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SUSTAINABLE DEVELOPMENT and ENGINEERING ECONOMICS

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Sustainable Development of Socio-Economic Systems

The issue is devoted to the consideration of theoretical and methodological problems of sustainable development of regional socio-economic systems in the conditions of modernization of leading economies and integration of countries into global economic, social and political processes. At the moment, it is necessary to scientifically substantiate the priority directions and mechanisms of sustainable socio-economic development of systems on the basis of more complete activation of regional sources of ecological and socio-economic development.

In the third issue of the 2023 Sustainable development and engineering economics journal, the authors contribute to the theory of sustainable development of socio-economic systems, which is currently in its infancy.

The first section named *Economics of engineering and innovation decisions as a part of sustainable development* is presented by the article “Modelling Profits Forecasts for the Russian Banking Sector Using Random Forest and Regression Algorithms” by Lomakin, N., Kulachinskaya, A., Naumova, S., Ibrahim, M., Fedorovskaya, E., Lomakin, I. In this study, authors to build two models: a random forest ML model and a neural network regression model. The practical relevance of this study is evidenced by the fact that the results of the digital profits forecasting for the Russian banking sector can be recommended for real-world use.

The second section named *Enterprises and sustainable development of regions* presents two works. The first is the article “Methodology of Financial Monitoring Based on Cluster Analysis for the Implementation of National Projects in the Russian Regions” by the authors Yashina, N., Kashina, O., Yashin, S., Pronchatova-Rubtsova, N. address the development of a methodology for financial monitoring of national project implementations in the constituent entities of the Russian Federation, taking into account the correlation of their target indicators and using cluster analysis and methods in mathematical statistics.

The second work – “Systematisation of Drivers for the Development of Socioeconomic Systems” by Viktorova, N., Karpenko, P., Voskanyan. M. presents analysis of the theoretical foundations for determining the specialisation of regional socioeconomic systems and the formation of a classification of factors influencing the development of regional socially significant systems. The study is based on the scientific works of Russian authors in the field of competitiveness, regional differentiation, the geoeconomic position of a region and its economic independence and development prospects.

To solve the problems of *Sustainable development of regional infrastructure*, the author Kokh, Yu. in the article “Developing technologically innovative industrial infrastructural facilities for their better efficiency: case study of technology parks in Russia” clarify recommendations for making technologically innovative industrial infrastructural facilities more efficient in accordance with the results of the modelling; it substantiates the mechanism of ensuring the competitiveness of technologically innovative industrial infrastructural facilities of the same type, based on the technical efficiency achieved by a facility, as a result of solving an optimization problem using the shell data analysis method.

The *Management of knowledge and innovation for sustainable development* section presents the work “Complex Modelling of Regional Tourism Systems” by the authors Gintciak, A., Burlutskaya, Zh., Zubkova, D., Petryaeva, A., the subject of which is to examine the prospects of various modelling tools in building complex models of regional tourism systems. It surveyed the international experience in forecasting tourist demands and modelling the tourism industry.

Irina Rudskaya, *Editor-in-Chief of SDEE Journal, Doctor of Economics, Professor*

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Research article

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Modelling Profits Forecasts for the Russian Banking Sector Using Random Forest and Regression Algorithms

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Abstract

This study is relevant because market uncertainty induces progressively more attempts at making accurate profits forecasts in the banking sector. The scientific novelty of this study lies in the profits forecasts for the Russian banking sector performed using a random forest machine learning (ML) model and a neural network regression model. Regarding technology, the two models are combined into a cognitive model, as they are executed in the same cloud service (Collab) and have a common dataset comprising a training set, scripts and result output. The aim of the study is to build two models: a random forest ML model and a neural network regression model. The dataset used in the random forest ML model and the regression model included data on the performance of the Russian banking sector and some macroeconomic data on the national economy and the stock market for the period 2017–2021. Specifically, the dataset for the models included the following: key rate (%), growth assets (%), overdue loans (%), gross domestic product (GDP, in billions of rubles), RTS index (points), USD rate (vs. RUB), investments in assets to GDP (%), exchange robots (%), capital outflow (in billions of rubles), bank assets (in trillions of rubles), stock accounts (pcs.), and bank profits (in billions of rubles). The practical relevance of this study is evidenced by the fact that the results of the digital profits forecasting for the Russian banking sector can be recommended for real-world use. In building the cognitive model, we used the Python language in the Collab cloud environment. The mean absolute error of the test set for the random forest ML model (DecisionTreeRegressor) was 414.67, which is 61% lower than for the linear regression model (LinearRegression), which had a mean absolute error of 667.65.

Keywords: digital model, cognitive model, ML model, random forest, profits forecast for banking sector

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Научная статья

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Моделирование Прогноза Прибыли Банковского Сектора РФ с Использованием Модели Случайный Лес и Регрессии

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Аннотация

В условиях рыночной неопределенности предпринимается все больше попыток используя системы искусственного интеллекта сформировать точный прогноз величины прибыли банковского сектора. Научная новизна данного исследования заключается в получении прогнозов величины прибыли российского банковского сектора с использованием модели машинного обучения (ML-модель) «Случайный лес» и нейросетевой модели регрессии. Технологически обе модели объединены в «Когнитивную модель», поскольку выполнены в одном «облачном сервисе» Collab, имеют общий датасет – обучающее множество, скрипты и вывод результата. Целью исследования является формирование моделей (ML-модель «Случайный лес» и модель регрессии) для получения прогнозных значений прибыли отечественного банковского сектора и сравнения результатов работы этих моделей. В целях формирования датасета, используемого для обучения модели машинного обучения «Случайный лес» и модели регрессии, использовались данные, отражающие результаты деятельности российского банковского сектора, некоторые макроэкономические показатели отечественной экономики и биржевого рынка за период 2017–2021 гг. В частности, в датасет моделей были включены: Ключевая ставка (%), Прирост банковских активов (%), Доля просроченных кредитов (%), ВВП (млрд руб.), Индекс RTS (пунктов), Курс USD (руб.), Инвестиции в активы к ВВП (%), Доля роботов на бирже (%), Отток капитала (млрд. руб.), Банковские активы (трлн. руб.), Количество счетов на бирже (шт.), Прибыль банков (млрд. руб.). Практическая значимость исследования заключается в том, что результаты цифрового прогнозирования прибыли банковского сектора РФ могут быть рекомендованы для дальнейшего практического применения. При формировании когнитивной модели, использовался язык Python в облачной среде Collab. Средняя ошибка прогноза на тестовом множестве у ML-модели «Случайный лес» (DecisionTreeRegressor) составила 414,67 и на 61% оказалась ниже в сравнении с моделью линейной регрессии (LinearRegression), средняя ошибка которой составила 667,65.

Ключевые слова: цифровая модель, когнитивная модель, ML-модель, случайный лес, прогнозирование прибыли банковского сектора

Цитирование: Ломакин, Н., Кулачинская, А., Наумова, С., Ибрахим, М., Федоровская, Э., Ломакин, И., 2023. Моделирование Прогноза Прибыли Банковского Сектора РФ с Использованием Модели Случайный Лес и Регрессии. Sustainable Development and Engineering Economics 3, 1. https://doi.org/10.48554/SDEE.2023.3.1

1. Introduction

The subject of this study is the performance of the banking sector, i.e., the profits it makes, which is determined by many factors. The focus of the study is the relationship between the profits made in the banking sector and how they are impacted by the factors we investigate. A critical problem in the banking sector and the finance sector is how to ensure financial stability and the stability of the economy as a whole, which cannot be done without having an accurate forecast of the sector's profits for the next year.

This study is relevant because market uncertainty induces progressively more attempts to use artificial intelligence systems to perform accurate profit forecasts for the banking sector. The scientific novelty of this research lies in the profits forecasts for the Russian banking sector made using a random forest machine learning (ML) model and a neural network regression model. Regarding technology, both models are combined into a cognitive model, as they are executed in the same cloud service (Collab) and have a common dataset comprising a training set, scripts and result output.

The practical significance of the study is that the results of the digital profits forecasting for the Russian banking sector can be recommended for real-world application. We used the Python language in the Collab cloud environment to build the cognitive model. The results of the study include the projected value for the sector's gross domestic product (GDP). This was obtained via the digital cognitive model, an integral component of which is the random forest ML model.

In choosing the determining factors to investigate, we relied on the findings of some previous studies; in particular, studies involving an analysis of the state of the banking sector in the Russian Federation (Polyanskaya, 2022) and an investigation of the quality of the loan portfolios and investment activities of banks as profitability factors impacting the financial sector (Vimalaratkhne, 2022).

The aim of this study is to build a random forest ML model and a regression model to forecast the profits of the nation's banking sector and then compare the results of these models.

To achieve this objective, the following hurdles had to be addressed:

1. Study the theoretical basis of a profitable operation of the banking system.

2. Understand the trends in the development of artificial intelligence (AI) systems in the banking sector and the finance sector.

3. Create a dataset for the model.

4. Calculate the projected value of the profits of the banking sector using the random forest ML model.

5. Analyse the results.

The results can be utilised in the credit and finance sector, as well as by investors, the business community, and the academic community. Anyone who needs an accurate profit forecast of the banking sector on an annual forecast horizon would be interested in employing the findings of this study. Economic and financial systems can become consumers of the information generated by the digital cognitive model, which has the random forest ML model as its critical component. It is essential to project the profits of the banking sector using input parameters that vary together with the changing global economic landscape and growing market uncertainty.

Badvan, Gasanov and Kuzminova, who researched various ways of ensuring the stability of financial markets, use cognitive modelling extensively in their study (Badvan et al., 2018). Cognitive modelling of the stability factors impacting financial markets and the creation of cognitive maps are considered in studies by Emelianenko and Kolesnik (Emelianenko et al., 2019).

Notably, given the digitalisation of the economy, all factors (both economic and technological) are essential. Their effect can be observed in the present and, even more importantly, will be felt in the future. Therefore, in the context of transitioning to a new technological paradigm (i.e., Industry 4.0), it is imperative to become familiar with the findings of a study conducted by Rodionov et al., researching the development of an innovation-industrial cluster strategy using a method that employs parallel and sequential real options (Rodionov et. al., 2022). Undoubtedly, attention should be paid to the proposals made by Balog et al. regarding human capital in the digital economy as a factor in sustainable development (Balog, 2022). According to Dianov, sustainable development can be achieved if effective organisational management systems are created (Dianov, 2022). Scientific interest has been sparked by the development of an innovative strategy for an industrial cluster using the concept of composite real options by Koshelev et al. (2023). It is quite possible that the factors studied by these aforementioned scientists can be parsed (collected, digitised and pre-processed) and used in the subsequent versions of the cognitive model.

2. Literature Review

This study is relevant because of the need to ensure the sustainability of the banking sector and the Russian economy as a whole in the face of growing market uncertainty and risk.

To frame the broad ideas and findings of previous studies clearly in this literature review, it is crucial to note—as the main thread—that many classical approaches to forecasting bank profits do not work well or are ineffective in many cases. Modern approaches in the literature are fragmented or inconsistent. However, the general vector of research studies shows that today's trends are characterised by the introduction of increasingly sophisticated AI forecasting systems and the extensive use of big data and business processes common to Industry 4.0.

AI and big data systems are fundamental tools for profits forecasting in the Russian banking sector. With these technologies, banks can analyse enormous amounts of data and identify trends that may affect business profitability. According to a report prepared by Accenture, using AI systems can increase a bank's profit by 34%. In addition, using big data can help banks reduce risks and improve their operational efficiency.[1]

An example of AI and big data systems being used successfully in the Russian banking sector is Sberbank. According to the Banki.ru portal, Sberbank uses an AI system for automatic decision-making regarding credit.[2] It should also be noted that an AI system and big data can help banks optimise costs. According to Forbes, banks can bring down their customer service costs by 20% using these technologies.[3]

Research indicates that the relationship between the categories of profitability and economic stability needs to be closely re-examined because the latter is a complex and multifaceted concept. Many studies by Russian and foreign scientists investigate the problem of the stability of economic systems. These problems have been explored by economists such as Gurvich, Prilepsky, Bobylev and Konishchev (Abdrakhmanova et al., 2019). The challenge of building a cognitive model of the national financial market—given its peculiarities—and the potential use of the model for assessing the operational safety of the market has been studied by Loktionova (2022).

Thus, AI and big data systems are essential tools for forecasting the profits of the Russian banking sector, as they help banks analyse enormous amounts of data, identify trends and make decisions that may affect the profitability of their businesses.

Today, it is important to study issues related to AI used to ensure sustainable economic development and reduce financial risks because of growing market uncertainty. Researchers such as Abdalmuttaleb and Al-Sartavi have reviewed the latest studies on AI applied to stable financing and sustainable technologies (Abdalmuttaleb, 2021). As presented by Lomakin et al. (2019) in the Global Economic Revolutions: The Era of Digital Economy international conference, the neural network model can be

[1]Accenture. Artificial intelligence in banking. URL: https://www.accenture.com/us-en/insights/banking/artificial-intelligence-in-banking Accessed on April 22, 2023.
[2]Banki.ru. Sberbank is using Artificial Intelligence when granting loans. URL: https://www.banki.ru/news/lenta/?id=10124323 Accessed on April 22, 2023.
[3]Forbes. How AI and big data can cut banks' costs by 20%.
URL: https://www.forbes.com/sites/tomgroenfeldt/2019/05/23/how-ai-and-big-data-can-cut-banks-costs-by-20/?sh=3b5f5a5d5c98 Accessed on April 22, 2023.

used to project the profits of enterprises operating in the real sector of the economy. Certain aspects of using neural networks in the financial sector intersect with economic analysis in financial management systems, as noted by Morozova, Polyanskaya, Zasenko, Zarubina and Verchenko. Notably, for an enterprise to operate effectively in today's economy, with ever-increasing competition, it must respond promptly to any change in any of the different factors that affect its operations (Morozova, et al., 2017).

A key aspect of the financial stability of the economy is the reliable operation of the banking sector. One of the most pressing issues regarding achieving this stability is preventing the growth of overdue debts. To achieve this goal, the creditworthiness and financial stability of enterprises must be assessed. Rybyantseva, Ivanova, Demin, Jamai and Bakharev studied various approaches to such an assessment and identified the most effective among them (Rybyantseva, et al., 2017). Hengxu Lin, Dong Zhou, Weiqing Liu and Jiang Bian proposed a deep risk model as a solution for deep learning and analysis of hidden risk factors. They experimented with stock market data and demonstrated the high efficiency of their solution. Their method allows users to achieve 1.9% more of the detected variance and reduces the risk of a global minimum variance portfolio (Hengxu et al., 2021). An important aspect of financial stability is the formulation of an investment portfolio. Of practical interest are the studies by Ni Zhang, Yijia Song, Aman Jakhar and He Liu on the development of graphical models of financial time series and the selection of a portfolio. They propose various graphical models for building the best portfolios (Zhan et al., 2021).

3. Materials and Methods

This study employs research methods such as monographic, analytical, statistical and cognitive models, including a random forest AI system and a program called Graphviz (a utility package developed by AT&T laboratories for automatic visualisation of graphs). The methodology employed in this study is based on a cognitive model.

A cognitive model is a software shell: a bot that collects information, creates a dataset, obtains and compares results, assesses the weight of parameters (based on the magnitude of correlation coefficients) if necessary, and removes weak factorial features from the training set. A cognitive model is expected to work cyclically.

With respect to technology, the two models (the random forest AI system and the multiple regression algorithm) are combined into a cognitive model, as they are executed in the same cloud service, Collab and have a common dataset (a training set, scripts and result output).

Financial and economic stability is modelled based on the cognitive model, which allows us to develop an original approach to supporting management decision-making at times of uncertainty through the ability to accurately forecast the profitability of the Russian banking sector.

This research proposes and attempts to substantiate the hypothesis that, at a time of uncertainty, when all types of risk are growing, the random forest ML model can be used to forecast the profits of the banking sector more accurately than a multivariate regression model.

The profitable operation of banks is closely related to their stability and the stability of the country's economy as a whole. Both Russian and foreign scientists are increasingly interested in the concept of the stability of financial and economic systems. Problems related to financial stability have been studied by many Western scientists, including John Chant, Andrew Crockett, Wim Duisenberg, Roger Ferguson, Michael Foot, Sir Andrew Large, Frederick Mishkin, and Garry Schinasi.

The deeper the tree, the more complex the decision-making rules and the more accurate the model. There are two types of decision trees used for both classification and regression problems. An understanding of the importance of variables in random tree forests is expressed in many studies, including one by Louppe et al. (2020).

A cognitive model acts as a trigger that launches methods as independent modular programs; in particular, it launches a decision tree that can be used to obtain forecasts of the profits of the banking system. The dataset of the decision tree model used in this study is presented in Table 1.

Table 1. Data used to create the dataset for the random forest ML model (fragment)

Year	Key Rate	Growth Assets (%)	Overdue Loans (%)	GDP (billions of rubles)	RTS Index	USD Rate
2021	8.50	16.0	23.5	131015	1608	73.7
2020	4.25	16.8	17.8	1073015	1376	73.8
2019	7.25	10.4	5.9	109241	1549	61.9
2018	7.75	6.4	7.5	103861	1157	69.8
2017	8.25	−3.5	9.3	91843	1154	57.6

Investments in Assets to GDP (%)	Exchange Robots (%)	Capital Outflow (billion rubles)	Bank Assets (trillion roubles)	Stock Accounts (pcs.)	Bank Profits (billion rubles)
21.2	58	72.0	120.0	38300	2400.0
16.5	55	53.0	103.7	32300	1608.0
20.6	55	25.2	92.6	3069	1715.0
20.6	51	60.0	92.1	1955	1705.0
21.4	51	33.3	85.2	1310	1300.0

The data presented in Table 1 were collected manually, but the process can be automated using a data parsing program. The ML model was generated in the cloud by Google Collab using Python programming language.

Describing the sample seems worthwhile. To create a dataset for training the random forest ML model and regression model, we used performance data on the Russian banking sector and macroeconomic data on the national economy and the stock market for the period 2017–2021. In particular, the dataset for the models included the following: key rate (%), growth assets (%), overdue loans (%), GDP (in billions of rubles), RTS index (points), USD Rate (vs. RUB), investments in assets to GDP (%), exchange robots (%), capital outflow (in billions of rubles), bank assets (trillion rubles), stock accounts (pcs.) and bank profits (in billions of rubles).

4. Results

4.1. Digital Cognitive Model

The Graphviz program was used to visualise the digital cognitive model. Graphviz is a utility package offered by AT&T laboratories for the automatic visualisation of graphs based on their textual descriptions. The package is distributed as an open-source code file and runs on Windows and other operating systems.

The cognitive model acts as a kind of trigger that launches methods as independent modular programs; in particular, it launches a decision tree that can be used to obtain a profits forecast of the banking system. Figure 1 is a schematic diagram of the digital cognitive model.

