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Forecasting the Indicators of Scientific, Technological and Innovative Development of the Region Using Recurrent Neural Networks

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Abstract. The article forecasts indicators of scientific, technological and innovative development of a constituent entity of the Russian Federation and regional institutions of innovative development using recurrent neural networks. Forecasting using neural networks has become widespread and is a relevant, high-quality and reliable way of making economic forecasts and is applicable within the framework of socio-economic analysis, including analysis of territories. However, when studying the scientific literature, it was not possible to find works in which the scientific, technological and innovative development of regions was predicted using the neural network method, which determines the scientific novelty of the research being carried out. The relevance of the study is due to the increasing attention on the part of regional authorities to the scientific, technological and innovative development of territories and the need to form state programs of the constituent entities of the Russian Federation in the field of scientific and technological development. The research hypothesis is that forecasting indicators of scientific, technological and innovative development of the region and the activities of regional institutions for innovative development using recurrent neural networks will give more accurate results than using the linear regression method, moving average model or the Holt – Winters method. As part of the study, a recurrent neural network model was formed based on a system of interconnection of indicators of scientific, technological and innovative development of a constituent entity of the Russian Federation and regional institutions of innovative development. As a result, a forecast of indicators of scientific, technological and innovative development of a constituent entity of the Russian Federation and the activities of regional institutions for innovative development was obtained, which correlates with the real situation in this area.

Key words: regional scientific and technological policy, innovative development institutions, recurrent neural networks, forecasting, scientific and technological development indicators, regional economy.

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Introduction

At present, when attempts at structural shifts are being made in the Russian economy; attention to scientific, technological and innovative development in the regions of the country is increasing, and the role of the authorities of constituent entities of the Russian Federation in creating conditions for the progressive growth of a technological component of regional economies is increasing (Altyner et al., 2022). Evidence of a growing interest on the part of the federal authorities includes a series of instructions from the President of the Russian Federation; the Concept of Technological Development of the Russian Federation adopted in 2023; revision of the Strategy of Scientific and Technological Development of the Russian Federation; launching state programs on scientific and technological development in the regions. The attention of regional authorities to this issue can be emphasized by decrees of the heads of constituent entities of the Russian Federation[1], which raise issues of creating conditions for scientific, technological and innovative development. These

[1] On additional measures to stimulate investment activity in the Krasnoyarsk Territory and technological development of the region: Decree 283-ug of the Governor of the Krasnoyarsk Territory, dated September, 23, 2022; On declaring 2024 the year of scientific and technological development in the Republic of Tatarstan: Decree 639 of the Rais of the Republic of Tatarstan, dated September 14, 2023.

issues are also related to the activities of regional innovative development institutions, which have recently begun to be created in Russian regions (Dezhina, 2021; Golova, 2022; Myslyakova, 2022; Vasilieva et al., 2023; Egorov, Kovrov, 2023; Kuznetsova, 2023).

Forecasting scientific, technological and innovative development of Russian regions becomes relevant in the formation of regional state programs for scientific and technological development, as well as assessments of the performance of regional innovative development institutions (Shirov et al., 2016; Aganbegyan, 2019). The aim of the study is to design and test a technique for forecasting region's scientific, technological and innovative development using recurrent neural networks. A neural network is a mathematical model that is based on the principles of how the brain of living organisms works; that is, it consists of nodes (neurons) and their communication channels, each of which affects the result. A distinctive feature of a recurrent neural network compared to other architectures is that when predicting neurons, they take into account not only the current input, but also its previous state, and what happened to other neurons at previous inputs. The hypothesis of the study is that forecasting the indicators of region's scientific, technological and innovative development and the activities of regional institutions of innovative development using recurrent neural networks will produce more accurate results than using the linear regression method, the moving average model or the Holt – Winters method, due to the possibility of training the network and taking into account more interrelated variables when making a forecast.

Literature review

Currently, forecasting scientific, technological and innovative development, as well as using artificial intelligence methods in economic research, is gaining great popularity (Coates et al., 2001; Bengisu, Nekhili, 2006). One of these approaches is the use of neural network models. Forecasting based on neural network models is carried out to consider the dynamics of regions' socio-economic indicators, modeling the structure and dynamics of human capital, forecasting solar energy generation, forecasting energy consumption and in many other areas (Fedotov, Semenkin, 2014; Ketova et al., 2020; Pazikadin et al., 2020; Ghaith et al., 2021; Jin et al., 2022).

A review of the scientific literature on forecasting using neural network models indicates the high accuracy and adequacy of the method. In a study led by T.V. Azarnova, the authors predict socio-economic development parameters of the Voronezh Region and conduct neural network training over a retrospective period. As a result, the adequacy of the forecast to the real economic processes in the region is stated. When comparing the forecast of the neural network and the forecast of experts in relation to the indicator of gross regional product, the authors note that the forecast of the neural network is more cautious, while it is impossible to give preference to either of the methods (Azarnova et al., 2020).

Using neural networks, O.V. Kitova clarifies the data of a forecast of tourism indicators in regions with coal mining, obtained using linear regression. The author concludes that neural networks provide higher accuracy and quality of prediction (Kitova et al., 2023; Kitova et al., 2016).

Yu.V. Trifonov used a neural network model to forecast economic potential of Russia's regions. The model used allows calculating indicators and process large amounts of information quickly, efficiently and accurately (Trifonov et al., 2021).

Jiayou Qiu and co-authors use neural networks with an attention mechanism to predict stock prices. The authors note that the model based on neural networks has a wide application prospect and is not inferior to existing classical forecasting methods (Qiu et al., 2019).

