from the federal budget and rate of decreasing interest rates on loans, respectively, at time t, $j_i \in \tilde{J}_i,\ i \in \tilde{I},\ t \in \tilde{T}$;

✦ $\{V_{j_i}(t),\ \tilde{V}_{j_i}(t)\}$ are outputs expressed in physical and monetary terms in j_i-th industries of the FEFD at the time t, $j_i \in \tilde{J}_i, i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{G_{j_i}(t),\ \tilde{G}_{j_i}(t)\}$ are intermediate consumptions expressed in physical and monetary terms in j_i-th industries of the FEFD at the time t, $j_i \in \tilde{J}_i, i \in \tilde{I}, t \in \tilde{T}$;

✦ $g_{u_i j_i}(t)$ is the share of the product of ui-th industry of the economy ($u_i \in \tilde{J}_i$) required for the production of one product unit of j_i-th industry ($j_i \in \tilde{J}_i$) (i.e. the "input to output" matrix):

$$\sum_{u_i=1}^{J_i} g_{u_i j_i}(t) = 1\,;$$

✦ $\{p_{j_i}(t),\ h_{j_i}(t)\}$ are average domestic prices for final and intermediate products by j_i-th industries at the time t, $j_i \in \tilde{J}_i, i \in \tilde{I}, t \in \tilde{T}$;

✦ $e_{j_i}(t)$ is the average export prices of products by j_i-th industries at the time t, $j_i \in \tilde{J}_i, i \in \tilde{I}$, $t \in \tilde{T}$;

✦ $\{Ex_{j_i}(t),\ \delta ex_{j_i}(t)\}$ are the share of exports and the growth rate of the share of exports by products of j_i-th industries at the time t, $j_i \in \tilde{J}_i$, $i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{\inf_{j_i}(t),\ \delta\inf_{j_i}(t)\}$ are consumer price inflation and the rate of decreasing the inflation in j_i-th industries at the time t, $j_i \in \tilde{J}_i, i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{P_i(t),\ \delta\tilde{P}_i(t),\ \lambda_i(t)\}$ are the total population, the increase in the economically active population and its share in i-th regions of the FEFD at the time t, $i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{R_i(t),\ \delta s_i(t)\}$ are real incomes of the population and the rate of wage growth by FEFD region, in i-th regions of the FEFD at the time t, $i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{GDP_i(t),\ ST_i(t)\}$ are GRP and the state of the socio-economic system in i-th regions of the FEFD at the time t, $i \in \tilde{I}, t \in \tilde{T}$;

✦ $\{c_{1j_i},\ c_{2j_i},\ \ldots, c_{Nj_i}\}$ are regression coefficients calculated using the least square method (LSM), where N is the number of coefficients;

✦ $\{\mu_{1i},\ \mu_{2i}\}$ are coefficients of significance of real incomes of the population and the state of fixed assets (in housing construction, transport, housing utilities and municipal services) for the growth of population size.

Production of the final product expressed in physical terms is calculated using the well-known Cobb–Douglas function:

$$V_{j_i}(t) = A_{j_i}(t)\big(K_{j_i}(t)\big)^{\alpha_{j_i}}\big(L_{j_i}(t)\big)^{\beta_{j_i}} \quad (1)$$
$$j_i \in \tilde{J}_i,\ i \in \tilde{I},\ t \in \tilde{T},$$

Production of the final product expressed in monetary term is:

$$\tilde{V}_{j_i}(t) = p_{j_i}(t)\,V_{j_i}(t)\,\big(1 - Ex_{j_i}(t)\big) + \\ + e_{j_i}(t)\,V_{j_i}(t)\ Ex_{j_i}(t) \quad (2)$$

Prices for the final products in monetary term, taking inflation into account are:

$$p_{j_i}(t) = \inf_{j_i}(t)\,p_{j_i}(t-1). \quad (3)$$

The export share is:

$$Ex_{j_i}(t) = \delta ex_{j_i}(t)\,Ex_{j_i}(t-1). \quad (4)$$

The inflation index is calculated depending on the j_i-th industry beloning to housing construction, transport or to other industries:

$$\inf_{j_i}(t) = \begin{cases} c_{1j_i}\,V_{j_i}(t), \text{ if } j_i \in \tilde{Z}_i \\ \delta\inf_{j_i}(t)\ \inf_{j_i}(t-1), \text{ if } j_i \notin \tilde{Z}_i, \end{cases} \quad (5)$$