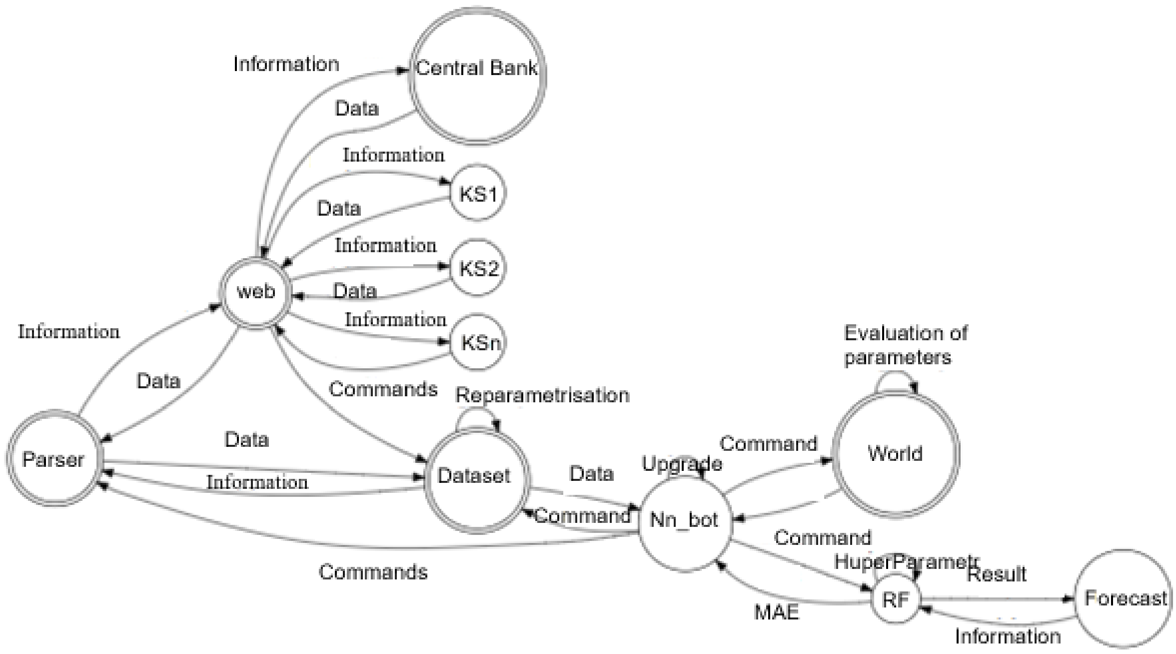

Figure 1. Digital cognitive model

The concept behind the cognitive model is based on the interaction of its main modules, the ultimate goal of which is to collect all the necessary information, process it and then create a dataset for the random forest ML model and a heat map of the pairwise coefficients of the multifactor linear regression model, which return the predicted profits of the banking sector. An integral element of the digital cognitive model is the random forest ML model, which performs the neural forecasting of banking sector profits.

4.2. Random Forest ML Model

A random forest is an ML learning algorithm that uses an assembly of decision trees to solve classification and regression problems. It is applied to different sectors, including finance, medicine and business, and is suitable for improving the accuracy of forecasts and reducing the probability of retraining the model.

Decision trees (DT) are based on a nonparametric learning method with a teacher and are used for classification and regression. The purpose of this method is to create a model that predicts the value of the target variable based on the study of simple decision-making rules obtained from the characteristics of the data. The tree can be considered a piecewise constant approximation. Table 2 presents the dataset of the random forest ML model.

Table 2. Random forest ML model dataset (fragment)

	Key rate	Growth assets	Overdue loans	GDP	RTS	USD	Investments	Exchange robots	Capital outflow	Bank assets	Stock accounts	target
0	8.50	16.0	23.5	131015.0	1609.7	73.70	21.2	58	72.0	120.0	38300	2400.0
1	4.25	16.8	17.8	107315.3	1376.4	73.80	16.5	55	53.0	103.7	32300	1608.0
2	7.25	10.4	5.9	109241.5	1549.4	61.98	20.6	55	25.2	92.6	3069	1715.0

A binary classification tree (i.e., regression) (Breiman et al., 1984) is an input-output model represented by a tree structure T from a random input vector $(X_1 \ldots X_p)$, taking its values in $(X_1 * \ldots * X_p) = X$ into a random output variable $Y \in \mathcal{Y}$. The tree is built from a training set of size N, taken from $P(X_1 \ldots X_p, Y)$ and using a recursive procedure that in each node t identifies partition $s_t = s^*$, for which the partition of the samples of node N_t into t_L and t_R maximises the reduction of a certain impurity measure i(t) (e.g., the Gini index, the Shannon entropy, and Y variance) (Equation 1).

$$\Delta_i(s,t) = i(t) - p_L i(t_L) - p_R i(t_R), \tag{1}$$

where $p_L = N_t L / N_t$ and $p_R = N_t R / N_t$

The building of the tree stops, for example, when the nodes become pure along Y or when all variables X_i are locally constant. The tree is finally exported and mapped in the tree structure presented in Figure 2, which is visualised using a special service[4] by copying the data from the tree '.file' with a dot. Figure 2 shows the first level of the decision tree.

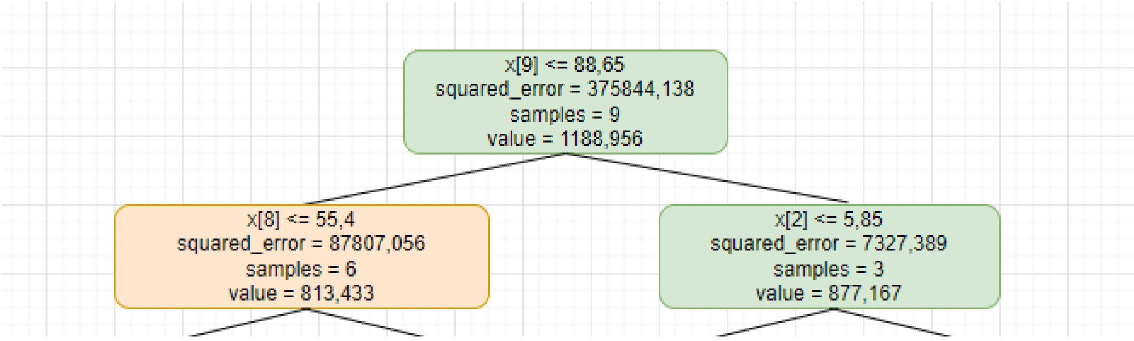

Figure 2. First two levels of the decision tree

To forecast the profits of the banking sector for the next year, you need to use a specific script in which the latest values of the input parameters are introduced.

4.3. Multivariate Linear Regression Model

An AI multivariate linear regression model was used to forecast the profits of the banking sector. The multivariate linear regression model is also used to project the value of a target indicator based on the values of several features; however, it relies on a linear combination of these features. In each *i-th* observation, we obtain a set of values of independent variables and the corresponding value of the dependent variable Y_i. If we assume that there is a linear relationship between the independent variables *x1, x2,... xi* and the dependent variable Y_i, then Equation 2

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m + \varepsilon \tag{2}$$

expressing the linear relationship between variables is called a theoretical multiple regression equation.

In the course of the study, a matrix of pairwise correlation coefficients was obtained (Table 3).

Table 3. Matrix of pairwise correlation coefficients

	Key rate	Growth assets	Overdue loans	GDP	RTS	USD	Investments	Exchange robots	Capital outflow	Bank assets	Stock accounts	target
Key rate	1.000	0.042	-0.072	-0.058	-0.550	0.280	0.445	0.207	0.123	-0.039	-0.300	-0.323
Growth assets	0.042	1.000	-0.034	-0.166	-0.152	-0.023	-0.255	-0.130	0.283	-0.163	0.078	-0.368
Overdue loans	-0.072	-0.034	1.000	0.720	0.175	0.620	-0.351	0.613	-0.051	0.755	0.948	0.675
GDP	-0.058	-0.166	0.720	1.000	-0.048	0.835	-0.199	0.901	-0.046	0.973	0.686	0.741
RTS	-0.550	-0.152	0.175	-0.048	1.000	-0.461	0.048	-0.373	-0.290	-0.088	0.320	0.518
USD	0.280	-0.023	0.620	0.835	-0.461	1.000	-0.367	0.957	-0.017	0.877	0.519	0.419
Investments	0.445	-0.255	-0.351	-0.199	0.048	-0.367	1.000	-0.249	-0.043	-0.280	-0.497	-0.119
Exchange robots	0.207	-0.130	0.613	0.901	-0.373	0.957	-0.249	1.000	-0.128	0.921	0.506	0.479
Capital outflow	0.123	0.283	-0.051	-0.046	-0.290	-0.017	-0.043	-0.128	1.000	-0.180	0.053	-0.306
Bank assets	-0.039	-0.163	0.755	0.973	-0.088	0.877	-0.280	0.921	-0.180	1.000	0.693	0.744
Stock accounts	-0.300	0.078	0.948	0.686	0.320	0.519	-0.497	0.506	0.053	0.693	1.000	0.686
target	-0.323	-0.368	0.675	0.741	0.518	0.419	-0.119	0.479	-0.306	0.744	0.686	1.000

[4]Graphviz in the Browser. URL: http://www.webgraphviz.com

The multifactorial linear regression model considers that the relations between mass economic phenomena are dependent on the fact that—in reality—a certain phenomenon is determined by a multitude of simultaneously and collectively acting causes. Therefore, in a general case, a dependent variable can be a function of several variables.

To visualise the matrix of pairwise correlation coefficients, it is advisable to use a heat map (Figure 3).

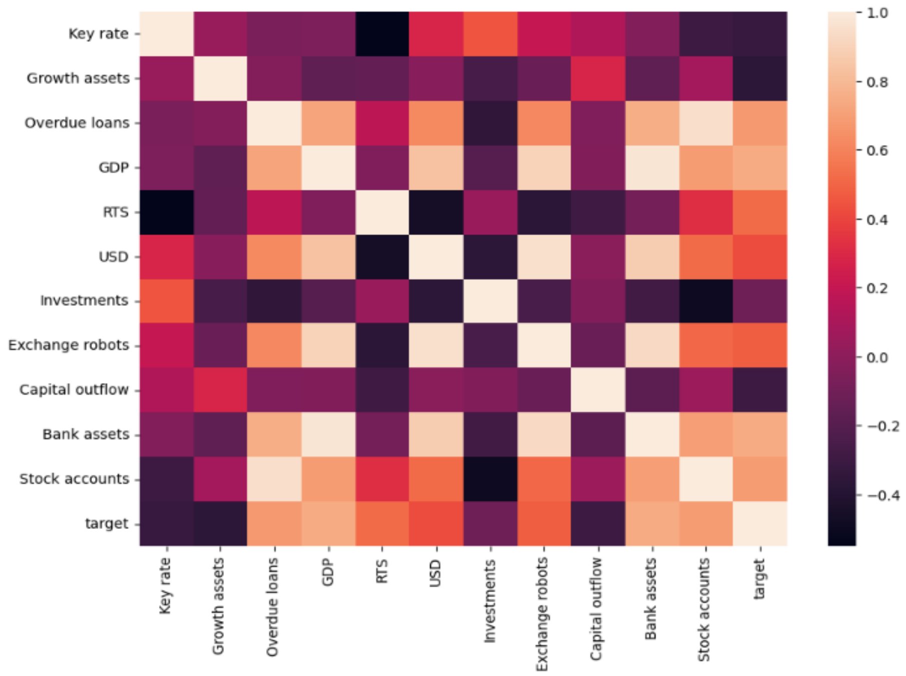

Figure 3. Heat map of the multivariate linear regression model

The correlation coefficients between factorial and resultant features are as follows: the key rate is −0.323, growth assets (%) are −0.368, overdue loans (%) are 0.675, GDP (in billions of rubles) is 0.741, the RTS index is 0.518, the USD rate is 0.419, investments in assets to GDP (%) are −0.119, exchange robots (%) are 0.479, capital outflow (in billions of rubles) is −0.306, bank assets (in trillions of rubles) are 0.744, and stock accounts are 0.686.

Using the Pandas and lin_reg.coef libraries, we calculated the regression equation coefficients, which are presented in Table 4.

Table 4. Regression equation coefficients

Key rate	Growth assets	Overdue loans	GDP	RTS	USD	Invest-ments	Exchange robots	Capital outflow	Bank assets	Stock accounts
−4.0337	−39.572	103.239	−0.0953	−6.8288	−107.00	−11.027	−91.4689	−2.9446	89.20268	3.60045

It is important to analyse the results obtained.

4.4. Analysing the Results

The quality of the forecast was assessed based on a comparison of the following parameters:

1. Mean absolute error.

2. Mean squared error, which is applied in case we need to highlight large errors and then choose the model that results in fewer large errors for the forecast.

3. Root mean squared deviation (RMSD) or root mean squared error (RMSE), which is a commonly used measure of disparity between the values (sample or population) predicted by a model or an assessor and the actual observed values. The RMSD is the square root of the second sampling moment

of differences between the predicted values and the observed values, or the root mean squared value of these differences. These deviations are either called excesses, when the calculations are made with the data sample used for the assessment, or errors (also prediction errors), if the calculations are made beyond the sample.

An analysis of the findings shows that the ML model ensures a more precise result than the multifactor linear regression model (Table 5).

Table 5. Comparison of the results of using the ML model and a linear regression model

Name	DecisionTreeRegressor	LinearRegression	Deviation (%)
Mean Absolute Error	414.6666667	667.6533333	0.610096463
Mean Squared Error	232246	1325.48	−0.994292776
Root Mean Squared Error	481.9190803	1361.887	1.825966133

The mean absolute error of the forecast for the test set of the random forest ML model (DecisionTreeRegressor) was 414.67, which proved to be 61% lower than that for the linear regression model (LinearRegression), which had a mean absolute error of 667.65.

5. Discussion

It seems reasonable that the views and results obtained in this study should be thought over critically. Undoubtedly, the results are consistent with those of other published studies in the international academic domain.

In the course of this study, we solved the problems that had been identified as hurdles and obtained the following outcomes: the theoretical basis of profitable operation of the banking sector was investigated, the development trends of AI systems in the banking and finance spheres were studied, a dataset for the ML model was created, profits forecasts for the banking sector were calculated using a random forest ML model, and the results obtained were analysed.

The mean absolute error of the forecast for the test data was 414.67 for the random forest ML model (DecisionTreeRegressor), which is 61% lower than that for the linear regression model (LinearRegression), which has a mean absolute error of 667.65. Comparing the results obtained with the issues discussed in the introduction, we can say that other advanced neural network models should be used in future research.

A convolutional neural network (CNN) is a deep learning algorithm that can accept input parameters and assign weight (digestible weights and biases) to various areas/objects depending on the purpose of study. Due to the growing computing power of modern cloud clusters, modern neural CNN-based algorithms can be used with parallel calculations in open Hadoop and Spark frameworks to make complex economic and financial forecasts.

More sophisticated AI models should be applied in future research. AI is increasingly used in robotic advising, and the financial sector is no exception. Catherine D'Hondt, Rudy De Wynn, Eric Giesels and Steve Raymond studied the use of an AI alter ego system in the field of robotic investments, introducing the concept of AI AlterEgo, which is a type of shadow robot investor (D'Hondt, 2019). One of the promising areas where deep neural networks can be used is the banking sector. For example, Krzysztof et al. propose performing a neural risk assessment of networks with unreliable resources (Krzysztof, 2022).

Our cognitive model opens wide opportunities for AI systems that are suitable for providing management decision support, forecasting banking sector profits and increasing the stability of the economic and financial sector.

6. Conclusion

In this study, we came to the following conclusions:

Using a digital cognitive model, with a random forest ML system as its integral component, is essential for achieving stable economic growth based on forecasting banking sector profits because it stimulates the competitiveness of the national economy.

Using the results of the digital cognitive model, which has a random forest ML system as its integral component, opens ample opportunities for applying AI systems in management decision support, thus increasing the profitability of the banking sector and improving economic stability.

The results obtained in this study have practical significance, and the proposed algorithm can be used to forecast banking sector profits. The mean absolute error of the forecast for the test set of the random forest ML model (DecisionTreeRegressor) was 414.67, which is 61% lower than that of the linear regression model, which had a mean absolute error of 667.65.

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SECTION 2

ENTERPRISES AND THE SUSTAINABLE DEVELOPMENT OF REGIONS

РАЗДЕЛ 2

ПРЕДПРИЯТИЯ И УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНОВ

Research article
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Methodology of Financial Monitoring Based on Cluster Analysis for the Implementation of National Projects in the Russian Regions

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Abstract

The need to take into account imbalances among regional indicators in the development of state policy for financing national projects makes it necessary to develop a methodology that will enable objective assessment of the effectiveness of socially significant projects in Russia. This paper reports the development of a methodology for financial monitoring of national project implementations in the constituent entities of the Russian Federation, taking into account the correlation of their target indicators and using cluster analysis and methods in mathematical statistics. The proposed methodology was tested on health and demography national project data obtained from the Federal Treasury of Russia, the Federal State Statistics Service and the Accounts Chamber for 2020–2021. The analysis of public funding for national projects based on centralization indices and target indicators for their implementation enabled classifying the regions of Russia according to the levels of effectiveness and the financial risks of implementing the projects. The results of the study correspond to the actual effectiveness of national projects and can be used in the development of flexible state policy in financing national projects, taking into account the level of the target indicators achieved.

Keywords: national project, target indicators, cluster analysis, financial monitoring

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Методика Финансового Мониторинга Реализации Национальных Проектов в Российских Регионах с Использованием Кластерного Анализа

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Аннотация

Необходимость учета процессов сбалансированности, диспропорций и поляризации показателей регионов при разработке государственной политики финансирования национальных проектов как залога успешного достижения стратегических целей и задач государства обуславливает потребность развития методического инструментария, позволяющего объективно оценить результативность социально-значимых проектов в российских регионах. Статья посвящена разработке методики финансового мониторинга реализации национальных проектов в субъектах Российской Федерации с учетом взаимосвязи их целевых показателей с использованием кластерного анализа, а также методов математической статистики. Апробация предложенной методики была проведена на основе данных Федерального казначейства России, Федеральной службы государственной статистики и Счетной палаты за 2020–2021 гг. на примере национальных проектов «Здравоохранение» и «Демография». Анализ государственных ассигнований на национальные проекты в регионах России на основе индексов централизации и установочных целевых индикаторов выполнения национальных проектов дает основание классифицировать регионы России по уровням эффективности и финансовых рисков реализации данных проектов. Результаты исследования полностью сопоставимы с фактическими показателями исполнения национальных проектов и могут быть использованы при формирования гибкой государственной политики финансирования национальных проектов с учетом уровня достижения целевых показателей.

Ключевые слова: национальный проект, целевые индикаторы, кластерный анализ, финансовый мониторинг

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1. Introduction

Increased external challenges and threats have slowed the growth of Russia's gross domestic product as a basic source of financial resources, which is affecting standards of living and birth rates in the country. Decree of the President of the Russian Federation No. 204, dated July 21, 2020, "On the National Development Goals of the Russian Federation for the period up to 2030",[1] defined national targets for the development of the country. The primary task of the state is to guarantee the well-being and health of the citizens. President Putin V.V. noted that there is a "difficult situation" in Russia in the field of demography and that it is necessary to ensure increases in both the birth rate and life expectancy.