Qing Zhang uses a neural network with a radial basis function in combination with a genetic algorithm to forecast the gross regional product of Shandong Province. The authors conclude that the use of neural networks to predict gross regional product is appropriate and reliable (Zhang et al., 2022).

In a study by A.V. Babkin, a comparative assessment of the effectiveness of various forecasting methods is carried out using the example of forecasting the socio-economic development of the Astrakhan Region. As a result, it is concluded that forecasting using neural networks shows fewer errors and a higher degree of objectivity (Babkin et al., 2015).

Forecasting regions' scientific, technological and innovative development is starting to gain popularity; therefore, researchers use mainly classical forecasting methods – the foresight and extrapolation method.

An example of works devoted to forecasting regions' scientific, technological and innovative development can be found in a study by D.A. Alferyev, who suggests using the foresight method. The author concludes that the use of the foresight method for long-term forecasting is effective and with its help it is possible to form not only the forecast itself, but also the ways of its implementation (Alferyev, 2018). In addition, the foresight method is considered for forecasting in a number of works by other authors (Belyakov, Shumakov, 2018; Shelomentseva et al., 2015). However, this method has its drawbacks, it is an expert method; therefore, the human factor and the quality of the expert group are of great importance in making a forecast. The researchers also note that in the case of making a forecast for a region, a special methodology is needed for each region, taking into account its characteristics.

D.A. Endovitsky forecasts the dynamics of region's innovative development using extrapolation of data. By analyzing the initial data and the obtained forecast, the author concludes that the proposed method does not allow making any reliable forecast of innovative development dynamics, since functional diversification in its composition is not showing stable development (Endovitsky et al., 2023).

Thus, the currently used methods of forecasting scientific, technological and innovative development have some disadvantages; this fact necessitates searching for new relevant forecasting methods.

Forecasting using neural networks has become widespread and is an up-to-date, high-quality and reliable way of making economic forecasts, applicable in the framework of socio-economic analysis, including the analysis of territories. At the same time, it was not possible to find works in which the forecasting of regions' scientific, technological and innovative development was carried out using the method of neural networks, which determines scientific novelty of the research.

Materials and methods

To form the forecast, we chose a model of the system of regional innovative development institutions, which includes several agents: scientific and innovation fund, business incubator and technopark. Such a system of innovative development institutions located on the territory of a constituent entity of the Russian Federation allows solving scientific and technological problems that are most relevant in the region, but not covered at the federal level, as well as providing support measures for projects at all levels of technology readiness and creating a comfortable and attractive environment in the region for the development of science, technology and innovation (Byvshev, 2024; Mazilov et al., 2020).

The Krasnoyarsk Territory was chosen as a model constituent entity of the Russian Federation, since it has two of the three regional innovative development institutions designated in the model – the Krasnoyarsk Regional Fund for Support of Scientific and Scientific-Technical Activities (KRFS) and the Krasnoyarsk Regional Innovative and Technological Business Incubator

(KRITBI), scientific, technological and innovative potential available in the region, confirmed, among other things, by the national rating of scientific and technological development of RF constituent entities[2] (2021 – 25th place, 2022 – 21st place). The technopark's activity in the region was forecasted during the research process.

The research materials included statistical data from the official information portals of the KRFS[3], KRITBI[4], associations of technoparks of Russia[5], data from Rosstat[6] and the Federal Tax Service unified register of small and medium-sized businesses[7]. In order to ensure data comparability, the minimum period of 2020–2022 was used to make the forecast.

The scientific, technological and innovative development of RF constituent entities, including the model region – Krasnoyarsk Territory – can be characterized using a system of indicators reflecting, among other things, the performance of regional innovative development institutions *(Tab. 1)*.

The system of indicators that we use is based on publicly available data from open sources of Rosstat and the Federal Tax Service of Russia. The selection of indicators for the system was carried out by analyzing the works of N.I. Komkov, Wang Yushan, V.G. Basareva, as well as ratings of scientific, technological and innovative development[8] and target indicators of the activities of regional innovative development institutions[9] (Basareva, 2019; Komkov et al., 2019; Wang, 2021).

The activities of regional innovative development institutions are characterized by a system of indicators in accordance with their statutory goals and objectives, as well as indicators included in the state program of the region from which funding is provided *(Tab. 2, 3)*.

Table 1. System of indicators characterizing scientific, technological and innovative development of the Krasnoyarsk Territory

Indicator code	Indicator	2020	2021	2022
1r	Internal research and development costs from all sources, billion rubles	26.60	29.56	36.50
2r	Advanced production technologies used, units	3932	4145	4421
3r	Number of applications for the results of intellectual activity, units	536	489	508
4r	Number of researchers under 39 years old, people	2164	2125	2183
5r	Number of small and medium-sized businesses operating in the scientific, technological and innovative fields, units	210	218	216
6r	Volume of innovative goods, works, services, billion rubles	135.37	92.42	98.00
Source: own elaboration.				

[2] National rating of scientific and technological development of constituent entities of the Russian Federation. Available at: https://clck.ru/34MTeK (accessed: February 24, 2024).

[3] Official Internet portal of the Krasnoyarsk Regional Fund for Support of Scientific and Scientific-Technical Activities. Available at: https://clck.ru/393GkA (accessed: February 24, 2024).

[4] Official Internet portal of the Krasnoyarsk Regional Innovative and Technological Business Incubator. Available at: https://kritbi.ru/doc (accessed: February 24, 2024).

[5] Official Internet portal of the Association of Clusters, Technoparks and SEZ of Russia. Available at: https://akitrf.ru/ (accessed: February 24, 2024).