The volumes of intermediate consumption in physical and monetary terms are:

$$G_{j_i}(t)=\sum_{u_i=1}^{J_i} V_{u_i}(t) g_{u_i j_i}(t), \quad (6)$$

$$\tilde{G}_{j_i}(t)= h_{j_i}(t)\, G_{j_i}(t), \quad (7)$$

$$\sum_{u_i=1}^{J_i} g_{u_i j_i}(t)=1,$$

$$u_i \in \tilde{J}_i,\ j_i \in \tilde{J}_i,\ t \in \tilde{T}.$$

The volume of fixed assets, depending on the growth rate of investments in fixed assets is:

$$K_{j_i}(t)=K_{j_i}(t-1)+ \\ +\frac{1}{\delta r_i(t)}\,\delta \mathrm{Inv}_{j_i}(t)\ \delta B_{j_i}(t)\ \mathrm{Inv}_{j_i}(t-1) \quad (8)$$

The volume of labor resources, depending on the growth of the economically active population is:

$$L_{j_i}(t)=L_{j_i}(t-1)+c_{2 j_i}\,\delta \tilde{P}_i(t). \quad (9)$$

The increase in the economically active population depends on the total population size, which trends with people's quality of life in the region:

$$\delta \tilde{P}_i(t)=\lambda_i(t) P_i(t), \quad (10)$$

$$P_i(t)=P_i(t-1)+\mu_{1i}\, P_i(t-1)\, R_i(t)+\mu_{2i}\tilde{K}_i, \quad (11)$$

$$\tilde{K}_{j_i}(t)=\begin{cases}\sum_{j_i}^{J_i} K_{j_i}(t), \text{ if } j_i \in \tilde{Z}_i,\\ 0, \text{ if } j_i \notin \tilde{Z}_i.\end{cases} \quad (12)$$

Real income of the population is:

$$R_i(t)=\frac{1}{\mathrm{inf}_{j_i}(t)}\,\delta s_i(t)\ R_i(t-1). \quad (13)$$

The gross regional product by region of the FEFD, determined by the production method is:

$$GDP_i(t)=\sum_{j_i=1}^{J_i}\tilde{V}_{j_i}(t)-\tilde{G}_{j_i}(t). \quad (14)$$

The value of the integrated indicator determining the state of the socio-economic systems of the FEFD regions is:

$$F_i(t)=w_1\frac{GDP_i(t)}{\sum_{i=1}^{I} GDP_i(t)}+w_2\frac{P_i(t)}{\sum_{i=1}^{I} P_i(t)}+w_3\frac{R_i(t)}{\sum_{i=1}^{I} R_i(t)}$$

$$i \in \tilde{I},\ t \in \tilde{T}, \quad (15)$$

where $\{w_1, w_2, w_3\}$ are coefficients that determine priority of the appropriate indicators for the decision maker.

The state of the socio-economic systems of the FEFD regions is determined using assessment of the value of the integrated indicator:

$$ST_i(t)=\begin{cases}1, \text{ if } F_i(t)\ge \underline{F},\\ 2, \text{ if } \underline{\underline{F}} \le F_i(t) < \underline{F},\\ 3, \text{ if } F_i(t) < \underline{\underline{F}},\end{cases} \quad (16)$$

where $\{\underline{\underline{F}}, \underline{F}\}$ are threshold values for the integrated indicator, defined by the decision maker.

At the same time, the following control parameters of the model are used:

$$\delta \mathrm{Inv}_{j_i}(t), \delta B_{j_i}(t), \delta r_i(t), \delta \mathrm{inf}_{j_i}(t), \delta ex_{j_i}(t), \delta s_i(t).$$

Other characteristics (in particular, export prices) are exogenous (out-of-model); they can be considered as scenario parameters.

2. Results of simulation modeling

The proposed model of the socio-economic system of the FEFD (1)–(16) was implemented using the AnyLogic simulation system, which enables us to combine system dynamics methods and agent-based modeling within a single model. It allowed us to predict and visualize the state of agents (regions) depending on evaluating value of the integrated indicator (14). At the same time, the current states of agents (regions) are displayed on the map of Russia (*Figure 2*).