To achieve the strategic goals and objectives of the state, tools are needed to assess the effectiveness of national projects in the Russian regions (Fattakhov et al., 2019). The need for these tools is also due to imbalances in the indicators of the regions, which should be taken into account in the development of state policy for financing national projects. Among the top-priority national projects responsible for economic growth and human capital development are those directed to health and demography. National healthcare and demography projects are important strategic tasks in modern Russia, the implementation of which will ensure development of the main components in the growth of human capital: longevity and high-quality medical care for the population. The achievement of these objectives should be considered taking into account their mutual correlation. Cluster analysis which has been tested in numerous studies (Revnyakov, 2017; Pushkarev, 2018; Piskun and Khokhlov, 2019) can be conducted to solve these problems. In this regard, the current authors propose a methodology for financial monitoring of national project implementations in Russian regions based on cluster analysis, which will make it possible to classify the regions according to the level of potential threats to the implementation of national healthcare and demography projects, monitor changes in achieving project targets, coordinate management activities at all levels, and allocate financial resources in a timely manner.

2. Literature review

A characteristic feature of the Russian economy is the imbalance in the socio-economic development of its regions due to their geographical location and the availability of natural and other resources (Yashina et al., 2022(a); Yashina et al., 2022(b); Yudintsevand Troshkina, 2023). To assess local regional disparities, multidimensional classifications, as well as methods of factor cluster and discriminant analysis are widely used (Piskun and Khokhlov, 2019). The problem of regional disparities makes it necessary to improve the system for monitoring national projects and government programmes in order to increase the effectiveness of their implementation in the regions of the Russian Federation (Ezangina and Gromyshova, 2020). The need to improve the management of the socio-economic systems of regions has been highlighted in numerous works (e.g. Bogovizetal, 2019; Romanovaetal, 2019; Chebyshev, 2021). In addition to the divergence and convergence of the development of the regions and the country as a whole, Ezangina and Gromyshova (2020) pointed out the lack of methodological support for the current state strategic planning system, as well as the lack of transparent and accessible information to improve this system, as key reasons for the imbalance in the level of regional socio-economic situations. These issues were also discussed by Endovitsky et al. (2021) and Mishlanova (2022).

As mentioned earlier, an important national state task is to ensure sustainable positive indicators in the fields of health and demography in the Russian regions, taking into account their uneven development and risks (Averinetal, 2018; Ariste and Matteo, 2017; Kozlova et al., 2017). However, these indicators should be considered taking into account the relationships between them (Gallardo-Albarrán, 2018; Sharma, 2018; Mihalache, 2019). In particular, funding for healthcare, as one of the key instruments of state policy, largely determines the quality of medical care provided (Shahetal., 2021; Soofi et al., 2021). High-quality care contributes to a lower mortality rate in the country and a more favourable demographic situation (Balkhi et al., 2021; Wirayuda and Chan, 2021). Ivankova et al. (2022) assessed the relationship between funding for healthcare, mortality, and gross domestic product in OECD countries

[1]Decree of the President of the Russian Federation No. 204 Dated July 21, 2020 "On the national development goals of the Russian Federation for the period until 2030": official internet portal of legal information. URL: http://publication.pravo.gov.ru/Document/View/0001202007210012

for the period 1994–2016. The study was conducted by the authors taking into account types of healthcare systems. The working-age population was the object of the study. The authors found that countries with high healthcare funding had lower mortality rates and higher gross domestic products compared to countries with an insurance-based healthcare system (Bismarck system). In this regard, it is obvious that the risks of not meeting the targets of national projects in the fields of health and demography are mutually reinforcing.

The authors of a number of publications have applied cluster analysis as a tool for assessing the effectiveness of various regional strategies, including in the field of innovation (Khayrullina, 2014; Revnyakov, 2017; Pushkarev, 2018). Cluster analysis allows us to identify objects in numerous classification features using many variables. Piskun and Khokhlov (2019) confirmed the hypothesis that any region can be described by a set of interrelated variables that reflect its socio-economic situation over the analysed time interval. Despite a large number of scientific publications devoted to various aspects of regional development, insufficient attention has been paid to financial monitoring of the national projects implemented in the Russian regions that would take into account the relationships between their indicators based on cluster analysis. The issue of expanding the set of criteria for evaluating the effectiveness of national projects needs further development and justification.

3. Materials and methods

Our methodology for financial monitoring of the implementation of national projects in the Russian regions using cluster analysis of government subsidies for national projects and criteria for their effectiveness contains several stages.

The first stage includes the development of a database of the target indicators of national projects based on information from the Ministry of Finance of the Russian Federation and the Federal State Statistics Service. The methodology for assessing the effectiveness of public financing for the implementation of national projects is based on the analysis of two systems of indicators: indicators of public funding and indicators for setting target indicators for national projects. The methodology was tested on health and demography national projects.

The system of public funding itself includes two indicators: budget execution in the context of the analysed national projects: % (FDH 1); and budget execution in the context of the analysed national projects per inhabitant, in rubles (FDH 2).

The system of target indicators of the analysed national projects includes the values presented in Table 1.

Table 1. Target indicators for the implementation of health and demography national projects

Health national project	Symbol	Demography national project	Symbol
Mortality of the working-age population, per 100,000 people of the population of the corresponding age	ICH 1	Life expectancy of citizens at the age of 55, years	ICD 1
Mortality from diseases of the circulatory system, per 100,000 population	ICH 2	Healthy life expectancy, years	ICD 2
Mortality from neoplasms, including malignant ones, per 100,000 population	ICH 3	Mortality of the population older than working age per 100,000 people of the population of the corresponding age	ICD 3
Infant mortality, the number of children who die before the age of 1 year, per 1000 live births	ICH 4	Total fertility rate, number of children per woman	ICD 4
		Number (share) of citizens leading a healthy lifestyle, %	ICD 5
		Employment rate of women with preschool-aged children	ICD 6

Further, in relation to the system of indicators, the criteria for the centralization of public funding and target indicators for the implementation of the analysed national projects in the Russian regions were determined:

1. Level of centralization (LC_{ij}), representing the share of public funding and the concentration of the set targets of national projects by region (1);

2. Index of centralization (IC_{ij}), defined as the sum of the squared levels of centralization for each region of Russia (2) by analogy with the Herfindahl–Hirschman index. However, the centralization index has a different interpretation and is adapted to a specific task, which is to determine the degree of concentration of public financial resources and to achieve the specified target indicators of national projects in a given territory. The centralization index is calculated for each indicator included in the system, that is, the indices are determined for each indicator in the system of public funding and target indicators for the implementation of national projects (formulas 1, 2):

$$LC_{ij} = \frac{P_j}{\sum_j^N P_j}, \quad (1)$$

where P_j is the value of the *i*-th indicator in the system of indicators of budget appropriations or the system of target indicators of the national project implementation in the *j*-th region.

$$IC_{ij} = \sum_{i=1}^{M} IC_{ij}^2 = \sum_{i=1}^{M} \left(\frac{P_j}{\sum_j^N P_j} \right)^2, \quad (2)$$

where IC_{ij} is the level of centralization of the *i*-th indicator in the *j*-th region.

The centralization index (IC_{ij}) ranges from 0 to 1 (formula 3); the greater the value of this indicator, the higher the concentration of budget allocations and the level of achievement of target indicators for the implementation of national projects in a particular region.

$$0 < IC_{ij} \leq 1. \quad (3)$$

The third stage of the development of our methodology for monitoring national projects involves ranking for each index of centralization of public finance; the higher the rank, the lower the level of effectiveness of indicators for each analysed national project. The ranking is carried out by the centralization indices of financing, both in the context of national projects, %, and per one inhabitant (in rubles), etc.

The final rank of the public funding is determined on the basis of the total rank. The final total rank serves as a criterion for determining the levels (9 levels) of potential risks of the national project implementation in the system of indicators that characterize public funding. The value of the final total rank (FDH) decreases with the level of financial risks of the national project implementation and vice versa.

At the fourth stage, the ranking is carried out for each centralization index in the system of the target indicators set for the implementation of the national project, in particular, for health national projects – ICH 1, ICH 2, ICH 3, ICH 4; and for demography national projects – ICD 1, ICD 2, ICD 3, ICD 4, ICD 5, ICD 6.

A lower index of centralization for ICH 1, ICH 2, ICH 3, or ICH 4 (health national projects) or ICD 3 (demography national projects) indicates a lower rank for the target indicator. For the other indicators ICD 1, ICD 2, ICD 4, ICD 5, and ICD 6 (demography national projects), on the contrary, the centralization index decreases as the rank for the target indicator increases.

The final rank for all the target indicators for national project implementations is determined on the basis of the total rank (FTR), which serves as a criterion for determining the effectiveness of the implementation of a national project; the lower the value of the final total rank (FTR), the fewer the threats to the implementation and vice versa.

The final values in the system of public funding and target indicators for the implementation of a national project are the criteria for clustering regions according to the level of effectiveness and financial risks of the national project (Figure 1).

Target indicators	**3 FTR**	1 cluster	4 cluster	6 cluster
	2 FTR	7 cluster	2 cluster	5 cluster
	1 FTR	9 cluster	8 cluster	3 cluster
		1 FDH	**2 FDH**	**3 FDH**
		Level of funding		

Figure 1. Effectiveness matrix for national project implementations in the Russian regions based on a comparison of the level of public funding and achievement in the specified target values of the projects

The fifth stage consists in interpreting the obtained monitoring results based on the clustering of regions by public funding level and target indicators for the implementation of national projects (Table 2). For region clustering, a non-overlapping algorithm was used, according to which each region was to be included in only one cluster. The key requirement for clustering optimization was to minimize the standard error of partitioning. The cluster centre was defined using the centralization indices, which were discussed above.

Table 2. Characteristics of clusters of national project implementations in the Russian regions

Cluster name	Correlation between level of funding and target indicators	Correlation of level of effectiveness and potential financial risks of health and demography national project implementations
1 cluster	1 FDH – 3 FTR	low effectiveness / low risk
2 cluster	2 FDH – 2 FTR	balanced level of effectiveness and risks
3 cluster	3 FDH – 1 FTR	high effectiveness / high risk
4 cluster	2 FDH – 3 FTR	low effectiveness / moderate risk
5 cluster	3 FDH – 2 FTR	moderate effectiveness / high risk
6 cluster	3 FDH – 3 FTR	extremely low effectiveness / highest risk
7 cluster	1 FDH – 2 FTR	medium effectiveness / low risk
8 cluster	2 FDH – 1 FTR	high effectiveness / medium level of risk
9 cluster	1 FDH – 1 FTR	highest effectiveness / low risk

Region clustering will allow us to identify and study in detail possible local factors that contribute to problems in public funding and the implementation of national projects in the health and demography fields. In addition, the results will contribute to the development of a national strategy and of tactics adapted to a specific region in order to achieve the target values of national projects.

4. Results

The methodology was tested on the database of the Federal Treasury of Russia, the Federal State Statistics Service of the Russian Federation, and the Accounts Chamber for 2020–2021. The analysis of the implementation of healthcare and demography national projects based on the centralization indices of public funding and target indicators enables us to classify the regions of Russia according to potential threats to the implementation of these projects. Potential threats to national projects are the risks of failure to achieve the expected socio-economic effects and financial risks caused by the impacts of both external and internal economic factors. The results of clustering Russian regions in accordance with the proposed methodology for financial monitoring of national projects are presented in Table 3.

Table 3. Clusters of Russian regions according to level of effectiveness and risk in implementing national projects related to demography and healthcare

Subject of the Russian Federation	National Project Funding Class (FDH)	Class of specified target indicators (FTR)	Cluster
Magadan region	1 FDH	3 FTR	cluster 1
Altai Republic	1 FDH	3 FTR	cluster 1
Ryazan Oblast	1 FDH	3 FTR	cluster 1
Chukotka Autonomous Okrug	1 FDH	3 FTR	cluster 1
Kaluga region	2 FDH	2 FTR	cluster 2
Republic of Buryatia	2 FDH	2 FTR	cluster 2
Khanty-Mansi Autonomous Okrug	2 FDH	2 FTR	cluster 2
Sevastopol	3 FDH	1 FTR	cluster 3
Kabardino-Balkar Republic	3 FDH	1 FTR	cluster 3
Republic of Ingushetia	3 FDH	1 FTR	cluster 3
Republic of Tatarstan (Tatarstan)	3 FDH	1 FTR	cluster 3
Tyumen region	3 FDH	1 FTR	cluster 3
Chechen Republic	3 FDH	1 FTR	cluster 3
Chuvash Republic-Chuvashia	3 FDH	1 FTR	cluster 3
Amur region	2 FDH	3 FTR	cluster 4
Arhangelsk region	2 FDH	3 FTR	cluster 4
Vologda region	2 FDH	3 FTR	cluster 4
Voronezh region	2 FDH	3 FTR	cluster 4
Jewish Autonomous Region	2 FDH	3 FTR	cluster 4
Novosibirsk region	2 FDH	3 FTR	cluster 4
Primorsky Krai	2 FDH	3 FTR	cluster 4
Republic of Kalmykia	2 FDH	3 FTR	cluster 4
Republic of Karelia	2 FDH	3 FTR	cluster 4
Komi Republic	2 FDH	3 FTR	cluster 4
Republic of Khakassia	2 FDH	3 FTR	cluster 4
Tambov region	2 FDH	3 FTR	cluster 4
Tver region	2 FDH	3 FTR	cluster 4
Tomsk region	2 FDH	3 FTR	cluster 4
Tula region	2 FDH	3 FTR	cluster 4

St. Petersburg	3 FDH	2 FTR	cluster 5
Krasnodar region	3 FDH	2 FTR	cluster 5
Moscow region	3 FDH	2 FTR	cluster 5
Murmansk region	3 FDH	2 FTR	cluster 5
Penza region	3 FDH	2 FTR	cluster 5
Perm region	3 FDH	2 FTR	cluster 5
Republic of Adygea (Adygea)	3 FDH	2 FTR	cluster 5
Republic of Dagestan	3 FDH	2 FTR	cluster 5
Republic of Crimea	3 FDH	2 FTR	cluster 5
Mari El Republic	3 FDH	2 FTR	cluster 5
Rostov region	3 FDH	2 FTR	cluster 5
Udmurt republic	3 FDH	2 FTR	cluster 5
Altai region	3 FDH	3 FTR	cluster 6
Astrakhan region	3 FDH	3 FTR	cluster 6
Belgorod region	3 FDH	3 FTR	cluster 6
Bryansk region	3 FDH	3 FTR	cluster 6
Vladimir region	3 FDH	3 FTR	cluster 6
Volgograd region	3 FDH	3 FTR	cluster 6
Transbaikal region	3 FDH	3 FTR	cluster 6
Ivanovo region	3 FDH	3 FTR	cluster 6
Irkutsk region	3 FDH	3 FTR	cluster 6
Karachay-Cherkess Republic	3 FDH	3 FTR	cluster 6
Kemerovo region	3 FDH	3 FTR	cluster 6
Kirov region	3 FDH	3 FTR	cluster 6
Kostroma region	3 FDH	3 FTR	cluster 6
Krasnoyarsk region	3 FDH	3 FTR	cluster 6
Kurgan region	3 FDH	3 FTR	cluster 6
Kursk region	3 FDH	3 FTR	cluster 6
Leningrad region	3 FDH	3 FTR	cluster 6
Lipetsk region	3 FDH	3 FTR	cluster 6
Nizhny Novgorod region	3 FDH	3 FTR	cluster 6
Novgorod region	3 FDH	3 FTR	cluster 6
Omsk region	3 FDH	3 FTR	cluster 6
Orenburg region	3 FDH	3 FTR	cluster 6
Oryol region	3 FDH	3 FTR	cluster 6
Pskov region	3 FDH	3 FTR	cluster 6
Republic of Bashkortostan	3FDH	3 FTR	cluster 6
Samara region	3 FDH	3 FTR	cluster 6
Saratov region	3 FDH	3 FTR	cluster 6
Sverdlovsk region	3 FDH	3 FTR	cluster 6
Smolensk region	3 FDH	3 FTR	cluster 6
Stavropol region	3 FDH	3 FTR	cluster 6
Ulyanovsk region	3 FDH	3 FTR	cluster 6

Khabarovsk region	3 FDH	3 FTR	cluster 6
Chelyabinsk region	3 FDH	3 FTR	cluster 6
Yaroslavl region	3 FDH	3 FTR	cluster 6
Kamchatka Krai	1 FDH	2 FTR	cluster 7
Nenets Autonomous Okrug	1 FDH	2 FTR	cluster 7
Republic of Mordovia	1 FDH	2 FTR	cluster 7
Republic of Sakha (Yakutia)	1 FDH	2 FTR	cluster 7
Sakhalin region	1 FDH	2 FTR	cluster 7
Kaliningrad region	2 FDH	1 FTR	cluster 8
Republic of North Ossetia-Alania	2 FDH	1 FTR	cluster 8
Moscow	1 FDH	1 FTR	cluster 9
Tyva Republic	1 FDH	1 FTR	cluster 9
Yamalo-Nenets Autonomous Okrug	1 FDH	1 FTR	cluster 9

A detailed analysis of the obtained data confirmed a close correlation between the results of regional clustering based on the proposed method of financial monitoring and information on the achievement of the target indicators of the national projects under study – healthcare and demography. For example, the Nizhny Novgorod region fell into the 6th cluster, which is characterized by an extremely low level of effectiveness and the highest level of financial risk in the implementation of national projects in the fields. Information from the Electronic Budget system[2] and the Chamber of Control Accounts of the Nizhny Novgorod region[3] was used as a database for the established indicators of national project implementation. According to official data on total public funding of all projects, 3.4% of funds were allocated for the implementation of the healthcare national project and 20.2% of funds were allocated for the demography project. According to information published by the Nizhny the Chamber of Control Accounts of the Nizhny Novgorod region, the percentage of deviations from the target values for the demography project was 27.3% and for the healthcare project 39.0%. According to the Federal State Statistics Service, the Nizhny Novgorod region ranked 60th in terms of birth rate and 65th in terms of mortality rate among the regions of the Russian Federation in 2021, while decreases in birth rate and life expectancy and increases in mortality rate and morbidity were recorded. In accordance with the methodology for calculating the Federal State Statistics Service, the highest rank (place) is assigned to regions with the most critical values of indicators (the higher the rank, the worse the socio-economic indicators). Thus, the negative trends in the fields of healthcare and demography confirm the low effectiveness of national project implementations in the Nizhny Novgorod region, justifying its place in the 6th cluster.

5. Discussion

The results of the study confirm the applicability of cluster analysis to assessing the effectiveness of national projects, based on the correspondence of public funding volume with national project target value achievement, which has been discussed in a number of research works (Khayrullina, 2014; Revnyakov, 2017; Pushkarev, 2018). However, it was proved that the amount of public funding for national projects is not a determining factor in the success of their implementation, which was also noted in the work of Ezangina and Gromyshova (2020). For example, among the regions with the largest amount of funding, only three (Moscow, Tyva Republic, Yamalo-Nenets Autonomous Okrug) fell into the 9th cluster, which is characterized by the highest level of effectiveness and low financial risk. At the same time, the Republic of North Ossetia-Alania is characterized by a high level of effectiveness in the implementation of national projects, with a moderate financial risk despite the relatively low volume of public funding.