[6] Official Internet portal of Rosstat. Available at: https://24.rosstat.gov.ru/folder/27085 (accessed: February 24, 2024).

[7] Federal Tax Service unified register of small and medium-sized businesses. Available at: https://ofd.nalog.ru/ (accessed: February 24, 2024).

[8] The rating of innovative development of constituent entities of the Russian Federation. Issue 7 of the Higher School of Economics, 2021; Methodology of the national rating of scientific and technological development of constituent entities of the Russian Federation. RF Ministry of Science and Higher Education. Available at: https://clck.ru/32hVJh

[9] On the approval of the state program of the Krasnoyarsk Territory "Development of small and medium-sized enterprises and innovative activities": Resolution 505-p of the Government of the Krasnoyarsk Territory, dated September 30, 2013.

Table 2. System of indicators characterizing the activities of the KRFS

Indicator code	Indicator	2020	2021	2022
1f	R&D funding from the regional budget, billion rubles	0.15	0.09	0.20
2f	Funds from the regional budget for the provision of activities, billion rubles	0.02	0.02	0.02
3f	Amount of funds raised via co-financing, billion rubles	0.14	0.17	0.11
4f	Number of applications for the results of intellectual activity, units	34	35	38
5f	Number of researchers under 39 years old, people	789	576	444
6f	Number of research and technological developments, units	14	14	14
Source: own elaboration.				

Table 3. System of indicators characterizing the activities of KRITBI

Indicator code	Indicator	2020	2021	2022
1i	Funds from the regional budget for the provision of activities, billion rubles	0,11	0,11	0,08
2i	Amount of funds raised via co-financing, billion rubles	0,18	0,37	0,18
3i	Number of innovative small and medium-sized businesses created, units	16	16	16
Source: own elaboration.				

The KRFS activities are aimed at providing financial support for the scientific, technological and innovative sphere of the Krasnoyarsk Territory by issuing grant funding on a competitive basis for the implementation of projects. The indicators characterizing the activities of this regional innovative development institution are financial and performance indicators, as well as indicators of coverage of the activities of participants in scientific, technological and innovative processes in the region.

KRITBI's activities are aimed at promoting the development of small and medium-sized businesses in the scientific, technological and innovative fields. Its activities are characterized by financial indicators and indicators of environment formation.

To forecast the technopark's activity and assess its potential contribution to the scientific, technological and innovative development of the Krasnoyarsk Territory on the basis of summary data

Table 4. Performance indicators of technoparks in Russia

No.	Indicator	2020	2021	2022
1	Number of technoparks in the Russian Federation, units	183	129	113
2	Number of regions that have technoparks, units	54	39	33
3	Number of applications for intellectual property objects created by residents of technoparks, units	2 222	1 782	1 018
4	Volume of innovative goods, works, and services shipped (performed) by residents of technoparks, million rubles	71 471,04	72 298,31	73 296,53
5	Volume of innovative goods, works, and services shipped (performed) in the regions where technoparks operate, million rubles	4 723 052,80	4 918 069,00	4 994 516,40
6	Number of intellectual property objects registered in the regions where technoparks operate, units	23364	20 088	19 440
7	Internal research and development costs from all sources in the regions where technoparks operate, billion rubles	1 118.60	1 132.00	1 224.20
8	The amount of R&D costs by residents of technoparks, million rubles	33 875	41 719	50 820
9	Investments in the infrastructure of technoparks from regional budgets per technopark, billion rubles	0.16	0.25	0.30
Source: own elaboration.				

on the activities of technoparks in Russia, formed by the Association of Clusters, Technoparks and Special Economic Zones *(Tab. 4)*, an algorithm was formed for calculating the values of indicators characterizing the activities of this type of regional innovative development institutions.

At the first stage of the algorithm, the average relative contribution of the activities of one technopark to the scientific, technological and innovative development of the territories where technoparks operate is calculated in the context of the corresponding indicators for the period from 2020 to 2022 *(Tab. 5)*:

$$\lambda = \frac{\sum_{i=1}^{n} \frac{I_{\text{tech}}^{i}}{\alpha^{i}}}{\sum_{i=1}^{n} \frac{I_{\text{reg}}^{i}}{\beta^{i}}}, \qquad (1)$$

where:

i – index of year (data were used for three years: 2020, 2021, 2022);

n – number of years for which the indicators are used in the study;

I_{tech}^{i} – value of the indicator of technoparks' activity for the i-th year;

I_{reg}^{i} – value of the indicator of scientific, technological and innovative development in the regions where technoparks operate for the i-th year;

α^{i} – number of technoparks in Russia in the i-th year;

β^{i} – number of Russia's regions where technoparks operate in the i-th year;

λ – share of the technopark's contribution to the region's scientific and technological development.

As a result, we obtain average relative values, on the basis of which we calculate the estimated values of performance indicators for one technopark in the Krasnoyarsk Territory in 2020–2022 *(Tab. 6)*:

$$I_{\text{tech\_KT}} = I_{\text{KT}} \times \lambda, \qquad (2)$$

where:

$I_{\text{tech\_KT}}$ – value of the indicator obtained as a result of the work of the technopark;

I_{KT} – value of the indicator characterizing the scientific, technological and innovative development of the Krasnoyarsk Territory;

λ – share of the technopark's contribution to the region's scientific, technological and innovative development.