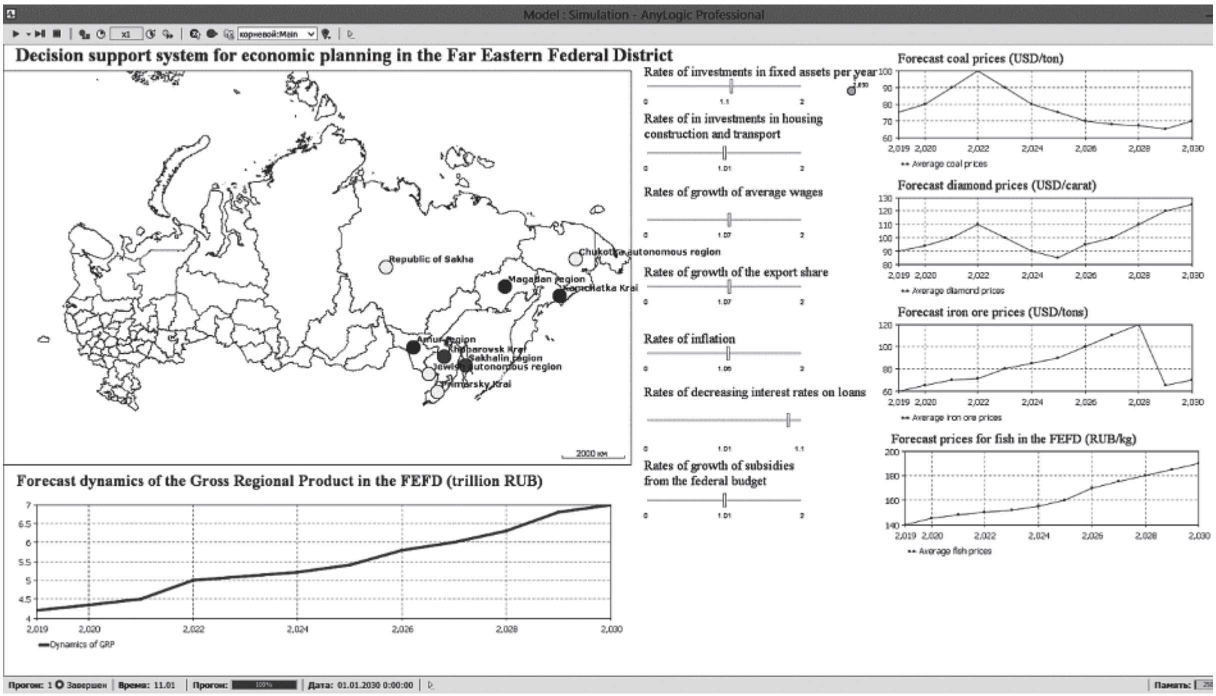

Fig. 2. Simulation model of socio–economic system of the FEFD in AnyLogic

At the same time, a "drill-down" mechanism is supported. It allows us to analyze the dynamics of the individual states of each specific region of the FEFD, for example, Khabarovsk Krai (*Figure 3*).

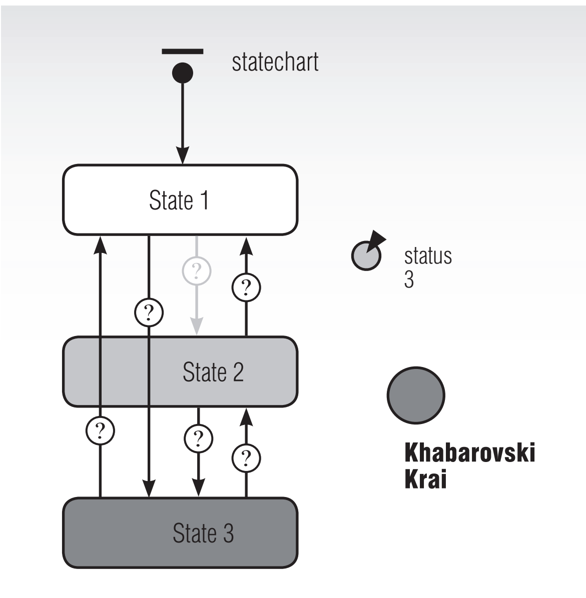

Fig. 3. The visualization of a state of the selected region (on the example of the Khabarovsk Krai)

Proceeding further, the following possible scenarios of the FEFD socio-economic system development were investigated:

Scenario 1: realistic; it assumes stabilization of prices for major energy resources (including oil, gas, coal) and minerals with parallel growth of investments in fixed assets;

Scenario 2: pessimistic; it is caused by falling prices for energy resources, diamonds, fishery products, etc., and a further reduction in the numbers of the economically active population in the FEFD;

Scenario 3: optimistic; it assumes stable growth of prices and demand for products of all main industries in the FEFD, while maintaining current growth rates in industry and agriculture.