It is obvious that the financial monitoring of national projects should be carried out taking into

[2]Unified portal of the budget system of the Russian Federation “Electronic budget”. https://budget.gov.ru/Регионы
[3]Chamber of Control and Accounts: official website. https://ksp.r52.ru/

account the relationships and interdependence of the results achieved (Balkhi et al., 2021; Wirayuda and Chan, 2021; Ivankova et al., 2022); therefore, the proposed methodology can be improved by expanding the set of national project indicators and developing models based on them.

6. Conclusion

The study confirmed the importance of improving financial monitoring as an element of state control over the implementation of national projects in the Russian regions.

The hypothesis was proved that the risks of not achieving the targets of national projects in the fields of health and demography reinforce each other. The problems in achieving target indicators for healthcare and demographic national projects implementation in the Russian regions are caused by the following factors:

- lack of one-time support for the births of fourth, fifth, and subsequent children;

- lack of in vitro fertilization cycles for families with infertility;

- low employment level for women with children of preschool age;

- lack of access to preschool education for children aged 1.5 to 3 years;

- insufficient coverage of citizens older than working age with preventive examinations, including clinical examinations;

- lack of geriatric centres and geriatric departments;

- high mortality rate of women aged 16–54 and men aged 16–59 years;

- insufficiency of public funding to meet national goals in the fields of health and demography in regions with insufficient own financial resources; and

- shortage of personnel to meet national goals in the fields of health and demography.

The correlation of the results of the study with the actual implementation of national projects confirms the effectiveness of the proposed methodology for their financial monitoring based on cluster analysis. The data obtained in the course of monitoring can be used by state authorities to develop a flexible strategy for national project funding in the Russian regions, taking into account the level of target indicator achievement.

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Systematisation of Drivers for the Development of Socioeconomic Systems

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Abstract

The Russian economy's recovery processes during the postcrisis period are accompanied by clear heterogeneity in the development of regional socioeconomic systems. Domestic researchers note that over the past twenty years, the level of regional competition for both labour and financial resources has increased. For example, in the Russian Federation, in the period from 2011 to 2018, the number of labour migrants within the country increased by 1.59 times from 1894.1 thousand to 3,004.2 thousand people (although the 2018 figure decreased by 3% to 2928.0 thousand people in 2019), and the inflow of foreign investment for the period from 2011 to 2018 decreased by 40.4%. At the same time, in 2018, the largest share of foreign direct investment accounted for by the Central Federal District was 60%. Differentiation of regional development is complicated not only by economic, but also by natural, ecological, ethnic, political and other factors. In this regard, the role of a competent economic policy at the regional level is increasing, the main goal of which should be the sustainable development of territories in conditions that change under the influence of these factors. Thus, 'the implementation of an effective regional policy in the context of the overall development of the country's economy is impossible without an analysis of regional specialisation and concentration of production in the country'. Therefore, the purpose of this study is to analyse the theoretical foundations for determining the specialisation of regional socioeconomic systems and the formation of a classification of factors influencing the development of regional socially significant systems. The study is based on the scientific works of Russian authors in the field of competitiveness, regional differentiation, the geoeconomic position of a region and its economic independence and development prospects.

Keywords: regional competitiveness, specialisation formation factors, the regional differentiation problem, sustainable regional development

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Систематизация Драйверов Развития Социально-Экономических Систем

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Аннотация

Процессы восстановления российской экономики в посткризисный период сопровождаются явной неоднородностью развития региональных социально-экономических систем. Отечественные исследователи отмечают, за последнее двадцатилетие возрастает уровень региональной конкуренции как за трудовые, так и финансовые ресурсы. Так, например, в период с 2011 по 2018 года в Российской Федерации количество трудовых мигрантов внутри страны возросло с 1894.1 тыс. до 3004.2 тыс. человек, т.е. в 1.59 раз (но в 2019 году сократилось на 3% по сравнению с 2018 годом до 2928 тыс. человек), а приток иностранных инвестиций за период с 2011 по 2018 сократился на 40.4% (при этом в 2018 году наибольшая доля прямых иностранных инвестиций приходилась на Центральный федеральный округ, 60%). Дифференциацию регионального развития осложняют не только экономические, но и природные, экологические, этнические, политические и прочие факторы. В этой связи возрастает роль грамотной экономической политики на региональном уровне, главной целью которой должно являться устойчивое развитие территорий в меняющихся под влиянием данных факторов условий. Таким образом, проведение эффективной региональной политики в контексте общего развития экономики страны невозможно без анализа региональной специализации и концентрации производства в стране. Следовательно, целью данного исследования является анализ теоретических основ к определению специализации региональных социально-экономических систем и формирование классификации факторов, влияющих на развитие региональных социально-значимых систем. Исследование базируется на научных трудах отечественных авторов в области конкурентоспособности, региональной дифференциации, геоэкономического положения региона, его экономической самостоятельности и перспектив развития.

Ключевые слова: конкурентоспособность региона, факторы формирования специализации, проблема дифференцированности регионов, устойчивое развитие региона

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1. Introduction

The competitiveness of a national economy is determined by the competitive capabilities of regional socioeconomic systems, which are considered local centres for generating benefits. Accordingly, the choice of directions for regional development is critical. The differentiation of regional development is complicated not only by economic but also by natural, ecological, ethnic, political and other factors. The relevance of this study is dictated by the growing role of a competent economic policy at the regional level, the main goal of which should be the sustainable development of territories in conditions that change under the influence of these factors. Thus, 'the implementation of an effective regional policy in the context of the overall development of the country's economy is impossible without an analysis of regional specialisation and concentration of production in the country' (Rodionov et al., 2019(a)). The purpose of this article is to analyse the theoretical foundations for determining the specialisation of regional socioeconomic systems and to study the classifications of factors that influence the development of regional socially significant systems.

A large number of works by scientists in three main areas are devoted to the development of the theory of regional specialisation: the 'neoclassical theory of economics, new trade and new economic geography' (Rodionov et al., 2019(a)). Regional specialisation, regardless of approach or direction, is based on a set of factors that explain it (Rodionov et al., 2019(b)). At the same time, as Rastvortseva (2012) notes, 'all the factors that underlie the definition of regional specialisation can be divided into two main groups: "primary factors (geography and natural resources) and secondary (geographical distance between economic agents)"'. Depending on the direction, these factors, in different combinations, form the basis of regional specialisation. 'So, for example, neoclassical theory emphasises the role of primary factors, and the theory of new trade, in turn, supplements primary factors (geographical location, availability of production factors, technologies) with secondary ones' (Rastvortseva, 2018).

As Vasiliev (2007) notes, the distinctive features of the region – diversity of resources and conditions for economic activity – form the prerequisites for the specialisation of regions. At the same time, the specialisation of regional socioeconomic systems is directly related to the ability of the territories to effectively produce mass products – that is, to use available economic and natural resources to reduce the cost of products (Vasiliev, 2007; Kudryavtseva and Shvediani, 2018). An important aspect in this case is the concentration of any industry in the region, which can be represented as a set of geographically neighbouring organisations united by the field of activity and complementing each other, or, in other words, clusters (Frevel, 2013). Cluster theory is currently being widely studied by both foreign and domestic scientists (see, e.g., Rastvortseva and Kuga, 2012; Shvediani and Kudryavtseva, 2018). Within the issue of regional specialisation, cluster theory once played an important role by explaining the emergence of positive economic effects from the concentration of high-tech industries in one territory. Graphic systematisation is shown in Figure 1.

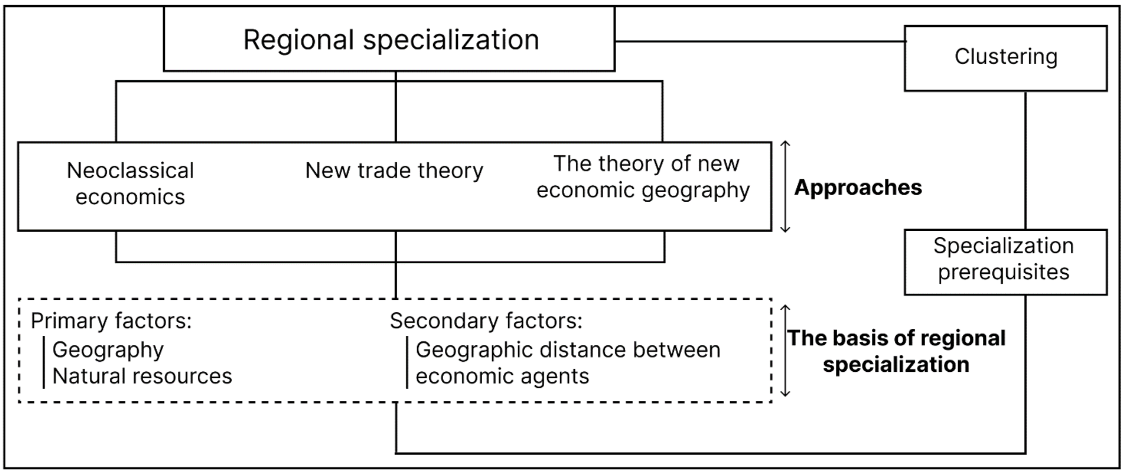

Figure 1. Theoretical aspects of the formation of regional specialisation

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Thus, to summarise, the basis of regional specialisation rests on external factors, such as geographical location, the availability of a resource base for production, the spatial location of enterprises and their interaction with each other, as well as the internal ability of regions to effectively manage external factors for the production of a regional product. It is these provisions that unite various interpretations of regional specialisation, which, in general, can be understood as the dominance of any type of economic activity in a certain territory (Rastvortseva and Kuga, 2012), the result of which is that products focused on satisfying not only their own needs but also the needs of other regions or, in some cases, export oriented (Vasiliev, 2007).

2. Literature Review

The prerequisites for uneven regional socioeconomic system development may be the differences in the elements that form the regional systems at the institutional, technical and technological, social, economic, environmental and other levels, which cause deformation and reduce the efficiency of the functioning of these systems (Buvaltseva and Sokolovsky, 2008). At the same time, Buvaltseva and Sokolovsky (2008) note that it is precisely 'the results of the process of forming the spatial structure of the national economy' that have the greatest influence on the differentiation of regions, as a result of which there has been a shift in redirecting national income to some regions to the detriment of others. On the one hand, the infrastructural, resource, technological and production potential accumulated in a region determines the directions of development of regional specialisation; on the other hand, it increases the gap between those regions that were once deprived of these resources.

The differentiation of regions, which is based on their specialisation, is currently being studied with great interest by domestic researchers. Thus, in a study by Rastvortseva (2018), the author carried out an analysis of the spatial economic dynamics to identify the differentiation of the regions of the Russian Federation by assessing the specialisation (using the Krugman Specialisation Index) and concentration of industrial production (using Herfindahl–Hirschman indicators, the Gini Index, the Krugman Concentration Index and concentration ratios 3 and 4 (CR3 and CR4). According to the results of the study, Rastvortseva uggested that during the analysed period (from 2002 to 2010), there was a decrease in the specialisation index in 78.5% of the regions, while in the rest, either an increase or an absence of any structural changes was observed. After ranking regions according to the degree of specialisation, Rastvortseva (2018) identified three groups of regions.

1. 'Regions with a high degree of specialisation (regions with a strong extractive sector), which are characterised by an excess of the average value of GRP per capita, labour productivity and wages, and the unemployment rate in such regions is close to the national average.

2. Other regions – regions with a high value of the specialisation index, but with lower than the national average indicators of GRP, wages and labour productivity, and on the contrary, a high unemployment rate relative to the national average.

3. Regions with a low level of specialisation, which are characterised by the lowest level of specialization, GRP per capita, labour productivity, wages, and low unemployment (which, according to the author, is the result of the diversification of the manufacturing industry in the region)'.

It should be noted that one of the main results of Rastvortseva's (2018) work is undoubtedly the conclusion that 'narrow specialisation in any sector of industry' can afford 'only regions that ensure the development of the economy through mining', which generally confirms the raw material orientation of the Russian economy.

For the purposes of analysing and identifying the different points of view that Russian authors have adopted on the issue of differentiation of Russian regions, which is based on their specialisations, we will consider the work of Kutsenko and Eferin (2019). In their study, based on the methodology of the European Cluster Observatory, the authors conducted a comprehensive study on the topic of industry specialisation and the dynamics of development of regions in the Russian Federation in the period from 2005 to 2015 (eighty constituent entities of the Russian Federation participated in the selection, but the analysis was carried out only for seventy-one due to the absence of a pronounced concentration of industries in a number of regions) (Kutsenko and Eferin, 2019). Using statistical analysis methods, data including average employee numbers and data on accrued wage indicators by industry, Kutsenko and Eferin (2019) determined that in 2015, considering the number of industries of specialisation and the degree of their development, the regions were divided into four main categories.

1. 'Agglomeration' (high indicators of the number of specialised industries and their levels of development: St. Petersburg, the Leningrad region, Moscow and the Moscow region, the Republic of Tatarstan).

2. 'Diversification' (a large number of areas of competence not distinguished by high growth rates: for example, the Vladimir, Yaroslavl and Kirov regions).

3. 'Specialisation' (regions characterised by a narrow set of professional activity areas: for example, the Murmansk, Tyumen and Rostov regions).

4. 'Differentiation' (regions characterised by a small number of specialised industries and a low degree of development: for example, the Republic of Buryatia and the Tambov and Astrakhan regions).

The typology of sectoral development identified by the authors of the study was compared with 'dynamic development models, such as "emergence", "intensification", "fading", and "disappearance"', which allowed Kutsenko and Eferin (2019) to identify the following pattern: 'regions with a large number of industries of specialisation (types of "agglomeration" and "diversification") are subject to large-scale structural changes, while regions of the "specialisation" or "differentiation" type are characterised by a wide variability of structural models, which can be explained, first of all, by geography'. 'Structural changes are most often observed in the regions of the western part of Russia, while for the eastern part the situation is the opposite: either no changes occur, or there is a "disappearance" of specialization industries' (Grinchel and Nazarova, 2019). Factors such as proximity to million-plus cities play an important role, and the authors of the study found that the greatest structural changes occur 'around the territories where such cities are present; in areas remote from economically developed centres, these processes are rarely carried out' (Kutsenko and Eferin, 2019). The observed regularities allowed the authors of the study to formulate a new typology of regions according to the speed of structural changes: regional location zones described as 'funnel', 'streams' and 'safe haven'. Thus, 'the approach developed by the authors formulates theoretical grounds for clarifying the measures of sectoral development in regions that differ in the pace of structural transformations, proximity to large agglomerations, and sensitivity to changes in the sectoral portfolio' (Kutsenko and Eferin, 2019).

In the context of Russian regions' increased interest in innovation, one promising area in the theory of regional development has become 'smart specialisation' (Kutsenko et al., 2018). Unlike the classical idea of the essence of specialisation, 'smart specialisation' is 'a set of rules for choosing priority areas within the framework of an innovative development strategy based on the competitive advantages of each region and the compliance of the strengths of the scientific and technical sphere with market needs' (Zemtsov and Barinova, 2016; Kutsenko et al., 2018). At the same time, 'smart specialisation' lies at the intersection of industries, and its interdisciplinary focus allows it to benefit from the advantages of new, rapidly growing areas of science and technology, which increases a region's chances of leadership (Kutsenko et al., 2018). From the point of view of regional management, 'smart specialisation' makes it possible to differentiate competencies and support measures for regions, thereby avoiding duplication and excessive or even unreasonable support from federal authorities (Zemtsov and Barinova, 2016).

Today, the problem of developing an effective innovation policy remains relevant for regions within the Russian Federation (Afanasyeva, 2014; Bekov et al., 2009). Using 'smart specialisation' principles at the regional level will make it possible to move away from 'the paradigm of supporting research and innovation activities of all regions, regardless of their priorities, specific features, geographic location and resource provision, and move to a strategy to support regions with high innovative potential'

(Zemtsov and Barinova, 2016). Zemtsov and Barinova (2016) considered the use of 'smart specialisation' principles to justify the need for a differentiated innovation policy within the Russian Federation. In this study, the authors performed a cluster analysis, which resulted in a new typology of regions and cities for the purpose of developing reasoned measures to support the innovative development of territories and other tools within the framework of regional innovation policy. Thus, the authors of the study identified seven categories of regions: the first group represents global centres for the development of innovations, including the federal cities of Moscow and St. Petersburg, which are characterised by concentrated innovation cycle stages that convey the maximum potential for innovative development and the presence of a developed infrastructure. Further, the regions are ranked according to the degree to which certain indicators decrease, which characterises their innovation potential, infrastructure equipment and industry specialisation. The typology of regions and a brief description of the identified groups are presented in Table 1.

Table 1. Typology of Russian Federation regions and their descriptions (Zemtsov and Barinova, 2016)

Region Type	Region Type Description
Global centres (Moscow, St. Petersburg)	'Concentration of all stages of the innovation cycle, maximum potential (largest agglomerations), developed innovation infrastructure, etc.'
Multifunctional innovation centres	'High potential, diversity of functions of the innovation system, centres for the creation and diffusion of innovations on an all-Russian scale, high concentration of human capital, developed infrastructure'
Specialised creative regions	'Medium-high potential, innovative systems are specialised in a number of scientific and industrial sectors. Presence of large cities and agglomeration effects'
Acceptor-creative research and production regions	'Average potential, but high research and production potential remains. The presence of strong technical universities and large enterprises. Active introduction of new technologies and methods in the manufacturing sectors. Predominance of localisation effects'
Strongly accepting middle regions	'Average potential. They borrow and implement more new technologies and products than they create. There is a group of raw materials and agricultural regions'
Weakly acceptor semi-peripheral regions	'Low to medium low potential. New technologies for the country are not being created. Diffusion of innovations due to remoteness or due to institutional factors is limited, new technologies are being introduced with low intensity'
Underdeveloped peripheral regions	'Weak innovative potential, low innovativeness of regional communities. High share of extraction of raw materials and agriculture in the economy'

According to Zemtsov and Barinova (2016) themselves, 'this typology requires further clarification for specific regions, with a preliminary identification of the scientific and industrial specialisation of the region'. In general, in our opinion, a strategy of regional innovation development that is based on the principles of 'smart specialisation' and focuses on supporting regions that have the potential and resource opportunities for the development and diffusion of innovations can become a promising strategy area for ensuring the balanced economic development of subjects of the Russian Federation. The research included in the literature review is presented in Table 2.