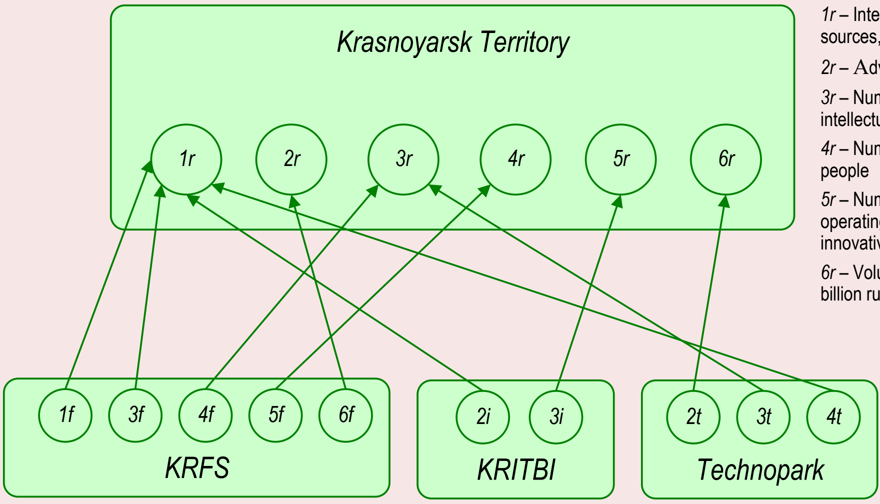
Table 5. Share of the technopark's contribution to the scientific, technological and innovative development of the region where the technopark operates

No.	Indicator	λ
1	Share of innovative goods, works, services shipped (provided), created in technoparks, %	0.4
2	Share of applications for the results of intellectual activity created by residents of technoparks, %	2.3
3	Share of internal research and development costs by residents of technoparks from all sources in the regions where technoparks operate, %	1.1
Source: own elaboration.		

Table 6. Potential values of technopark activity in the Krasnoyarsk Territory

Indicator code	Indicator	2020	2021	2022
1t	Funds from the regional budget for the provision of activities, billion rubles	0.16	0.25	0.30
2t	Volume of innovative goods, works, services, billion rubles	0.54	0.37	0.39
3t	Number of applications for the results of intellectual activity, units	12	11	12
4t	Internal research and development costs, billion rubles	0.29	0.33	0.40
Source: own elaboration.				

System of interrelation of performance indicators of regional innovative development institutions and upper-level indicators of scientific, technological and innovative development of the constituent entity of the Russian Federation



1r – Internal research and development costs from all sources, billion rubles

2r – Advanced production technologies used, units

3r – Number of applications for the results of intellectual activity, units

4r – Number of researchers under 39 years old, people

5r – Number of small and medium-sized businesses operating in the scientific, technological and innovative fields, units

6r – Volume of innovative goods, works, services, billion rubles

1f – R&D funding from the regional budget, billion rubles

3f – Amount of funds raised via co-financing, billion rubles

4f –Number of applications for the results of intellectual activity, units

5f – Number of researchers under 39 years old, people

6f – Number of research and technological developments, units

2i – Amount of funds raised via co-financing, billion rubles

3i – Number of innovative small and medium-sized businesses created, units

2t – Volume of innovative goods, works, services, billion rubles

3t – Number of applications for the results of intellectual activity, units

4t – Internal research and development costs, billion rubles

Source: own compilation.

The technopark's activity is characterized by financial indicators and indicators reflecting the performance of scientific, technological and innovative activities. The data obtained will be used to calculate the forecast values of the technopark as part of the regional system of innovative development institutions.

Each indicator characterizing the activities of regional innovative development institutions is associated with upper-level indicators characterizing the region's overall scientific, technological and innovative development. Based on these connections, a model used in the neural network was compiled *(Figure)*.

The presented relationships of the indicators are determined by the logic of regional innovative development institutions' activities, as well as regional normative legal acts that contain performance indicators for each institution.

After determining the interrelationships between the system of indicators for the scientific, technological and innovative sphere of the RF constituent entity and regional innovative development institutions, we proceed to the forecasting process based on a neural network. Let us describe the operation of the neural network with the following function:

$$sign\ (w_0 + w_1 x_1 + w_2 x_2 + \cdots + w_d x_d). \quad (3)$$

To forecast time series, a model is needed that will not perceive inputs as independent variables. The recurrent neural network takes into account not only the current value of the series, but also the previous ones. In the presented model, the output of a neural network depends on the three previous input values. That is, the implemented model works with its three previous calculations:

$$\begin{gathered} y_i = f(x_{i-3}, x_{i-2}, x_{i-1}, s_2) = \\ = f\big(x_{i-3}, x_{i-2}, x_{i-1}, h(x_{i-4}, x_{i-3}, x_{i-2}, s_1)\big) = \\ = f\Big(x_{i-3}, x_{i-2}, x_{i-1}, h\big(x_{i-4}, x_{i-3}, x_{i-2}, \\ h(x_{i-5}, x_{i-4}, x_{i-3}, s_0)\big)\Big), \end{gathered} \quad (4)$$

where s_0 – initial state of the network (hidden state of the neural network, which depends on its states at the previous calculation steps and the current input, in this case, the zero vector);

f – function containing network parameters (number of layers, number of neurons on each layer, etc.);

h – activation function;

$X = (x_1, x_2, \ldots, x_d)$ – input data of the neural network. Within the framework of this study, multidimensional time series were applied to the input of the neural network.

Neural network models were trained using gradient methods (Adam, AdamW, RMSProp).

Before building neural network models, input data was preprocessed in two stages.

The first stage, data augmentation, was carried out by the method of local polynomial interpolation (formula 5):

$$F(X) = a_0 + a_1 \times x + a_2 \times x^2 + \cdots + a_m \times x^m, \quad (5)$$

where $X = (x_1, x_2, \ldots, x_m)$ – ordinal number of the indicators of innovative development institutions, on the basis of which the polynomial is constructed.