The results of forecasting of GRP dynamics in the FEFD related with the scenarios considered are shown in *Figure 4.* It should be noted that all three considered scenarios provide stable increasing GRP for the FEFD, mainly due to increasing the production base, increasing

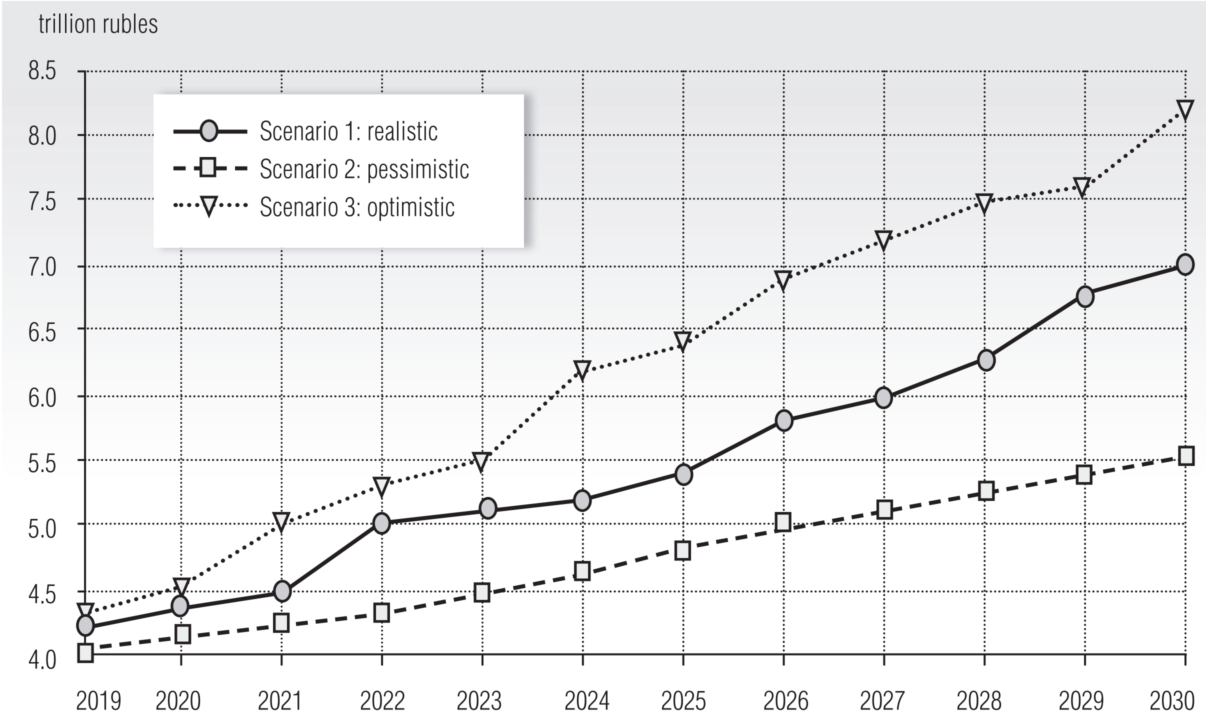

Fig. 4. Forecast dynamics of GRP of the FEFD determined using the proposed simulation model

the growth rate of investments in fixed assets, as well as reducing inflation and loan rates. Such conditions make it possible to achieve GRP growth, even under conditions of decreasing export prices and demand for products of the main industries of the FEFD. At the same time, a slight increase of the population size is possible, if people's real incomes rise and quality of life is improved.

Conclusion

This article presents the decision support system we developed for sustainable economic development of the Far Eastern Federal District (FEFD). An economic-math and simulation model of the socio-economic system of the FEFD (implemented using AnyLogic) is proposed. The main feature of the model is taking into account the most important feedback relations between main characteristics of regional socio-economic systems. Particularly, this concerns determining the relationships between investments in housing utilities, real incomes of the population and growth of the population size in the regions of the Federal District.

The system we developed allows for variable values of multiple control parameters, for example, growth rates of investments in fixed assets, growth rates of average wages, growth rates of subsidies from the federal budget, etc. It also allows us to visualize the current state of agents (regions) on the map of Russia.

Using the proposed model, forecasted GRP dynamics for the FEFD may be determined for various scenarios: realistic, pessimistic and optimistic.

The decision support system we developed can be used for simulation and analysis of the characteristics of other regions of the Russian Federation. Further research will be directed at development of similar models for all regions of Russia, as well as modeling appropriate relationships between them, including related to trade, migration, financial aspects, etc. ■

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