Table 2. Literature review systematisation

Author(s)	Research Content	Methodology	Results
(Rastvortseva, 2018)	Analysis of spatial economic dynamics to identify the differentiation of the regions of the Russian Federation	Assess the specialisation (via the Krugman Specialisation Index) and concentration of industrial production (via the Herfindahl–Hirschman scores, the Gini Index, the Krugman Concentration Index and the CR3 and CR4 concentration scores)	Three groups of regions: - regions with a high degree of specialisation - regions with a low level of specialisation - other regions

(Kutsenko and Eferin, 2019)	Analysis of differentiation of Russian regions based on specialisation according to the methodology of the European Cluster Observatory	Statistical analysis using data on average employee numbers and accrued wage indicators by industry	Four categories of regions: - agglomeration - diversification - specialisation - differentiation
(Zemtsov and Barinova, 2016)	Changing the paradigm of regional innovation policy in Russia from alignment to 'smart specialisation'	Cluster analysis based on the principles of 'smart specialisation' (innovative potential indicators, infrastructure equipment and industry specialisation)	Seven types of regions: - global centres - multifunctional innovation centres - specialised creative regions - acceptor-creative research and production regions - strongly accepting middle regions - weakly acceptor semi-peripheral regions - underdeveloped peripheral regions

Thus, identifying sectoral specialisation in regional socioeconomic systems is important for the development of territories. Determining priority areas for development is impossible without clarifying external factors and a region's internal capabilities for implementing innovative socioeconomic development strategies (Gretchin and Polyanin, 2015; Dokukina and Polyanin, 2014). Analysing regional specialisations makes it possible to comprehensively study the dynamics of a region's development and differentiate all subjects according to the degree of their resource equipment and the possibility of production, on the basis of which to form reasonable requirements for regional authorities in the field of structural development of territories in order to obtain the maximum economic and social effect.

3. Materials and Methods

The literature review set the direction for further research into the classifications of economic factors and provided a rationale for focusing on factors related to science and innovation policy, wages and working conditions and traditional economic indicators. As highlighted in the literature review, the increase in the level of competition in world markets through the introduction of the results of intellectual and innovative activities, as well as a number of other equally important external factors, has affected regional socioeconomic system development in the Russian Federation indirectly or directly (Ivanov, 2006; Polyanin et al., 2014). To date, the domestic literature presents a wide variety of methods for assessing regional socioeconomic system development, which differ not only in the methodological apparatus used but also in the rationale for choosing the resulting indicators of regional development. To date, domestic authors, including those based on the fundamental works of foreign researchers, offer various methods for assessing regional socioeconomic system development.

It is difficult to form a unified classification of the economic factors that influence regional development because the Russian Federation is characterised by large territories and a number of climatic, geographical, ethnographic and other conditions that differentiate the regions significantly in terms of both the material and human resources available to them, which in turn determines the specifics of regional development. Domestic researchers agree that for the purposes of sustainable development of territories and the state as a whole, considering the principles of integrated and systematic approaches. The management system for the socioeconomic development of regions should consider all factors and conditions that affect the resulting indicators of territorial functioning as well as their competitiveness

(Bashirova, 2018; Rudenko, 2017; Shaporova et al., 2017).

The study uses modern general scientific methods: content analysis of modern and domestic scientific literature, synthesis and systematisation. The theoretical basis of the study is founded on articles by Russian authors in the fields of competitiveness, regional differentiation, regional geoeconomic positioning, regional economic independence and regional development prospects.

4. Results and Discussion

Bashirova (2018) notes that the conditions for the formation and development of regional socio-economic systems can be understood as a set of 'circumstances that characterise regional development both at the present time and the initial level (basic) of the economic development of the region, its parameters relative to the position susceptibility to innovation and socio-economic transformation'. In this context, Bashirova (2018) understands factors as 'a set of driving forces, reasons that determine the direction of the socio-economic development of the region and that can influence the sustainability and balance of this development'. Shaporova et al. (2017) offered a more comprehensive definition of the conditions for regional socioeconomic system development and presented them as 'a set of processes and relationships necessary to create and change the internal and external structures of the socio-economic system'. At the same time, the authors characterise the factors of development in the same way – as 'driving forces'. The interpretation of these economic categories in the study is interesting, and Lukyanenko (2014) points out that the factors of regional socioeconomic system development are 'the main resource of production activity and the economy as a whole; the driving force of economic, production processes that influence the result of production, economic activity', while under the basic conditions for the functioning and development of regional socioeconomic systems, the author understands 'the totality of factors (resources) possessed by this system'.

Despite different approaches to determining the factors and conditions for regional socioeconomic system development, the authors agree that these categories are not only interconnected through their influence on regional socioeconomic systems but are also capable of influencing each other. Thus, 'conditions allow the formation and change of factors, which, in turn, stimulate the transformation of conditions in accordance with adaptation to the new realities of the existence of socio-economic systems' (Bashirova, 2018).

To date, the domestic literature has accumulated major theoretical baggage related to the detailed classifications and typologies of factors and conditions for regional socioeconomic system development. At the same time, according to Bashirova (2018), it is impossible to accurately state the strength and nature of the influence of the identified factors; for example, not only can positive factors (such as the inflow of foreign direct investment or the growth of innovative activity in the region) have a stimulating effect, but negative ones, which can provoke governments to use extraordinary development tools, can also lead to stimulation. The next step of research is to consider several classifications of factors and conditions for the development of social and economic systems at the regional level proposed by domestic researchers.

The simplest classification considered is the division of 'factors into internal and external, which allows focusing on the location of the factors and subsequent qualitative assessment of the level of development of the region' (Lukyanenko, 2014). Thus, Dambueva and Boloneva (2019) distinguish between internal factors (e.g. institutional, organisational and managerial, market, natural resources, sociopolitical, scientific and technological progress) and external factors (e.g. political, legal and social). Gavrilov (2002) notes that environmental factors – external suppliers of goods and services, external consumers, competing regions, financial organisations, transport enterprises, general economic, general political, natural and environmental, demographic, scientific and technical factors – can also have an indirect influence. Gavrilov (2002) refers to the factors of the internal environment: 'the production and resource potential of the region; structure of the regional market; personnel potential of the region; regional budget; regional development strategy'. One of the main drawbacks of dividing factors by source of influence is the impossibility, based on the chosen typology, of identifying the specific features of a particular region and assessing their innovative attractiveness. In this regard, an approach was proposed to structure the factors that influence regional development, which consists of two main groups:

- *'traditional development factors* that ensure the ability to meet the demands of society, which are the factors of competitiveness;

- *attractive (innovative) factors of development* that characterise the unique features and attractiveness of the regional socio-economic system, which makes it possible to evaluate competitive advantages. Examples of attractive factors are natural, such as natural conditions or resources, and economic factors, such as labour resources, infrastructure, scientific and technological factors, etc.' (Lukyanenko, 2014).

An important feature of this classification is the duality caused by factors belonging to multiple groups. For example, scientific and technical factors can belong both to the group of traditional factors (i.e. characterising technological solutions in the process of production activities) and to the group of attractive ones (i.e. as a unique technology for the production of a product or service, such as innovation). Kisurkin (2012) suggests considering the factors and conditions of socioeconomic system development at the regional level and from the standpoint of an innovative approach. This approach is unique in that it makes it possible to solve a number of tasks aimed at achieving effective regional socioeconomic system development, including the following:

- searching for essential factors in the region's development,

- determining the institutional conditions for the region's development,

- identifying interrelations and hierarchy of the structure of factors,

- determining the optimal ratio of invested funds and the obtained scientific results, and

- evaluating the region's response to the impact of the identified factors of innovative development.

The result of Kisurkin's (2012) study is a classification of factors that influence innovative regional socioeconomic system development, as obtained by the multicriteria classification of direct and indirect factors divided into blocks (groups) of socioeconomic indicators for the purposes of applying the managerial approach. Figure 2 shows a graphical representation of the classification proposed by the author according to meaningful and formal features.

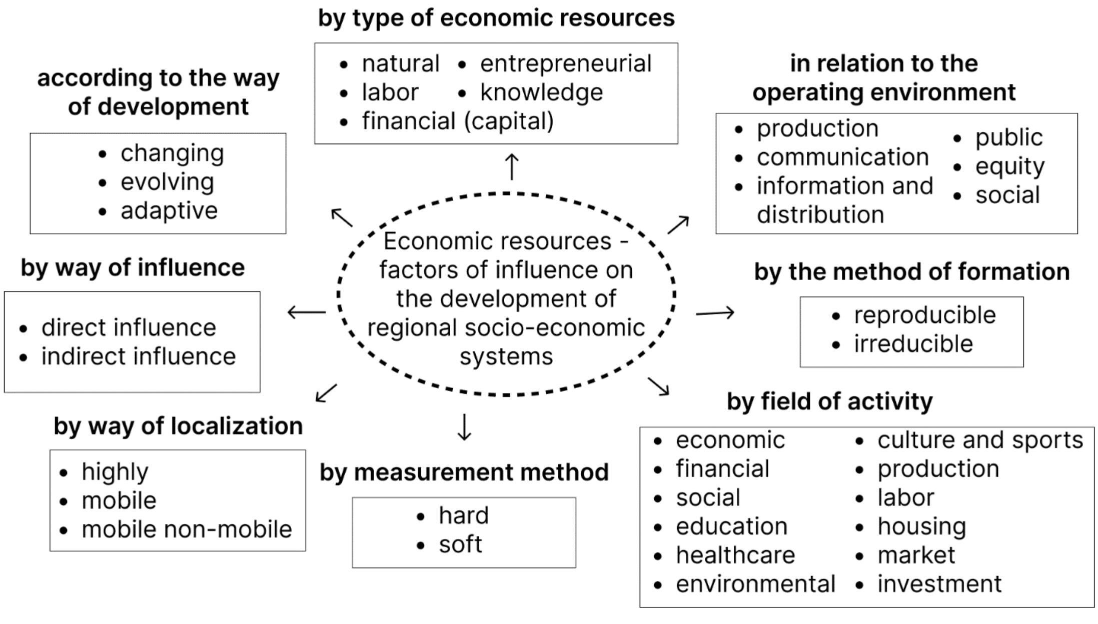

Figure 2. Classification of economic resources: factors influencing regional socioeconomic system development (Kisurkin, 2012)

Among the features of the classification presented by Kisurkin (2012), we note the feature 'according to the method of measurement', within which 'soft' and 'hard factors' are distinguished. This approach is often found in domestic review articles with links to foreign sources (Bashirova, 2012; Rudenko, 2017). The classification under consideration makes it possible to combine diverse factors in terms of the possibility of a quantitative assessment. So, among the hard (i.e. quantitatively measured) factors, we distinguish the following: factors focused on production resources, factors established and regulated by the state (e.g. tax systems, budget allocations, subsidies, other support programmes, etc.) and factors oriented to the manufacturing and service sectors (e.g. infrastructure, population and consumption patterns). Soft factors include those that cannot be quantified and that characterise the stability of the political system and social climate, the structure of the economy and individual economic entities, the quality and accessibility of the education system, health care, quality of life in the region and others.

The results of a study by Uraev et al. (2016) are interesting, and the authors consider the process of strategic regional socioeconomic system development using the example of an enterprise in the radio-electronic industry in the Republic of Tatarstan. Thus, the authors identified two large blocks that have direct and indirect impacts on various aspects of an enterprise's activities as a socioeconomic system:

1. The microenvironment, which is the immediate environment of the enterprise (i.e. the socioeconomic system), is formed by suppliers, consumers, dealers, marketing agents, existing and potential competitors and other entities.

2. The macroenvironment, which has an indirect impact on the activities of the enterprise through the activities of environmental actors (e.g. state, markets, financial institutions, etc.; Uraev et al., 2016).

Based on the need to jointly study the factors and conditions for the development of regional socioeconomic systems, Sharipova et al. (2017) considered three main approaches to the formation of an interconnected system of these categories based on the context of global economic systems (industrial and postindustrial economies). Table 3 summarises the characteristics of these approaches.

Table 3. Characteristics of approaches to forming a system of the factors and conditions of regional socioeconomic system development (Sharipova, 2017)

Approach	The regional socioeconomic system acts as...	System Development Factors	System Development Conditions
First approach: the system of priority factors in an industrial economy	A structural element of the industrial economy.	Natural resources, production capacity, human resources, research potential.	The totality of balanced factors forms the conditions for the development of regional socioeconomic system functioning.
Second approach: life cycle factors in a postindustrial economy	A resource base of the postindustrial economy.	The main factor of development is capital (factors of production) and services (or 'exclusive post-industrial product').	The totality of production factors (capital) forms the conditions for regional socioeconomic system development.
Third approach: factors of the internal and external environment in the conditions of the formation of a regional socioeconomic system	—	In this approach, the conditions and factors for the development of regional socioeconomic systems are equal (e.g., the institutional factor forms the institutional development environment).	

Based on the proposed classification, as well as the identified shortcomings, the authors of the study propose models for regional socioeconomic system development that consider the operating factors and necessary conditions for development. In the proposed models of 'progressive' regional socioeconomic systems – that is, systems that easily adapt to changing conditions – the authors identify the factors and conditions of development as follows:

- reducing fluctuations in governance at the regional level,
- regulating current risks,
- influencing federal development authorities,
- long-term interests of society,
- technological institutionalisation of the regional economy,
- spatial localisation, etc.

For ‘unstable’ regional socioeconomic systems – that is, systems that under conditions of adaptation to a changing environment cannot withstand competition and demonstrate the results of stagnant activity – the following ‘stabilising’ factors and development conditions are characteristic:

- regional budget,
- rendering assistance to large subjects of the system,
- creating economic zones,
- disseminating (diffusing) innovations,
- diversifying regional production specialisations, and
- maintaining a balance of priorities.

According to Malinin et al. (2019), in the current conditions of globalisation and increased world competition, the strongest impact on regional socioeconomic system development is exerted not only by the internal factors of national and regional economies but by the global factors of the modern world economy. Considering regional socioeconomic system development from the perspective of increasing competitiveness in world markets by increasing the productivity of available natural and economic resources, the authors distinguish between internal development factors (or factors of the internal environment): ‘the specifics of entrepreneurial the environment caused by the institute of entrepreneurship that has developed in the region; a specific combination of possible types of entrepreneurial activity, characteristic only for a given region’ (Malinin et al., 2019). Among the external development factors (factors of the external environment), the authors single out the geoeconomic position of the region and its ‘embedding’ in the overall picture of the formation of a single geoeconomic space (country and world).

In the current realities of the national economic system, the solution to most socioeconomic issues, including the issues of access to education, healthcare, housing, environmental protection and improving the quality of life of the population, has been moved to the regional level (Bashirova, 2018). At the same time, given Russian management practices at the regional and local levels, domestic researchers focus on the fact that most regions ‘adhere to a position of expectation’ and do not seek either economic independence or an active regional socioeconomic policy (Bashirova, 2018; Baranova, 2019; Smeshko, 2014). Despite this, Zimakova et al. (2019) note that regional socioeconomic systems within the Russian Federation have great potential for accelerated territorial development; however, the management of this development requires a better orientation than before, one that takes into account the influence of environmental factors and conditions on the functioning of these systems. At the same time, further promises about the development of regions and the country as a whole should be accompanied by innovative approaches to understanding the nature of socioeconomic processes at the local and regional levels (Bakharev et al., 2018; Konnikov et al., 2019). Moreover, it is necessary to understand that the constant impact of a combination of factors forces a regional one. The system is constantly changing and adapting to new conditions (Polyanin and Makarova, 2014). Thus, the more complex and dynamic the environment in which regional socioeconomic system development must take place, the more flexible and adaptive the regional management system should be (Bashirova, 2018).

5. Conclusion

This article discusses the theoretical aspects of the formation of regional specialisation. Based on scientific articles by domestic authors on regional differentiation within the Russian Federation and classifications based on them, this article analyses approaches to determining the factors and conditions for regional development and characterises approaches to forming a system of factors and conditions for regional socioeconomic system development. The conclusions reached by the author as a result of the study are as follows:

1. The basis of regional specialisation is founded on external factors, such as geographical location, the availability of a resource base for production, the spatial location of enterprises, their interactions with each other and the internal ability of regions to effectively manage external factors for the production of a regional product.

2. The analysis of regional specialisation makes it possible to comprehensively study the dynamics of a region's development and to differentiate all subjects according to the degree of their resource equipment and the possibility of production potential, on the basis of which it is then possible to create reasonable requirements for regional authorities in the field of territorial structural development to obtain the maximum economic and social effect.

3. In modern conditions of globalisation and increasing world competition, the strongest impact on the development of regional socioeconomic systems is exerted not only by internal national and regional economic factors but also by global factors related to the modern world economy.

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SECTION 3

SUSTAINABLE DEVELOPMENT OF REGIONAL INFRASTRUCTURE

РАЗДЕЛ 3

УСТОЙЧИВОЕ РАЗВИТИЕ РЕГИОНАЛЬНОЙ ИНФРАСТРУКТУРЫ

Research article
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Developing technologically innovative industrial infrastructural facilities for their better efficiency: case study of technology parks in Russia

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Abstract

The article discusses an approach to forming a model for evaluating the efficiency of a typical technologically innovative industrial infrastructural facility using a nonparametric modelling. The study models and measures the efficiency of technologically innovative industrial infrastructure (case study of technology parks in Russia) by using a data envelope analysis (DEA) method. Facilities are identified as efficient or inefficient from the standpoint of the DEA methodology, and the evaluation results are compared with the results obtained in the Technopark National Ranking. The article also presents recommendations for making technologically innovative industrial infrastructural facilities more efficient in accordance with the results of the modelling; it substantiates the mechanism of ensuring the competitiveness of technologically innovative industrial infrastructural facilities of the same type, based on the technical efficiency achieved by a facility, as a result of solving an optimization problem using the shell data analysis method.

Keywords: technologically innovative industrial infrastructure, development of innovative infrastructure, technical efficiency, data envelope analysis

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Развитие Объектов Производственно-Технологической Инновационной Инфраструктуры с Целью Повышения Эффективности Их Функционирования на Примере Технологических Парков России

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Аннотация

Статья затрагивает вопросы разработки подхода к формированию модели оценки эффективности типового объекта производственно-технологической инновационной инфраструктуры посредством непараметрического моделирования. В рамках исследования смоделирована и оценена эффективность производственно-технологической инновационной инфраструктуры (на примере технологических парков России) посредством метода оболочечного анализа данных (Data Envelopment Analysis, DEA), выявлены эффективные и неэффективные объекты с точки зрения методологии DEA; результаты оценки сравнены с результатами, полученными в рамках расчета Национального рейтинга технопарков. Автором предложены методические рекомендации по развитию объектов производственно-технологической инновационной инфраструктуры с целью повышения эффективности их функционирования с учетом результатов моделирования; обоснован механизм обеспечения конкурентоспособности объектов производственно-технологической инновационной инфраструктуры одного вида, основанный на достижении объектом технической эффективности в рамках решения оптимизационной задачи посредством метода оболочечного анализа данных.

Ключевые слова: производственно-технологическая инновационная инфраструктура, развитие инновационной инфраструктуры, техническая эффективность, Data Envelopment Analysis, метод анализа оболочки данных

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1. Introduction

The gradually forming dependence of economic development on institutional conditions and the larger roles of investment and new technology in accelerating economic growth have led to an innovative economy based on the formation and development of national and regional innovation systems wherein various innovative infrastructural facilities are growing and spreading. According to Article 2 of Federal Law No. 127-FZ of 23.08.1996 "On Science and State Scientific and Technical Policy", innovation infrastructure is a set of organizations that contribute to the implementation of innovative projects, including through providing managerial, logistical, financial, information, personnel, consulting, and organizational services.