Based on the constructed interpolation polynomial, data augmentation is performed by changing the intensity of augmentation:

$$F(X) = a_0 + a_1 \times x + a_2 \times x^2. \quad (6)$$

After the augmentation stage, an expanded data set was obtained, on the basis of which a neural network model will be built.

The second stage is data scaling. Scaling is performed according to the formula:

$$x_{new} = \frac{(x_i - x_{min})}{(x_{max} - x_{min})}, \quad (7)$$

where x_i – i-th value in the dataset;

x_{max} – maximum value in the dataset;

x_{min} – minimum value in the dataset.

As a result of the scaling, we get a data set that lies in the range from 0 to 1.

In the course of the research, a comprehensive model based on neural networks was developed to predict each indicator of scientific, technological and innovative development for a constituent entity of the Russian Federation and the system of regional innovative development institutions. Data on the number of layers, number of neurons and types of activation function are presented in *Table 7.*

The model was built using the following algorithm: 1. Dividing historical data into a training sample and a test sample in the ratio of 79:21; the training sample for the Krasnoyarsk Territory[10] used the values of Rosstat indicators since 2009; the values of indicators since 2009 were also used for the KRFS[11]; and for the indicators we used the number of researchers under 39 years old and the number of scientific and technological developments – from 2016 and 2017 respectively;

[10] Official Internet portal of Rosstat. Available at: https://24.rosstat.gov.ru/folder/27085 (accessed: February 24, 2024).

[11] Official Internet portal of the Krasnoyarsk Regional Fund for Support of Scientific and Scientific-Technical Activities. Available at: https://clck.ru/3BBNHR (accessed: February 24, 2024).

Table 7. Main characteristics of the recurrent neural networks we have developed

Indicator code	Number of hidden layers	Number of neurons in each layer	Activation function
Krasnoyarsk Territory			
1r	3	[9,6,5]	sigmoid
2r	5	[6,12,5,6,3]	hyperbolic tangent
3r	6	[12,10,8,6,8,8]	sigmoid
4r	4	[11,9,6,4]	
5r	2	[8,4]	
6r	3	[9,4,5]	
KRFS			
1f	5	[6,7,5,2,2]	sigmoid
2f	5	[8,9,7,3,2]	
3f	3	[10,8,5]	
4f	7	[8,6,5,9,5,4,3]	
5f	6	[5,6,8,7,3,2]	
6f	4	[4,3,5,5]	
KRITBI			
1i	6	[8,9,6,5,6,4]	hyperbolic tangent
2i	8	[8,5,6,6,6,7,8,9]	
3i	3	[3,3,4]	sigmoid
Technopark			
1t	5	[8,6,5,3,3]	sigmoid
2t	5	[10,7,5,6,2]	
3t	3	[8,5,3]	
4t	4	[6,5,5,2]	
Source: own elaboration.			

for KRITBI[12] and Technopark[13] – the augmented values of indicators from 2020 to 2022; for the test sample we used the values of indicators for all agents in 2020–2022.

2. Architecture selection and adjustment of the weight coefficients of neural network models on the training dataset using gradient methods (Adam, AdamW, RMSProp). That is, the training proceeds as follows: a neural network model is launched on a set of test data, with single weight coefficients; then the value of the loss function is calculated and, using gradient methods, the direction in which it will be less is determined; that is, the lower the value of the target function, the more accurate the forecast.

[12] Official Internet portal of Krasnoyarsk Regional Innovative and Technological Business Incubator. Available at: https://kritbi.ru/doc (accessed: February 24, 2024).

[13] Official Internet portal of the Association of Clusters, Technoparks and SEZ of Russia. Available at: https://akitrf.ru/ (accessed: February 24, 2024).

3. Making a forecast and checking the accuracy of the model on a test dataset.

At the forecasting stage, the tenth forecast value of KRITBI models was used to compare all indicators by year, since the intensity of augmentation is 10.

The mean absolute percentage error (MAPE) was used as a metric to determine the accuracy of the forecast of the neural network model, since it is one of the most common metrics used in calculating the percentage of forecasting error.

$$MAPE = \frac{1}{N}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|, \qquad (8)$$

where:

n – size of the training sample;

A_t – actual value;

F_t – forecast value.

Table 8. Forecast for the scientific, technological and innovative development indicators of the Krasnoyarsk Territory and regional innovative development institutions

Indicator code	Forecast							
	2023	2024	2025	2026	2027	2028	2029	2030
Krasnoyarsk Territory								
1r	43.61	51.37	55.05	65.88	69.90	76.42	80.37	84.41
2r	4538	4751	4838	5263	5324	5581	5602	5641
3r	532	575	581	613	616	658	682	699
4r	2208	2224	2229	2401	2428	2498	2536	2561
5r	218	221	221	223	223	224	224	224
6r	102.24	112.11	114.76	126.84	130.88	138.48	140.09	141.69
KRFS								
1f	0.25	0.18	0.22	0.27	0.29	0.36	0.37	0.41
2f	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.07
3f	0.17	0.18	0.19	0.20	0.23	0.28	0.29	0.30
4f	38	39	39	40	41	43	43	43
5f	621	579	602	625	626	633	639	645
6f	16	16	16	17	17	17	18	19
KRITBI								
1i	0.09	0.12	0.13	0.14	0.15	0.18	0.18	0.19
2i	0.33	0.26	0.27	0.34	0.37	0.40	0.42	0.42
3i	17	17	17	18	18	19	19	19
Technopark								
1t	0.38	0.39	0.40	0.41	0.42	0.46	0.48	0.50
2t	0.43	0.45	0.52	0.54	0.59	0.63	0.64	0.68
3t	12	12	12	13	13	14	14	14
4t	0.46	0.52	0.58	0.73	0.76	0.78	0.85	0.85
Source: own elaboration.								

The average forecasting accuracy of the obtained neural network model based on test historical data is 91.53%. For comparison, a forecast was made using other methods, the average accuracy on similar data for the linear regression method was 79.94%, the moving average was 76.87%, and the Holt – Winters method was 81.14%, which indicates the advantage of the applied method in terms of accuracy. In addition, a significant advantage of this method is the ability to take into account the relationships between a large number of indicators that affect the forecast.

As a result, a model of scientific, technological and innovative development for a constituent entity of the Russian Federation with a system of regional innovative development institutions, consisting of several agents, is implemented in the form of a software system – a recurrent neural network, with the help of which a forecast is made.

Empirical analysis of forecasting results for the scientific, technological and innovative development of the Krasnoyarsk Territory

The conducted research made it possible to make a forecast of the dynamics of indicators characterizing the scientific, technological and innovative sphere of the Krasnoyarsk Territory, as well as the performance of regional innovative development institutions and to predict the effects of creating a technopark on the territory of a model constituent entity of the Russian Federation. Table 8 shows the result of the work of the implemented system; the indicator number corresponds to the numbers in the description of the agents.

The cumulative dynamics of all indicators used in the study characterizing the scientific and technological development of the Krasnoyarsk Territory and the activities of regional innovative development institutions, including the modeled performance indicators of the technopark, have a positive trend and reflect high dynamics of scientific, technological and innovative development indicators for the Krasnoyarsk Territory in the perspective until 2030.

The base period used to make the forecast (2020–2022) takes into account two years with crisis trends for the country's economy: 2020 – the beginning of the COVID-19 pandemic and 2022 – the beginning of sanctions pressure on the economy of the Russian Federation by unfriendly countries. It is worth noting that in 2020, one of the key indicators characterizing the scientific, technological and innovative development of territories – internal research and development costs from all sources – decreased by only 1.85% in comparison with 2019 in the Krasnoyarsk Territory, while in 2022 it increased by 23.5 compared to 2021%, and in comparison with the pre-crisis year 2019 – by 34.7%. This indicates a minor impact of crisis phenomena on the area under consideration.

Let us look at the results of the forecast regarding the performance indicators of the scientific, technological and innovative sphere in the Krasnoyarsk Territory. The number of applications for the results of intellectual activity in 2030 will grow by 37.6% compared to 2022; regional innovative development institutions will provide 12.3% of this indicator. The number of advanced manufacturing technologies used will increase by 27.6%, but the share of regional innovative development institutions in the value of this indicator will remain insignificant. The volume of innovative goods, works and services will grow by 44.6%, while the activity of the technopark projected on the territory of the model region will provide 1.88% of the volume of the indicator. The growth rate of performance indicators of the scientific, technological and innovative sphere is significantly lower than the growth rate of the indicator of financial support for the sphere under consideration, which indirectly indicates high inflation rates during the forecast period, as well as wage growth in the scientific, technological and innovative sphere. The increase in wages is consistent with the Address of the President of the Russian Federation to the Federal Assembly, which indicates the need to convert the country's GDP growth into an increase in household incomes.

The trends identified on the basis of the forecast prove that the crisis phenomena did not affect the scientific, technological and innovative sphere of the region in a special way; moreover, they created prerequisites for its development, consisting in the need to solve problems and overcome challenges faced by Russian society, including with the help of scientific, technological and innovative spheres. Such a high dynamics of indicators reflected in the forecast does not look fantastic for the Krasnoyarsk Territory. The growth of domestic research and development costs during the forecast period is supported by the current growth of investments in the region's economy. According to this parameter, by the end of 2023, the region ranks 7th in the Russian Federation and 1st in the Siberian Federal District, while the largest increase in investment activity of organizations in 2023 was recorded in the scientific, technological and innovative sphere[14]. Thus, the growth of internal research and development costs will also ensure the growth of performance indicators in the field, such as the results of intellectual activity, innovative goods, works, services and advanced production technologies, which in turn will have a positive impact on the region's socio-economic development.

[14] The growth of investments in the Krasnoyarsk Territory by the end of 2023 amounted to 23%. Yenisey Siberia Development Corporation. Available at: https://clck.ru/39h6k7 (accessed: March 27, 2024).

The growth in the number of researchers up to 39 years old, presented in the forecast, also looks quite achievable. The main part of scientific, research and innovative organizations is concentrated in the capital of the region, Krasnoyarsk, which, unlike the entire region, which has a negative population dynamics that decreased by 0.9% in the period from 2018 to 2022, is characterized by its positive growth. During the same period, the population of Krasnoyarsk increased by 9.2%, which provides a high potential for growth in the number of researchers under the age of 39.

Conclusion

Within the framework of the study, we proposed and tested a methodological approach to forecasting indicators of scientific, technological and innovative development of the region and the activities of regional innovative development institutions based on recurrent neural networks, which are an element of artificial intelligence. Its integration into various public spheres helps to make optimal decisions for the management of companies and industries in general, which makes it possible to use the proposed methodological approach to generate forecasts of indicators of regional scientific, technological and innovative development within the framework of the development of strategic and program documents at the regional level in the field under consideration, including regional state programs for scientific and technological development that are currently being designed in the regions as was instructed by the President of the Russian Federation.