Technological industrial infrastructure provides innovative production facilities with access to an industrial environment and is a type of infrastructure for innovative activity (Khanchuk and Semke, 2016). Technological industrial infrastructure for innovative activity includes innovation and technology centres, technoparks, innovation and industrial parks, technology clusters, technology and innovation zones, centres for the collective use of technology, business incubators, engineering centres, cluster development centres, special economic zones, science cities, advanced development territories, spinouts, internal ventures, and innovative development zones (Chistyakova, 2018; Zemtsov, 2011).

Innovative infrastructural facilities, which are increasing in number and type, often have subtle differences, which aggravates the problem of their systematization and the design of programmes for their development. Moreover, in literature, in practice, and in the reports of regulatory authorities, authors often highlight the insufficient efficiency of innovative infrastructure. No complete evaluation of the efficiency of (most) types of production and technologically innovative infrastructure has been presented since most facilities have been in operation for a relatively short time and are significantly diverse; further, there are either no methods for evaluating their efficiency or these methods have significant shortcomings.

This study puts forward recommendations for the development of technologically innovative industrial infrastructural facilities (using an example of technoparks) in order to increase their efficiency. The objectives of the study were to develop a methodological approach to building a model for evaluating the efficiency of an technologically innovative industrial infrastructural facility; test the model for evaluating the efficiency of technologically innovative industrial infrastructural facilities by using the example of technology parks in Russia; identify efficient and inefficient technoparks by using the proposed methodology; verify the adequacy of the model for application; and offer methodological recommendations for the development of technologically innovative industrial infrastructural facilities in order to increase their efficiency.

2. Literature review

An innovation system imposes favourable conditions for economic growth, increasing the competitiveness of enterprises. Among other things, the interaction of players results in the innovative development of regions. Considering modern integration, efficient ways of operating innovation systems should be searched for in order to develop these systems (Solomatina and Slavnetskova, 2017).

Today, the competitiveness of a region's economy depends not only on innovation but also on organizational changes that contribute to commercial results – as well as on market techniques implementing and promoting innovation, which often justifies the formation of technologically innovative industrial infrastructure in a region (Akhmetshin et al., 2017; Rodionov et al., 2019).

Infrastructure develops as part of an evolutionary process, responding to the transformations and advances of economic systems. The model of infrastructural support in a regional economic system is in direct relationship with structural changes in economic systems, with the vector of infrastructural support being chosen when creating an environment that ensures competitiveness (Kalenskaya, 2015).

Innovation policy tools should be selected to address the specific problems and goals of an innovation system, as well as the peculiarities of administrative structures. The result of an investment policy depends on how well innovation policy tools are defined, adapted, and correlated with the goals and problems of the innovation system (Borrás and Edquist, 2013).

The researchers note that there is currently no comprehensive system for monitoring and evaluating innovation infrastructure in Russia. Moreover, there is a problem of inconsistency of the actual activities infrastructural innovation facilities are engaged in and the stated goals of creating an environment that stimulates innovation (Barinova et al., 2014).

Among the main scientific approaches to assessing the efficiency of technologically innovative industrial infrastructure, the following are worth highlighting:

- evaluating efficiency in a component analysis based on available indicators (assessing the contribution of each component to the total variance) (Latkin and Kharchenkova, 2019);

- using benchmarking technologies (Rodionov et al., 2012);

- evaluating the infrastructure by measuring innovation, with a set of evaluation criteria being selected for a specific research task. Such criteria can be economic efficiency, scalability, compatibility with infrastructure, problem-solving in specific industries, compatibility with regulatory requirements, degree of novelty, etc. (Bhattacharyya et al., 2017);

- making evaluations based on determining the attractiveness of innovative infrastructural facilities for potential residents and investors (Tkachenko and Meteleva, 2019);

- evaluating the impact of the infrastructure on levels of entrepreneurship/startup activity (Audretsch et al., 2015); and

- studying the functional dependencies of innovation production and innovation activity of the region (Acs et al., 2002).

Researchers outside Russia have noted that the development of technologically innovative industrial infrastructural facilities should be based on forming development strategies, defining the technological areas of specialization of the region, building the infrastructure (Yim, 2014), and improving communications within the facilities (Blasini, 2020).

Strategies for the development of innovative infrastructural facilities are influenced by the digital transformation of regions (Polyakov and Stepanova, 2020), comprehensive assessment of the level of economic security of the region given the innovative component (Zaytsev et al., 2021) evaluation of the structural capital of the innovative infrastructural facilities (Babkin et al., 2022).

In most scientific approaches to evaluating the efficiency of innovative infrastructure, the infrastructure is analysed as a subsystem of the regional innovation system. The basic principles of evaluation rely on the availability of information as well as an integrated approach (based on the analysis of a group of indicators/evaluation areas).

The comprehensiveness of an evaluation, which is often represented by multifactorial/multi-criteria models, is preconditioned by the variety of activities of the infrastructural facility and by the versatility of types of infrastructural facilities. Thus, the researchers propose to evaluate the efficiency of a regional innovation system (in the context of the dynamics of innovative development indicators) by considering the development indicators of the innovative infrastructure; we suggest that the efficiency of infrastructural facilities themselves be evaluated in various areas of activity, with the attractiveness of the facilities for investors being taken into account.

Given the specifics of technologically innovative industrial infrastructural facilities described above, it seems that existing approaches are not sufficiently uniform in assessing their efficiency, nor can they adequately assess shortcomings in the operation of these facilities. In this study, we are suggesting that innovative infrastructural facilities be evaluated in the context of their technical efficiency.

3. Materials and methods

In the literature, authors mainly distinguish technical from allocative efficiency. According to T.C. Koopmans (1951), a manufacturer achieves technical efficiency if it is technologically impossible to increase any output and/or to reduce any input without simultaneously reducing other outputs and/or increasing other inputs.

Technical efficiency characterizes the ability of a decision-making unit (DMU) to efficiently use available resources. It is always aimed at minimizing resource costs or maximizing outputs with the available resources.

Facilities within a technologically innovative industrial infrastructure are typically characterized by similar structures, modes of operation, and management. For our research, it seems appropriate to study the technical efficiency of innovative infrastructural facilities, since the totality of facilities of the same type is represented by a homogeneous sample that functions with limited resources and is characterized by approximately the same indicators responsible for the output.

It is proposed to measure the efficiency of technologically innovative industrial infrastructural facilities using a data envelope analysis (DEA) method. This method has proven itself in measuring the efficiency of homogeneous facilities.

DEA models have been successfully used in the scientific environment to assess the efficiency of a regional innovation system (Zemtsov and Kotsemir, 2019; Rudskaya, 2017), innovation activity as a whole (Feng et al., 2021), individual technologies in the production of equipment (Jie et al., 2012), and the efficiency of environmental innovation (Yang et al., 2022) and to measure the stimulating effect of tax incentives on the innovative activity of enterprises (He, 2021).

The DEA methodology defines the "efficiency of operation" of facilities in terms of the efficiency of converting input parameters into output ones. DEA is a nonparametric evaluation method and can be used to measure the technical efficiency of facilities. Nonparametric evaluation models are characterized by the fact that their structure is determined by actual data, while the nature and number of parameters can be flexible. The DEA method is distribution-free, that is, it can be used independently of the nature of the data distribution. In the DEA methodology, the results of the determined efficiency coefficients do not depend on the nature of the data distribution; it is suitable for calculating the desired coefficients without suggestions about distributions, but the results will correspond to those obtained through standard multidimensional analysis.

The DEA method is also chosen due to the need to measure the efficiency of facilities by comparing a significant number of indicators that can be expressed in various units of measurement. In addition, DEA allows one not to test hypotheses about the relationships of the indicators, since the parameters can be selected by the researcher based on the measurement goals and the specifics of the facilities.

Given the specifics of the objects being evaluated, a number of indicators must be included in the evaluation that are difficult to directly relate to resources or outputs. In particular, DEA can take into account variables that are external to the facility (such parameters are difficult to manage in the short term). In our case, such specific variables may be the areal characteristics of the property complex of the innovative infrastructural facility (land plots/buildings/premises) or the capacity of energy supply facilities.

The basis of the DEA method is the construction of the efficiency boundary, which is an analogue of the production function (Alimkhanova and Mitsel, 2019). The production function determines the maximum output of goods that can be produced from a given number of input parameters (resources) when using a technology. The production boundary, or the efficiency boundary, is determined in the case that several types of products are made. In this case, the facilities that show the maximum output from a fixed number of input factors will be recognized as efficient: their points in the input–output space will be at the efficiency boundary. The points at the efficiency boundary will correspond to the facilities that function inefficiently in terms of converting input parameters into output. At the same time, the degree of inefficiency of facilities will vary depending on how distant the point is from the efficiency boundary. Use of the DEA method is suitable for determining a efficiency limit that is not known in practice.

Again, the DEA methodology defines the efficiency of operating facilities in terms of the efficiency of input parameters converted into output. There are quite a few DEA models. They are usually categorized according to the following criteria (Lissitsa and Babiéceva, 2003):

- type of production function (partially linear, partially nonlinear or partially linear-logarithmic – a partially linear function is considered in research studies as a simplified normal case);

- orientation of the model (focused on resources or outputs, or a model without orientation); and

- returns to scale (constant or variable).

Researchers choose the model independently, taking into account the objectives of evaluating efficiency, the type of data analysed, the number of parameters responsible for inputs and outputs, the limitations of the model, returns to scale, etc.

To analyse the efficiency of technology parks, we choose the basic DEA model (i.e. CCR, standing for the first letters of the creators' names: Charnes, Cooper, Rhodes). This model measures the efficiency of the DMU by combining input and output parameters into scalar input and output indicators. This model corresponds to a partially linear view of the production function.

The model also assumes the presence of constant returns to scale (CRS), so the values of the output variables change proportionally in accordance with the magnitude of technical efficiency. The input parameters remain unchanged. For the purposes of our study, it is assumed that it is necessary to set permanent returns to scale, which implies a potentially infinite growth of indicators responsible for the output.

Thus, DEA efficiency is the ratio of the sum of weighted output indicators to the sum of weighted input indicators (Formula 1).

$$\textit{Efficiency} = \frac{\sum \text{weighted output indicators}}{\sum \text{weighted input indicators}}. \quad (1)$$

The advantage of the DEA method is that there is no need to set weights in advance, since the weights will be determined automatically as the linear programming problem is solved to maximize the ratio of outputs to inputs.

A distinctive feature of the DEA model is that the result of the evaluation is relative rather than absolute efficiency; the result indicates the efficiency of a DMU in relation to other DMUs named in the sample to be evaluated. For the purposes of our research study, this feature is an advantage, as we want to compare the efficiency of facilities of the same type. The DEA method allows one to determine the most efficient infrastructural facilities among facilities of the same type, with a measure of inefficiency being determined for all the rest.

Given that the final set of indicators for evaluating various types of technologically innovative industrial infrastructure may differ slightly based on the specifics of facilities (for example, the input indicator for technology parks may be floor area, while the property complex of SEZs and industrial parks is represented mainly by undeveloped land plots), further building of the model for measuring the efficiency of infrastructural facilities will be proposed by the authors using an example of technology parks (technoparks) in Russia.

The next step in building the DEA model is to determine a set of input and output indicators and collect data on them. We use data from statistical reports on Russian technoparks (with due regard to the rankings by the Association of Clusters, Technoparks and SEZs of Russia) as data for the analysis. Thus, the DMU whose efficiency is evaluated is a Russian technopark. The indicators for evaluating technoparks are chosen given the specifics of their operation, the features of the property complex, and the need to evaluate the infrastructural facility together with its management company.

Technoparks as innovative infrastructural facilities are engaged in activities aimed at creating favourable conditions for residents to carry out scientific, technical, and innovative activities. A technopark houses and ensures the development of innovative companies that are its residents. The property complex of a technopark is represented by a complex of real estate objects with premises for various purposes (production, offices, administrative spaces, etc.).

The current functioning of technoparks is inseparable from the activities of their management company. In the past, we found that the management companies of technologically innovative industrial infrastructural facilities show various economic results and are often loss-making.

Table 1 presents the data on the input and output indicators selected for evaluation.

Taking into account the fact that, objectively, there is a time interval between the formation of inputs and outputs of technoparks, statistical reporting of 2017 and 2020, respectively, is used as data. Because the specifics of the functioning of technoparks, the Association of Clusters, Technoparks and SEZs of Russia justifies a time interval of 3 years, during which the outputs of a technological park are formed, the authors also chose a time lag equal to 3 years.

Table 1. Input and output parameters of the model

Inputs (2017)	Outputs (2020)
1. Number of residents **(Residents)**, units 2. Floor area of premises, **(Premises)**, thousand square meters 3. Total investments by residents, **(Investments)**, million rubles 4. Residents' R&D costs, **(R&D Costs)**, million rubles 5. Investments in technopark infrastructure, **(Public Funds)**, million rubles 6. Investments in technopark infrastructure, **(Non-Public Funds)**, million rubles	1. Total amount of tax and customs deductions of residents, **(Deductions to Budget)**, million rubles 2. Residents' total revenue, **(Revenue)**, million rubles 3. Number of intellectual property objects registered by residents, **(R&D Outputs)**, units 4. Total exports of products from technopark residents, **(Exports)**, million rubles 5. Average revenue of the management company, **(Revenue of MC)**, million rubles

Source: compiled by the authors.

The Open Source DEA analysis package was used for the calculations.[1]

4. Results and Discussion

Table 2 presents the results of the calculations for the selected output model.

Table 2. DEA results

DMU Name	Efficiency Value	Efficiency
SIGMA. Novosibirsk Technopark	0.116749673	No
High Technology Park, KhMAO-Yugra	0.159961673	No
High Technology Park in the Republic of Mordovia	0.187029155	No
Moscow Technopolis	0.230380186	No

[1]Open Source DEA. URL: https://opensourcedea.org/

DMU Name	Efficiency Value	Efficiency
Scientific Technology Park of Novosibirsk Akademgorodok	0.243049062	No
Nanotechnology Center "Tekhnospark"	0.317588322	No
Sarov Technopark	0.332998344	No
Mosgormash Technopark	0.362845452	No
Center for Nanotechnology and Nanomaterial in the Republic of Mordovia	0.386907389	No
Lipetsk Technopark	0.513586331	No
Yakutia Technopark	0.670842295	No
West Siberian Innovation Center	0.793345412	No
High Technology Park "Zhigulevskaya Dolina"	0.997106825	No
Electropolis Industrial Technopark	1	Yes
Idea Innovation-Industrial Technopark	1	Yes
IKSEl Industrial Technopark	1	Yes
Polus Technopark	1	Yes
Mayak Technopark	1	Yes
Strogino Technopark	1	Yes
Kalibr Technopark	1	Yes
Elma Technopark	1	Yes
High Technology Park "IT Park"	1	Yes
Ankudinovka High Technology Park	1	Yes
St. Petersburg Technopark	1	Yes
Istok Technopark	1	Yes
Yablochkov Technopark	1	Yes
Kuzbass Technopark	1	Yes
Rameev High Technology Park	1	Yes
Kosmos-Neft-Gas Technopark	1	Yes
High Technology Park of Sverdlovsk Oblast	1	Yes
Idea-Yugo-Vostok Innovative Technology Park	1	Yes
Ulyanovsk Nanocenter (ULNANOTECH)	1	Yes
Podolie Technopark	1	Yes
Slava Technopark	1	Yes
Contact Technopark	1	Yes

Source: compiled by the authors

Thus, according to the results of the DEA, 22 technoparks are within the border of efficiency (i.e. they are efficient; the value of their technical efficiency = 1) in the methodology we use. Thirteen technology parks do not seem to function efficiently. Figure 1 shows the remoteness of each from the border of efficiency.

The West Siberian Innovation Center is closest to achieving technical efficiency (efficiency value 0.8). The developing technoparks with efficiency indicators of 0.5–0.8 are the Yakutia Technopark and the Lipetsk Technopark. The remaining technoparks show relatively low levels of technical efficiency (<0.5).

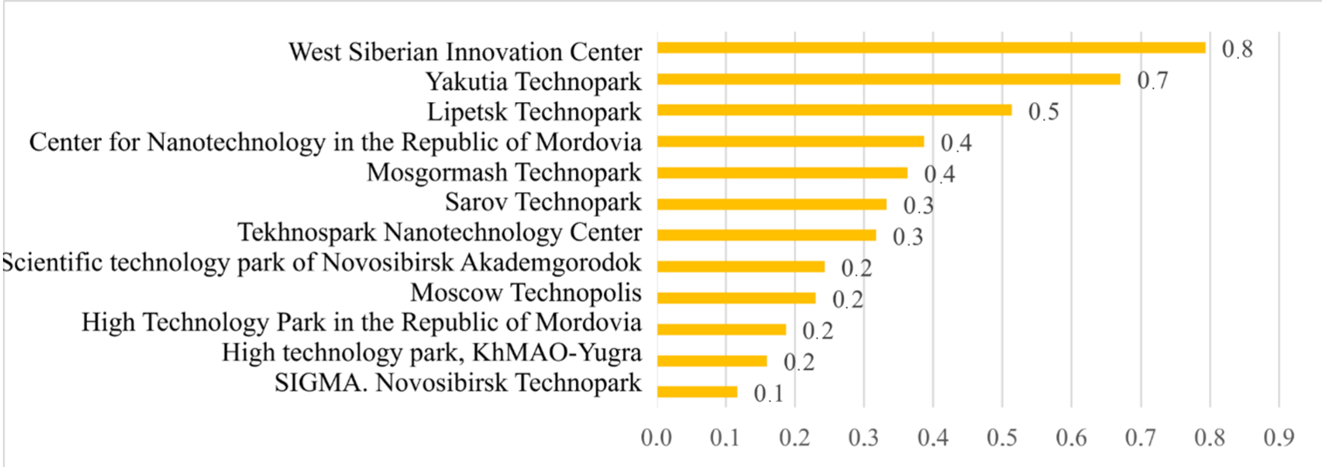

Figure 1. Remoteness of technology parks from the efficiency boundary

Table 3 presents a comparison of the efficiency evaluation results of the Russian technoparks obtained by the Association of Clusters, Technoparks and SEZs of Russia as part of the National Rankings of Technoparks for 2019-2020 and the results obtained by the DEA method.

The technoparks whose efficiency evaluation results differ significantly are highlighted in the table.

Table 3. Comparing the evaluation of the efficiency of Russian technoparks

Technopark	National Ranking of Russia Technoparks 2019–2020		DEA	
	Efficiency, %	Efficiency Level	Efficiency Value	Level (authors' interpretation)
SIGMA. Novosibirsk Technopark	98.53%	Moderately high	0.1	Weak
High Technology Park, KhMAO-Yugra	111.91%	Highest	0.2	Weak
High Technology Park in the Republic of Mordovia	100.62%	High	0.2	Weak
Moscow Technopolis	124.77%	Highest	0.2	Weak
Scientific Technology Park of Novosibirsk Akademgorodok	99.77%	Moderately high	0.2	Weak
Nanotechnology Center "Tekhnospark"	166.30%	Highest	0.3	Weak
Sarov Technopark	92.84%	Moderately high	0.3	Weak
Mosgormash Technopark	82.48%	Sufficient	0.4	Weak
Center for Nanotechnology and Nanomaterial in the Republic of Mordovia	102.61%	High	0.4	Weak
Lipetsk Technopark	78.85%	Sufficient	0.5	Developing
Yakutia Technopark	92.55%	Moderately high	0,7	Developing
West Siberian Innovation Center	90.28%	Moderately high	0,8	Developed

Technopark	National Ranking of Russia Technoparks 2019–2020		DEA	
	Efficiency, %	Efficiency Level	Efficiency Value	Level (authors' interpretation)
High Technology Park "Zhigulevskaya Dolina"	118.03%	Highest	1	Efficient
Electropolis Industrial Technopark	90.54%	Moderately high	1	Efficient
Idea Innovation-Industrial Technopark	110.73%	Highest	1	Efficient
IKSEl Industrial Technopark	57.90%	Sufficient	1	Efficient
Polus Technopark	125.60%	Highest	1	Efficient
Mayak Technopark	56.67%	Sufficient	1	Efficient
Strogino Technopark	117.20%	Highest	1	Efficient
Kalibr Technopark	111.48%	Highest	1	Efficient
Elma Technopark	135.49%	Highest	1	Efficient
High Technology Park "IT Park"	107.23%	High	1	Efficient
Ankudinovka High Technology Park	88.66%	Sufficient	1	Efficient
St. Petersburg Technopark	102.17%	High	1	Efficient
Istok Technopark	82.02%	Sufficient	1	Efficient
Yablochkov Technopark	75.12%	Sufficient	1	Efficient
Kuzbass Technopark	82.21%	Sufficient	1	Efficient
Rameev High Technology Park	96.64%	Moderately high	1	Efficient
Kosmos-Neft-Gas Technopark	73.55%	Sufficient	1	Efficient
High Technology Park of Sverdlovsk Oblast	138.66%	Highest	1	Efficient
Idea-Yugo-Vostok Innovative Technology Park	52.78%	Sufficient	1	Efficient
Ulyanovsk Nanocenter (ULNANOTECH)	104.74%	High	1	Efficient
Podolie Technopark	64.80%	Sufficient	1	Efficient
Slava Technopark	134.24%	Highest	1	Efficient
Contact Technopark	78.12%	Sufficient	1	Efficient

Source: compiled by the authors

Thus, significant differences in efficiency were revealed in relation to 18 technoparks out of 35.

The reliability of the model we propose for evaluating the efficiency of innovative infrastructural facilities should be verified. Thus, it seems reasonable to confirm the significance of the factors selected for the model and their impact on the outcome.

Researchers have identified several ways to justify the factors selected for DEA models (Nataraja and Johnson, 2011). They include: the Pastor test, which can be used to assess the significance of the input variables selected for the analysis by evaluating the model when they are excluded from it (Pastor et al., 2002); regression models; principal component analysis (factor analysis); and bootstrap analysis.

To establish the significance of the selected variables, we built multiple regression models. Since regression analysis is sensitive to the type of data distribution, we normalized the distribution of the source data (by logarithm) and checked the normality of the distribution based on the analysis of descriptive statistics using SPSS.

The results obtained from the regression models show that all the independent variables selected for the efficiency assessment model are significant for it. Therefore, the presented model is adequate and applicable for taking measures to evaluate the efficiency of technologically innovative industrial infrastructural facilities and to put forward recommendations for their more efficient operation and development.

Researchers often consider the impact of innovative infrastructure on the competitiveness of a region's economy (Rodionov and Sedov, 2013). However, thanks to the many types of innovative infrastructure now in use, there is competition for residents and investment between them. This is evident, among other things, in the blurring of fundamental differences between technologically innovative industrial infrastructural facilities, which, in fact, grant their residents access to a production environment, providing them with space and infrastructure.

The advantages of the DEA method include the ability to determine the target values of inputs and outputs for each technopark whose efficiency is determined as insufficient and to allow the former to achieve technical efficiency. Better efficiency of technologically innovative industrial infrastructural facilities and their increased competitiveness (among facilities of the same type) can be ensured with higher technical efficiency.

Projecting the point of an inefficient facility onto the efficiency boundary relies on the basic position of the DEA methodology, according to which if there are DMUs that manufacture a certain quantity of products from a limited number of factors, then an inefficient DMU can use the same number of factors of production to make the same quantity of product. Thus, the competitiveness of technologically innovative industrial infrastructural facilities can be formed if their technical efficiency is ensured among infrastructural facilities of this type (Figure 2).

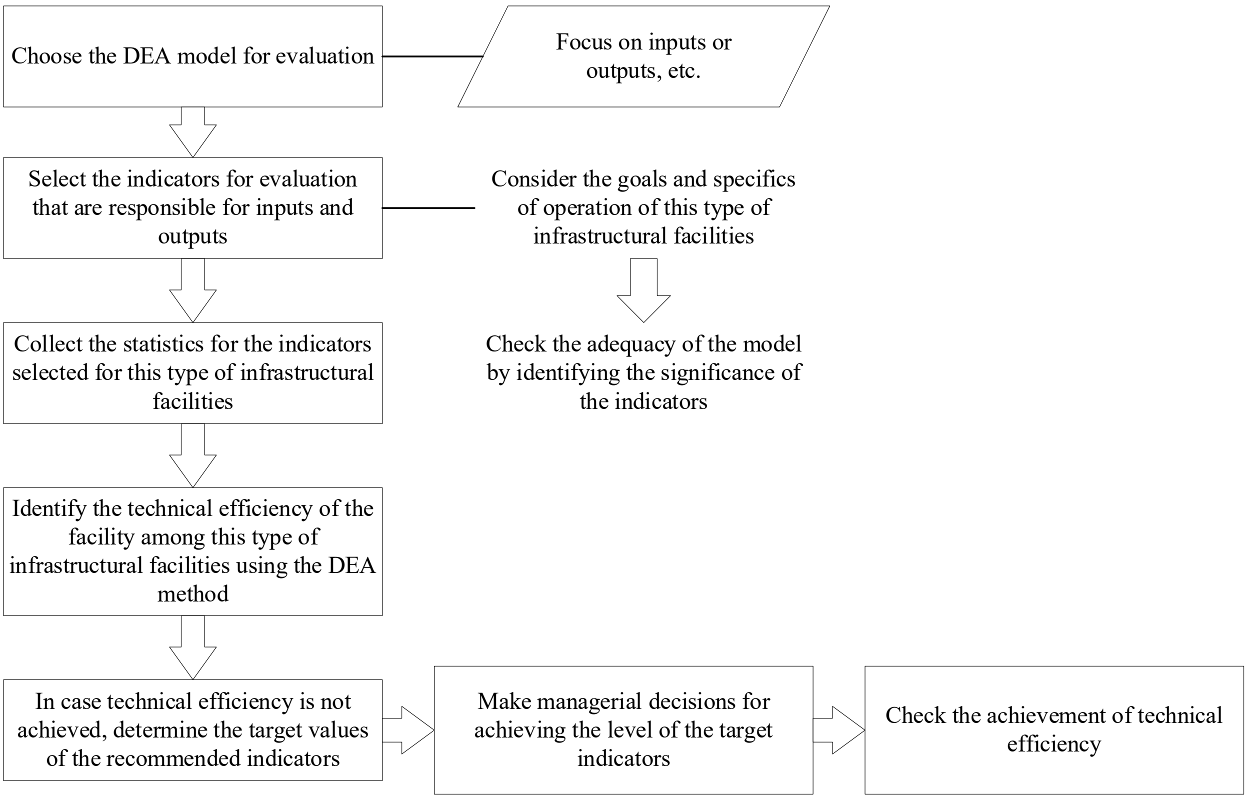

Figure 2. Forming the competitiveness of technologically innovative industrial infrastructural facilities of a single type by ensuring technical efficiency

According to the analysis, it can be stated that the efficiency of innovative infrastructural facilities can be influenced both by public authorities (which take part in funding the construction of engineering, transport, and other infrastructural facilities, grant incentives via legal regulation, etc.) and by the innovative infrastructural facility itself through the management company, which ensures the attraction of residents to the territory of the facility, management of the property complex, and the provision of various kinds of services to residents aimed at improved the results of innovation and economic activity.

Let us consider the methodological model for developing innovative infrastructural facilities by making them more efficient (Figure 3).

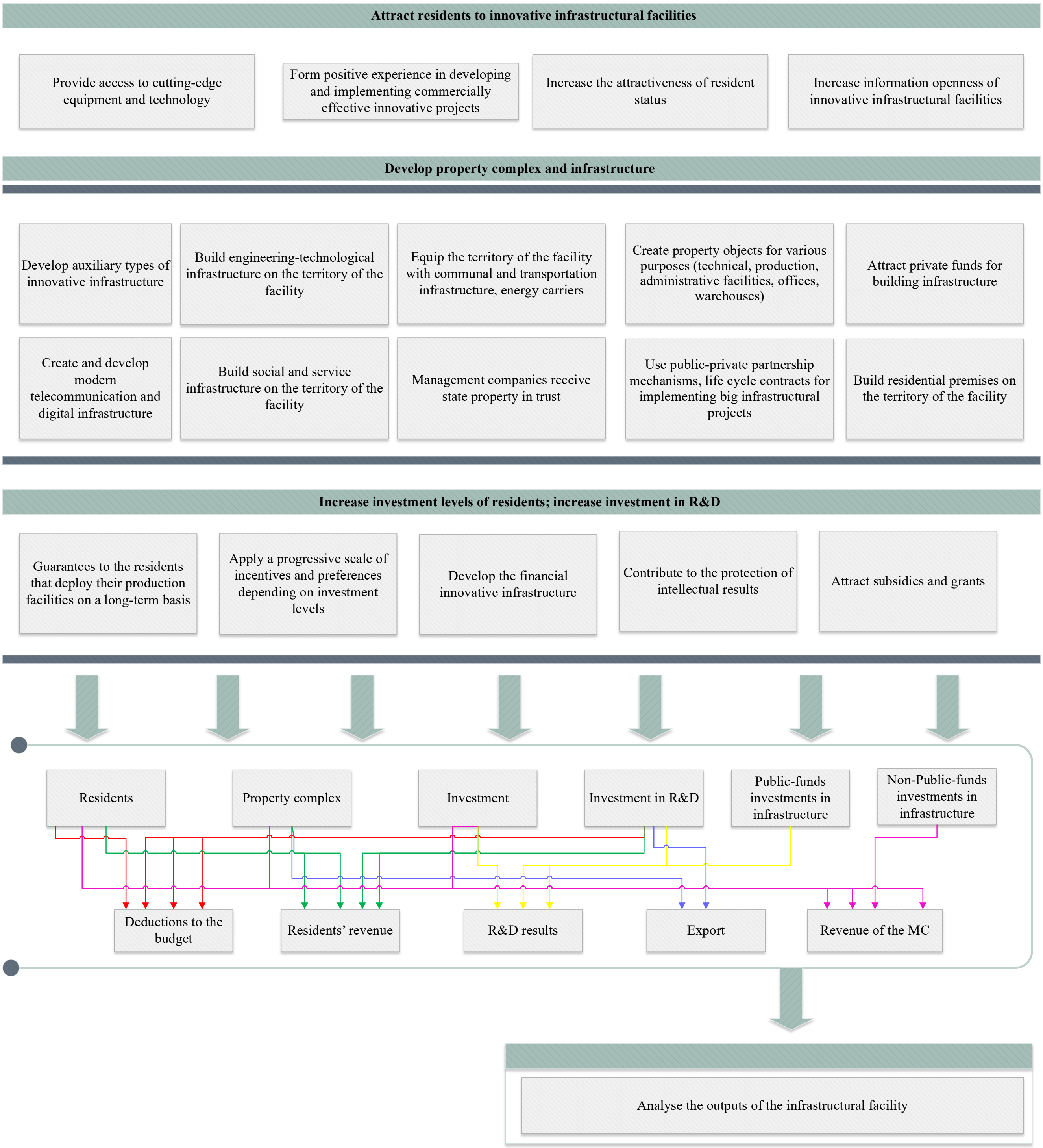

Figure 3. Methodological model for developing innovative infrastructural facilities and increasing their efficiency with key outputs

The presented model reflects the previously established links between the variables and contributes to improved efficiency of infrastructural facilities by using their key inputs.

Let us take a closer look and put forward methodological recommendations to management bodies (management companies, authorized public authorities) for developing the main areas of innovative infrastructural facilities.

Actions aimed at attracting residents to technologically innovative industrial infrastructural facilities.

1. Provide access to cutting-edge equipment and technology.

The attractiveness of an innovative infrastructural facility for residents is primarily ensured by the possibility of using the expensive innovative devices, equipment, modern telecommunications, and digital technology needed in research and development.

Thus, in order to attract residents, the management company of an innovative infrastructural facility should:

- provide residents with access to high-quality, advanced engineering and other technical infrastructure necessary for the organization of the production process (on favourable terms);

- provide access to modern telecommunications and digital infrastructure;

- ensure stability of the residents' business conditions; and

- develop different kinds of services rendered to residents and give them privileged conditions.

2. Form positive experience in the development and implementation of commercially efficient innovative projects in order to attract innovative industrial companies as residents.

3. Increase the attractiveness of resident status by providing various kinds of incentives (tax, customs, property). It is possible to consider the issue of exemption from individual payments for a period of 3 years or for the management company to provide residents with additional incentives, apart from those defined by the legislation for the type of facility.

4. Increase the information openness of innovative infrastructural facilities.

It is necessary to create and develop geoinformation systems containing comprehensive information about the design and functioning of innovative infrastructural facilities.

It also seems that attracting residents will be facilitated by holding various conferences, competitions for non-residents, advertising, congress and exhibition activities, implementing educational programmes, etc.

Actions aimed at developing the property complex and infrastructure of technologically innovative industrial infrastructure.

1. Develop different types of related innovative infrastructure in facilities in order to provide residents with a full range of services (engineering centres, spinouts, collective use centres, cluster development centres, prototyping centres, business incubators, accelerators, etc.) and develop consulting innovative infrastructure (organizations providing services on the problems of intellectual property, standardization, licensing, etc.).

2. Provide the best engineering possible on the territory of the facility, including housing and communal services, transport infrastructure, energy carriers, and real estate objects that can serve various purposes (technical, industrial, and administrative buildings, offices, warehouses).

3. Build social and service infrastructure on the territory of the facility.

4. Build residential premises on the territory of the facility.

5. Use public–private partnership mechanisms and life cycle contracts for large infrastructure projects.

6. Allot state property to management companies in trust.

7. Increase the percentage of used area in the facility and optimize maintenance costs of the property complex.

8. Increase the profitability of public funds invested in the infrastructure of facilities by attracting more investments per 1 ruble of public investments.

9. Ensure the output of products with a big share of value added by combining projects into technological chains.

10. Engage external investors in building infrastructure by increasing the attractiveness of work with residents of infrastructural facilities (lower logistics costs when goods are received from manufacturers, no customs barriers in work with residents, etc.).

Investors can be large companies interested in acquiring high-quality innovative products from the residents of facilities. In this case, investors will be sought by the management company, which can work actively in the information field: present the residents' products, search for long-term sales channels, and promote innovative products made at the facility.

Large residents can also take part in funding the building of infrastructure. According to the decision of the management company, the costs they incur can be partially reimbursed by providing them with additional incentives and services.

Actions aimed at increasing investment in industrial and technological innovative infrastructural facilities on the part of residents for acquiring and creating fixed assets, for building and reconstruction (expansion, modernization), etc.

1. Provide guarantees preserving the lease conditions of residents that deploy their production facilities on a long-term basis at the facility.

2. Apply a progressive scale of incentives and preferences depending on investment level.

3. Develop the financial innovative infrastructure, including various foundations: venture, insurance, public, investment foundations; attract leasing companies, banking and other credit organizations, business angels, and other development institutions to finance projects.

Actions aimed at increasing investments in R&D.

1. Assist in protecting the results of intellectual activity by co-financing residents' costs of maintaining patents, and help them protect R&D results outside the Russian Federation in countries chosen by the right holder (legal assistance and co-financing of costs).

2. Develop venture financing mechanisms for promising innovative projects and production facilities, including for the terms of co-financing of projects by the management company.

3. Attract subsidies (for reimbursing some R&D costs, some costs related to paying interest on loans, etc.) and grants.

In short, the methodological model is aimed at developing innovative infrastructural facilities by encouraging measures for the formation and use of the key inputs of these facilities. We refer to residents, the property complex of the facilities, investments in R&D, and investing public and non-public funds in the engineering, transport, social, and other infrastructure of such facilities.

It seems that implementation of the proposed methodological model can provide innovative infrastructural facilities with the inputs necessary to increase outputs.

5. Conclusion

This study proves that its model is appropriate for investigating the technical efficiency of innovative infrastructural facilities, as the totality of facilities of the same type is represented by a homogeneous sample that functions with certain limited inputs and is characterized by similar indicators responsible for the outputs.

According to the analysis, the efficiency of an innovative infrastructural facility is influenced both by public authorities and by the facility through its management company.

The main results of the study are as follows:

1. The study proposes and justifies the choice of a model for analysing the efficiency of technologically innovative industrial infrastructural facilities. It substantiates a set of input and output indicators for evaluating the efficiency of technology parks in Russia, given the specifics of their functioning as well as the distinctions of their property complexes.

2. The study evaluates the efficiency of technology parks in Russia by using the DEA method. It compares the efficiency of Russian technoparks as evaluated by the Association of Clusters, Technoparks and SEZ of Russia in the National Rankings of Technoparks for 2019–2020 with the results obtained by the DEA method. The reliability of the proposed model is confirmed with the significance of the selected factors and the influence of each on the output, which is supported by the regression models we built.

3. The study puts forward recommendations for improving the competitiveness of technologically innovative industrial infrastructural facilities and thus ensuring their technical efficiency among innovative infrastructural facilities of the same type.

4. Based on the analysis and the relationships identified between the variables, we propose a methodological model for developing innovative infrastructural facilities based on improving their efficiency with key inputs. We point out the main measures aimed at attracting residents to facilities, developing the property complex, and increasing the volume of investments made by residents and the volume of investments in R&D.

Our methodological model for the development of innovative infrastructural facilities is aimed at developing these facilities through measures for their formation and use of main inputs. The model reflects the relationships between the variables previously set in the study. The results of the study can be used in the practical activities of the management bodies of innovative infrastructural facilities as well as by specialized public authorities pursuing state policy in the formation and development of innovative infrastructural facilities.