Having tested the proposed methodological approach, we revealed its advantage over such forecasting methods as linear regression method, moving average model or the Holt – Winters method in terms of the accuracy of forecast values and the ability to take into account the relationship between a large number of indicators, which in turn increases the accuracy of the forecast.

The forecast values obtained during the research look realistic due to their consistency with the targets set by strategic and program documents for the scientific, technological and innovative sphere, as well as compliance with the currently implemented policy aimed at import substitution. In addition, the scientific, technological and innovative sphere has shown low dependence on the crisis phenomena of the beginning of the current decade, which indirectly confirms its resistance to possible crisis phenomena of the future.

The positive dynamics of scientific, technological and innovative development indicators reflects the tendency toward increasing the level of technological effectiveness of the Krasnoyarsk Territory's economy, expressed in an increase in R&D costs and an increase in human capital characterized by a growth in the number of researchers up to 39 years old, as opposed to a decrease in the total population of this age group due to the low birth rate in the Krasnoyarsk Territory in 1991–2007. The indicated growth will be carried out by increasing the attractiveness of the scientific, technological and innovative sphere for the younger generation in comparison with the traditional areas of employment for the region, as well as attracting residents of neighboring constituent entities of the Russian Federation to the region. Positive trends in science, technology and innovation reflect the overall positive socio-economic development in the region, which will confirm the status of one of the leading economic centers of Siberia and the Far East.

The activities of regional innovative development institutions have a positive effect on the growth of indicators of the scientific, technological and innovative spheres, while their relative contribution to the development of the sphere remains at a level comparable to the base period, which proves the stability and relative independence of the scientific, technological and innovative sphere of the region.

References

Aganbegyan A.G. (2019). Analysis and forecasting of socio-economic development of regions (methodical notes). *Srednerusskii vestnik obshchestvennykh nauk*, 17(14), 15–28. DOI: 10.22394/2071-2367-2019-14-4-15-28 (in Russian).

Alferyev D.A. (2018). Theory and practical academy of scientific and technological development. *Upravlenie investitsiyami i innovatsiyami*, 1, 5–16. DOI: 10.14529/iimj180101 (in Russian).

Altiner A., Bozkurt E., Topcuoglu O. (2022). The impact of R&D expenditures on high-tech product exports. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz=Economic and Social Changes: Facts, Trends, Forecast,* 15(5), 153–169. DOI: 10.15838/esc.2022.5.83.8 (in Russian).

Azarnova T.V., Treshchevskii Yu.I., Papin S.N. (2020). Forecasting the parameters of socio-economic development of the region using the apparatus of neural networks (on the example of the GRP of the Voronezh Region). *Sovremennaya ekonomika: problemy i resheniya=Modern Economics: Problems and Solutions*, 3(123), 8–25. DOI: https://doi.org/10.17308/meps.2020.3/2321 (in Russian).

Babkin A.V., Karlina E.P., Epifanova N.S. (2015). Neural networks as a tool of forecasting of socioeconomic systems strategic development. *Procedia-Social and Behavioral Sciences*, 207, 274–279.

Basareva V.G. (2019). Small innovative enterprises in regions: Strategic orientations and tactics for achieving them. *Region: Ekonomika i Sotsiologiya=Region: Economics and Sociology,* 2(102), 224–245. DOI: 10.15372/REG20190210 (in Russian).

Belyakov G.P., Shumakov F.P. (2018). Special features for forecasting the scientific and technological development of the region. *Aktual'nye problemy aviatsii i kosmonavtiki*, 2(4)(14), 773–775 (in Russian).

Bengisu M., Nekhili R. (2006). Forecasting emerging technologies with the aid of science and technology databases. *Technological Forecasting and Social Change*, 73(7), 835–844. DOI https://doi.org/10.1016/j.techfore.2005.09.001

Byvshev V.I. (2024). Formation of a model of scientific, technological and innovation policy in the constituent entity of the Russian Federation. *Zhurnal Sibirskogo federal'nogo universiteta. Seriya: Gumanitarnye nauki= Journal of SibFU.* Humanities & Social Sciences, 17(1), 117–136 (in Russian).

Coates V., Farooque M., Klavans R. et al. (2001). On the future of technological forecasting. *Technological Forecasting and Social Change*, 67(1),1–17. DOI https://doi.org/10.1016/S0040-1625(00)00122-0

Dezhina I.G. (2021). Picking winners in modern Russian science policy. *Voprosy gosudarstvennogo i munitsipal'nogo upravleniya=Public Administration Issues*, 3, 53–74 (in Russian).

Egorov N.E., Kovrov G.S. (2023). Analysis of rating methods for assessing the scientific and technological development of the Federal districts of the Russian Federation. *MIR (Modernizatsiya. Innovatsii. Razvitie)= MIR (Modernization. Innovation. Research)*, 14(4), 698–715. DOI: 10.18184/2079-4665.2023.14.4.698-715 (in Russian).

Endovitsky D.A., Treshchevsky Yu.I., Kanapukhin P.A., Kosobutskaya A.Yu. (2023). Empirical analysis and forecasting of the dynamics of the innovative development of Russian regions. *Vestnik VGU. Seriya: Ekonomika i upravlenie=Proceedings of Voronezh State University. Series: Economics and Management,* 1, 51–64. DOI: 10.17308/econ.2023.1/10932 (in Russian).

Fedotov D.V., Semenkin E.S. (2014). On forecasting economic indicators using neuroevolutionary models. *Sibirskii aerokosmicheskii zhurnal*, 5(57), 299–304 (in Russian).

Ghaith Z., Kulshreshtha S., Natcher D., Cameron B.T. (2021). Regional computable general equilibrium models: A review. *Journal of Policy Modeling*, 43(3), 710–724. DOI: https://doi.org/10.1016/j.jpolmod.2021.03.005

Golova I.M. (2022). Scientific and technical potential of the regions as the basis of technological independence of the Russian Federation. *Ekonomika regiona=Economy of Regions,* 18(4), 1062–1074. DOI: https://doi.org//10.17059/ekon.reg.2022-4-7 (in Russian).

Jin N., Yang F., Mo Yu. et al. (2022). Highly accurate energy consumption forecasting model based on parallel LSTM neural networks. *Advanced Engineering Informatics*, 51, 101442. DOI: https://doi.org/10.1016/j.aei.2021.101442

Ketova K.V., Rusyak I.G., Vavilova D.D. (2020). Mathematical modeling and neural network prediction of the structure and dynamics of human capital of the Russian Federation. *Vestnik Tom. gos. un-ta. Upravlenie, vychislitel'naya tekhnika i informatika*, 53, 13–24. DOI: 10.17223/19988605/53/2 (in Russian).

Kitova O.V., Kolmakov I.B., Dyakonova L.P. et al. (2016). Hybrid intelligent system of forecasting of the socio-economic development of the country. *International Journal of Applied Business and Economic Research*, 14(9), 5755–5766.

Kitova O.V., Savinova V.M., D'yakonova L.P., Bondarenko Yu.O. (2023). Forecasting tourism indicators in regions with coal mining: analysis of opportunities using the horizon information analytical system. *Ugol'= Russian Coal Journal*, 11(1173), 88–95. DOI: 10.18796/0041-5790-2023-11-88-95 (in Russian).

Komkov N.I., Tsukerman V.A., Goryachevskaya E.S. (2019). Analysis of the main factors of innovative development of the Arctic regions of Russia. *Problemy prognozirovaniya=Studies on Russian Economic Development*, 1(172), 33–40 (in Russian).

Kuznetsova O.V. (2023). Rating of scientific and technological development in regions: approaches, results, and challenges. *Problemy prognozirovaniya=Studies on Russian Economic Development*, 4(199), 94–103. DOI: 10.47711/0868-6351-199-94-103 (in Russian).

Mazilov E.A., Ustinova K.A., Davydova A.A., Klimova Yu.O., Ilyin V.A. (2020). *Formirovanie fondov podderzhki nauchnoi, nauchno-tekhnicheskoi i innovatsionnoi deyatel'nosti v regionakh: sostoyanie, zadachi, mekhanizmy realizatsii. nauch.-sprav. izd.* [Formation of Funds to Support Research, Scientific, Technological and Innovative Activities in the Regions: Status, Tasks, Implementation Mechanisms. Scientific Reference Edition]. Vologda: FGBUN VolNTs RAN.

Myslyakova Yu.G. (2022). Individualization of strategies for scientific and technological development of the economy of industrial regions of Russia, taking into account hereditary determinants. *Journal of Applied Economic Research*, 21(4), 685–707. DOI: http://dx.doi.org/10.15826/vestnik.2022.21.4.024 (in Russian).

Pazikadin A.R., Rifai D., Ali K. et al. (2020). Solar irradiance measurement instrumentation and power solar generation forecasting based on Artificial Neural Networks (ANN): A review of five years research trend. *Science of the Total Environment*, 715, 136848.

Qiu J., Wang B., Zhou C. (2019). Forecasting stock prices with long-short term memory neural network based on attention mechanism. *PLoS ONE*, 2.15(1): e0227222. DOI: https://doi.org/10.1371/journal.pone.0227222

Shelomentseva V.P., Nikitin E.B., Bespalyi S.V., Ifutina E.A. (2015). Using "foresight" method to predict scientific, technological and economic development of old industrial region (on the base of Pavlodar region of the Republic of Kazakhstan). *Vestnik Omskogo universiteta. Seriya "Ekonomika"=Herald of Omsk University. Series "Economics"*, 4, 242–248 (in Russian).

Shirov A.A., Gusev M.S., Sayapova A.R., Yantovskii A.A. (2016). The scientific and technological component of the macrostructural forecast. *Problemy prognozirovaniya=Studies on Russian Economic Development*, 6(159), 3–17 (in Russian).

Trifonov Yu.V., Sochkov A.L., Solov'ev A.E. (2021). Assessment of the economic potential of the regions of the Russian Federation based on the methodology of artificial neural network cluster analysis. *Vestnik Nizhegorodskogo universiteta im. N.I. Lobachevskogo. Seriya: Sotsial'nye nauki*, 3(63), 38–47. DOI: 10.52452/18115942_2021_3_38 (in Russian).

Vasilieva I.N., Rozova O.I., Korneeva N.D., Bogatova R.S. (2023). Effectiveness of state policy in the field of science and technology in the Russian Federation: Assessment methodology and approbation results. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz=Economic and Social Changes: Facts, Trends, Forecast*, 16(6), 155–173. DOI: 10.15838/esc.2023.6.90.9 (in Russian).

Wang Yu. (2021). Innovative development of Chinese regions: Experience and recommendations for Russia. *MIR (Modernization. Innovation. Research)=MIR (Modernizatsiya. Innovatsii. Razvitie)*, 12(2), 145–159. DOI: https://doi.org/10.18184/2079-4665.2021.12.2.145-159 (in Russian).

Zhang Q., Abdullah A.R., Chong C.W., Ali M.H.A. (2022). Study on regional GDP forecasting analysis based on Radial Basis Function Neural Network with Genetic Algorithm (RBFNN-GA) for Shandong economy. *Computational Intelligence and Neuroscience*, 12. DOI: https://doi.org/10.1155/2022/8235308

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