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SECTION 4

MANAGEMENT OF KNOWLEDGE AND INNOVATION FOR SUSTAINABLE DEVELOPMENT

РАЗДЕЛ 4

УПРАВЛЕНИЕ ЗНАНИЯМИ И ИННОВАЦИЯМИ В ИНТЕРЕСАХ УСТОЙЧИВОГО РАЗВИТИЯ

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Complex Modelling of Regional Tourism Systems

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Abstract

This study aimed to examine the prospects of various modelling tools in building complex models of regional tourism systems. It surveyed the international experience in forecasting tourist demands and modelling the tourism industry. It found that the hybrid approach – combining simulation modelling with econometric models to forecast tourist demands and deep learning models to process data from various sources – seems to be the most promising one. Simulation modelling is divided into two parts: system dynamics as a model of domestic tourism in terms of assessing state support's impact on the development of tourist infrastructure and agent-based modelling, which is used to form tourists' profiles and assess their needs as accurately as possible. Then, a more detailed study of the possibilities of using CGE models in the framework of integrated modelling of the tourism system, with an emphasis on sustainable development, was proposed. To reduce the level of uncertainty typical in a socio-economic system, integration into the CGE model of production functions was proposed. Thus, the potential applicability of using production functions for modelling tourism processes from the point of view of the state of the economy in a pandemic s being investigated. This study classified the production functions and adopted the function of constant elasticity of substitution to assess the income gained from the tourist products consumed by domestic tourists. Based on synthetic data, the possible income from tourist products were calculated using the income distribution in four groups of profitability. We performed the calculation using written code in the statistical programming language R. The formula we used considered the annual income of population groups, spending on rental housing and the consumer basket, as well as the elasticity of consumption of tourist services.

Keywords: simulation modelling, domestic tourism modelling, CGE model, production functions, CES function

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Комплексное Моделирование Региональных Туристических Систем

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Аннотация

Данная работа посвящена исследованию перспектив применения различных инструментов моделирования для построения комплексных моделей региональных туристических систем. В ходе исследования проводится изучение международного опыта прогнозирования туристического спроса и моделирования туристической индустрии. На основании проанализированной информации делается вывод о перспективности применения гибридного подхода, который сочетает имитационное моделирование с эконометрическими моделями для прогнозирования туристического спроса и моделями глубокого обучения для обработки данных из различных источников. Имитационное моделирование в концепции разделено на две части: системная динамика как модель внутреннего туризма с точки зрения оценки влияния государственной поддержки на развитие туристической инфраструктуры и агентно-ориентированное моделирование – для формирования профиля туриста и максимально точной оценки его потребностей. Затем предлагается более детальное изучение возможностей применении моделей CGE в рамках комплексного моделирования туристической системы с акцентом на устойчивое развитие. В рамках снижения типичного для социально-экономической системы уровня неопределённости предлагается интеграция в CGE модель производственных функций. Таким образом, исследуется возможность применимости использования производственных функций для моделирования процессов туризма с точки зрения состояния экономики в условиях пандемии. В ходе исследования проведена классификация проанализированных производственных функций и принята функция постоянной эластичности замещения для оценки доходов от туристических продуктов, потребляемых внутренними туристами. На основе синтетических данных, близких к реальным, были рассчитаны возможные доходы от туристических продуктов с распределением по четырем группам доходности. В дополнение, выполнен расчет с использованием написанного кода на статистическом языке программирования R. Формула учитывает годовой доход групп населения, расходы на аренду жилья и потребительскую корзину, а также эластичность потребления туристических услуг.

Ключевые слова: имитационное моделирование, моделирование внутреннего туризма, CGE модель, производственные функции, CES функция

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1. Introduction

The economic crisis caused by the pandemic has significantly affected the market of services and consumer goods (Hordofa et al., 2022). The business found itself in unusual conditions of isolation from consumers. In this continuously changing epidemiological situation, there is a need to use alternative measures to attract customers and analyse their new urgent needs. The governmental measures to restrict work and limit entry to public places and unpredictable consumer behaviour – all of it demands the need for flexibility and rapid adaptation to new conditions. Such an approach applies not only to the individual representatives of the industry but also to the industry as a whole. The tourism industry, the part of the economy most affected by the pandemic, needs flexible management methods, which can be provided only if there is a flexible forecasting system that can change along with the outside world. Since no part of the economy can exist separately from the outside world, it is necessary to consider the tourism industry by examining a country's general economic situation. The development of tourism infrastructure has fundamental importance for individuals – it is a tool to combat unemployment (new jobs) – for entrepreneurs –they can ensure the need for tourist products – and for the country's economy – tourism is an indicator that affects investment attractiveness and the level of people's well-being (Esfandiar et al., 2019). At the same time, uncontrolled development of tourist infrastructure can significantly harm the environment and culture (Berawi et al., 2016; Widaningrum et al., 2020). From this point of view, the issue of developing a general model of domestic tourism has been presented as the only competent approach to stimulate the tourism industry for sustainable development. This article examined the experiences of foreign researchers in modelling tourist flows. The articles that modelled domestic and international tourism were selected for analysis. In selecting the sources, emphasis was given to the articles' relevance in the field of tourism in general and in terms of the modern technologies and data used. The availability of reasonable results, considering the provision of data on statistical errors/deviations, was also emphasised.

This study also paid special attention to the prospects of using CGE models and, in particular, an approach to forecasting revenue from domestic tourism based on the income groups of the population. The revenue from domestic tourism is a key element of the domestic tourism model, which describes the relationship between the stabilisation of the region's economic indicators and the degree of development of domestic tourism. The model was developed using synthetic data, which is as close as possible to real data. The data obtained from the various open sources form a network that includes a region's economy, the level of citizen well-being, and the state of the regional tourism sector. This is the first study to offer results regarding an initiative project to develop a regional model of domestic tourism.

2. Literature review

Based on the research goals, we defined the basic rules for finding suitable sources. First, we limited the search queries to the field of tourism in general and the modelling of tourist processes in particular. We selected the sources from the Scopus database using the keywords "tourism" and "model". Next, we selected the most cited reviews (with at least 20 citations) in the last six years (2017–2022) that were most relevant to our topic. When we found a relevant article, we also analysed its lists of sources to evaluate the results of the described model that is based on several studies. As a result, we selected articles that described the model or approach most profoundly for further analysis. Thus, our review included articles from a much earlier period. For the analysis, it is worth noting that we considered articles that were not only about domestic tourism but also international tourism.

Among the variety of articles on modelling in the field of tourism, it was important to choose the most applicable ones for forecasting tourist flow. Accordingly, we repeated the procedure for selecting articles but changed the combination of the keywords: "tourism" and "demand".

The tourism sector includes varies types of tourism based on goals, types of tourists, and other classifications. Based on the United Nations World Tourism Organizations (UNWTO) methodology, we assumed the importance of models that allow us to predict the behaviour of tourists depending on their needs and preferences. At the next stage of the literature selection, we thus focused on examining tourist processes and analysing tourist behaviour. Thus, the review included articles modelling tourist routes or the satisfaction of a tourist from visiting attractions. It is important to note that the models of the Autoregressive Integrated Moving Average (ARIMA) and artificial neural networks (ANN) families were the most common among the analysed sources. To ensure diverse results, we tried to select the most typical articles describing these models, while the rest were not included. The final choice of the articles also depended on the availability of a comparison of the results within the same study, a requirement that was dictated by the complexity inherent in comparing different scientific papers.

The review included 36 articles: five articles discuss the mutual influence of economic growth and tourist infrastructure, and 31 articles describe the forecast models of tourist flow or other tourist processes. The selected models were divided into four types: simulation models (22%), econometric models (42%), deep learning models and neural networks (14%), and hybrid models (22%) (Table 1).

Table 1. Classification of the analysed models by type and size

Model type	City or less	Country	World
Simulation models	ABM (Santoso et al., 2020); Plog model (Litvin et al., 2016)	ABM (Li et al., 2021); System dynamics models (Mai et al., 2018); CGE (Blake, 2009)	Plog model (Griffith, 1996); Scienario-based modelling + TVP-PVAR model (Wu et al., 2021)
Econometric models	ARDL (Song et al., 2010); ARIMA, SARIMA (Millán et al., 2021)	Monte Carlo Forecasting + Polynomial-Fourier Series Model (Danbatta et al., 2021); Factor model + LARS-EN (Lourenço et al., 2021)	MIDAS method (Bangwayo-Skeete et al., 2015); Panel data model (Darani et al., 2018); SEM (Turner et al., 2001); GM, Verhulst, DGM (Nguyen et al., 2017); BGVAR (Assaf et al., 2018); Gravity model (Harb et al., 2018); KS-AR model, VAR, SARIMA (Nicholas et al., 2021); SARIMA, HW, GM (Sharma et al., 2020)
Deep learning models, neural network	DLM (Law et al., 2019); Latent dirichlet allocation (Wang et al., 2020); P-DBSCAN (Vu et al., 2015); MNL (Lubis et al., 2019)		

Simulation models

Simulation models allow replacing the system under study with a model that describes system's behaviours and its key indicators. This approach ensures the transparency of the processes occurring within the system, which means that it allows one to predict the development of the system by considering the changes in its various indicators. The analysed articles we analysed used two types of simulation models: system dynamics and agent-based modelling.

The system dynamic model is used as an alternative to forecasting models for the scenario-based planning of tourism destinations (Mai et al., 2018). The advantage of this model is its ability to consider a system's natural limitations, indicating that the classic approach, while capable of accurately predicting the growth rate, does not consider the possible negative consequences of excessive or too rapid development of a destination (overpopulation, flooding, shortage of drinking water sources, etc.).

Simulation models are ideal for analysing the risks and prospects of certain management decisions. The use of the computable general equilibrium (CGE) model adapted to the tourism sector allows for the assessment of the most promising investment directions in terms of the subsequent effect on the country's economy and the durability of the results (Blake, 2009).

Simulation modelling is often based on econometric models as an upper-level superstructure that allows the interpretation of the results and establishing logical connections (Wu et al., 2021). The time-varying parameter panel vector autoregressive (TVP-PVAR) model in combination with scenario modelling shows the results calibrated on historical data. This approach allows to evaluate the quality of the forecast and choose the optimal planning horizon.

Another approach to the simulation of tourist processes is agent-based modelling. The basis of research in such works is the study of behavioural factors that determine the rules of the behaviour of agents (tourists). In Li et al. (2021), there exists a parallel between the tourist's tendency to optimise and his tourist route.

The most common model created specifically for describing travel agents is the Plog model. The model describes tourists in terms of their psychotype and behaviour, distinguishing two types with intermediate subtypes: adventurers and psychocentrics. According to the typology of Plog, psychocentric people tend to visit popular proven places, while adventurers will explore local features and stay away from tourist areas. It is assumed that the number of visitors changes with the development of resorts (Griffith et al., 1996). Santoso et al. (2020) used behavioural factors to determine the degree of satisfaction tourists gained from visiting the main attractions in Indonesia. However, a limitation of the Plog's model is that it ignores the tourists' motivations, activities, and modes of transport (Litvin et al., 2016).

Econometric models

The better part of analysed models were econometric models. This type of model involves analytical tools based on mathematical and statistical modelling, allowing managers to make managerial decisions based on accurate forecasts. The largest number of the analysed articles used regression results, with the most typical representative of the regression models being the MIDAS model. The MIDAS model consists of only one equation, and while this does not allow the model to analyse the pairwise correlations between indicators, this makes it less prone to specification errors (Bangwayo-Skeete et al., 2015).

Regression is a productive and convenient tool for analysing the correlations between indicators. Song et al. (2010) used the autoregressive distributed lag (ARDL) to analyse the elasticity of tourists' demands in Hong Kong from a set of indicators (income level, search queries, and advertising costs). The study found a long-term relationship between demand, income, and prices, demonstrating that tourists' income levels are the most important factor determining tourism demand in the long term.

Econometric models may also be used to analyse bottlenecks. In Harb et al. (2020), the gravity model was used to confirm the need to use multi-lateral resistance to tourism (MRT) when assessing the attractiveness of a tourist destination. The classical models, the researchers noted that, did not consider the attractiveness of the alternative directions expressed in the MRT indicator. Integrating the gravity model with the common correlated effects (CCE) proved the need for analysing data to detect the magnitude of cross-sectional dependence and, when the latter is omnipresent, employing MRT-robust estimations.

Another approach is demonstrated in the study of tourist flows in Portugal, which used a factor model based on data processed by the Least-Angle Regression algorithm (LARS-EN) (Lourenço et al., 2021). For each country, the algorithm identified the most significant factors, which made it possible to increase the accuracy of forecasts. The researchers highlighted the usefulness of survey data in predicting tourism.

Inventive research was conducted on analysing the demand for dark tourism based on the statistical data on age, average income, and education level (Millán et al., 2021). The Seasonal Autoregressive Integrated Moving Average (SARIMA) model demonstrated the demand for visiting Cordoba with an error of 5%. SARIMA also surpassed the Grey model in forecasting tourist demands (Sharma et al., 2020). The Grey model family showed statistically significant results in forecasting tourism demand in Vietnam, but it demonstrated different accuracy for different countries (Nguyen et al., 2019). Some advantage over SARIMA was demonstrated by the KS-AR model, which combines kitchen sink (KS) modelling with the AR autoregressive model (Nicholas et al., 2021). It is worth noting that all the studies noted the applicability of one-dimensional models exclusively for short-term planning.

Though the VAR family of models is popular in short-term forecasts, it can also be adapted for long-term forecasting (up to four quarters ahead). The Bayesian global vector autoregressive (BGVAR) model tested in nine countries in Southeast Asia showed its ability to capture the spillover effects of international tourism demand in this region (Assaf et al., 2019).

As an alternative approach to forecasting tourist demands, it is worth considering the seasonally restacked multi-series structural time series model (M-STSM) (Chen et al., 2019). This model is similar to the multivariate method but includes a new data restacking technique: a quarterly tourism demand series is split into four component series, and the component series are then restacked to build a multi-series structural time series model. This method offers the best forecast accuracy compared with traditional univariate models (ARIMA, ETC).

Among the approaches to modelling tourist demand, we can distinguish panel data models that allow for tracking the dynamics of data changes, considering the assessment of elasticity, standard deviation, and other statistical indicators (Darani et al., 2018). This approach assumes that the demand for tourism depends on a country's macroeconomic indicators.

Danbatta et al. (2021) predicted tourist flow based on the data on the tourist's actual arrival by a mathematical model using a random variable generator. Thus, a model based on a Fourier series was received at the input, which was then processed by the Monte Carlo method based on the obtained data, and the probabilistic characteristics of the process under consideration were calculated. The forecast was considered statistically significant.

The most complete multidimensional analysis was presented in Turner et al. (2001). The SEM model implies modelling with structural equations (that is, conducting a multidimensional analysis based on regression analysis, path analysis, and factor analysis). Based on a multidimensional analysis of various indicators (GDP, income level, etc.), it can be concluded that there are significant differences between the independent variables that influence the demand for business, holidays, and tourist types. These results are of fundamental importance when building a model of tourist infrastructure.

Deep learning models, neural networks

A whole series of articles is devoted to the use of machine learning for predicting tourist demand and analysing its routes. Law et al. (2019) presented research results confirming the increase in forecast accuracy when using the Deep Learning Model (DLM) compared to using models such as ANN, ARIMAX, SVR, and so on. However, it is worth considering that these results were obtained with the short-term forecasting of demand and cannot be unambiguously used for long-term planning without additional research.

An alternative way to use machine learning models is to analyse the psychological perception of a tourist destination based on travel geotagged photos (Wang, 2020). Using Latent Dirichlet Allocation allowed categorising the analysed content into topics and then create a polynomial distribution model.

Vu et al. (2015) used social media photos to identify the most developed tourist routes. The data were clustered using the P-DBSCAN algorithm, and regions of interest were selected based on geographic data. Using the Markov chain, tourist trajectories were constructed.

Neural network models are also used to analyse the load of public transport. Lubis et al. (2019) presented the approbation of a Multinomial Logit model (MNL) for predicting high-speed rail (HSR) route loading. The developed model allows you to predict the load by considering alternative modes of transport.

Hybrid models

The last category highlighted in this study is hybrid models. Using various econometric models with each other or with machine learning models improves the accuracy of forecasts, because it considers both dynamically changing indicators and the impact of the macroeconomic situation.

Rafidah et al. (2020) used the support vector machine (WSVM) model and decomposition ensemble model (Benchmark EMD-SARIMA and EMD_WSVM) to predict tourist flow, obtaining results that revealed a greater efficiency of using the hybrid model than individual approaches.

The smallest measurement error was provided by a combination of MIDAS-SARIMA econometric models (Wen et al., 2021). Based on the data on search queries for specific keywords, the model predicted tourist flow with greater accuracy than the same models individually or the hybrid MIDAS-AR type.

A similar study on combining econometric models was conducted by Wen et al. (2019). The results obtained for the Hybrid Arimax / Narx Model were also almost one and a half times more accurate than when these models were used separately.

However, if the source data is restricted to search queries, it is worth highlighting the DBEDBN model. Using a deep web of trust allows one to extract the most valuable information from the initial data. The resulting forecast is then processed by vector regression algorithms, which ensures minimum error in the results (Huang et al., 2021).

The integration of the AR model with a big data approach was introduced in Fronzetti Colladon et al. (2019). A specific web crawler was developed to extract information from the TripAdvisor travel forum. The crawler parsed HTML pages and extracted information of interest, with associated timestamps to allow a longitudinal analysis. The highest accuracy of the results was achieved for the one-month forecast (in comparison with AR, the accuracy for some cities exceeded by more than 30%), and the excess inaccuracy was no more than 5% for three months. It is important to note that the crawler produced a significant amount of incomplete or inconsistent data for some cities.

In Silva et al. (2019), the researchers used Singular Spectrum Analysis (SSA) to account for the seasonality of demand. The introduced DNNAR model showed better results than the NNAR model by 10%–30% for different countries. Improved results were obtained for all the planning horizons: from a month to a year. Compared to ARIMA and ETS forecasts, the DNNAR model showed better results for all horizons except the one-step-ahead forecast, indicating that seasonality is more problematic for NN models.

A more structured and complete data was supported by the VAR (P) model, which considers traditional structured data (ticket information) with unstructured data (web requests). The wide range of the data included data on infrastructure, weather conditions, and bookings in hotels, restaurants, theatres, and so on (Liu et al., 2018). This model forecasted the changes in tourism demand in conjunction with the intentions of tourists.

3. Materials and methods

The choice of the model depends on characteristics such as openness (it is necessary to consider the external links of the system with the world as the outflow of tourists to other countries or exchange rate) and the transparency of the results (it is important to establish the rules for the interaction of all the internal elements of the system to simulate the economic effect depending on changes in certain indicators). It seems that the most profitable approach is to combine the results of mathematical (econometric) tools for predicting tourist flow with machine learning tools for filtering and processing big data (Liu et al., 2018; Wen et al., 2019; Vu et al., 2015) and embed this into the simulation model (Fig. 1). At this stage of the study, it was difficult to choose between agent-based modelling (Li et al., 2021; Santoso et al., 2020; Griffith et al., 1996) and the system dynamics model (Mai et al., 2018; Blake, 2009), since both approaches are equivalent in the depth and prospects of the study. It is worth noting that scenario modelling corresponds to the goals of building a model of domestic tourism in terms of assessing the impact of state support on the development of tourist infrastructure in the country and increasing tourist flow. However, only agent-based modelling will help to form tourists' profile and assess their needs as accurately as possible. In this case, agent-based modelling is more complex and may be used in a longer perspective.

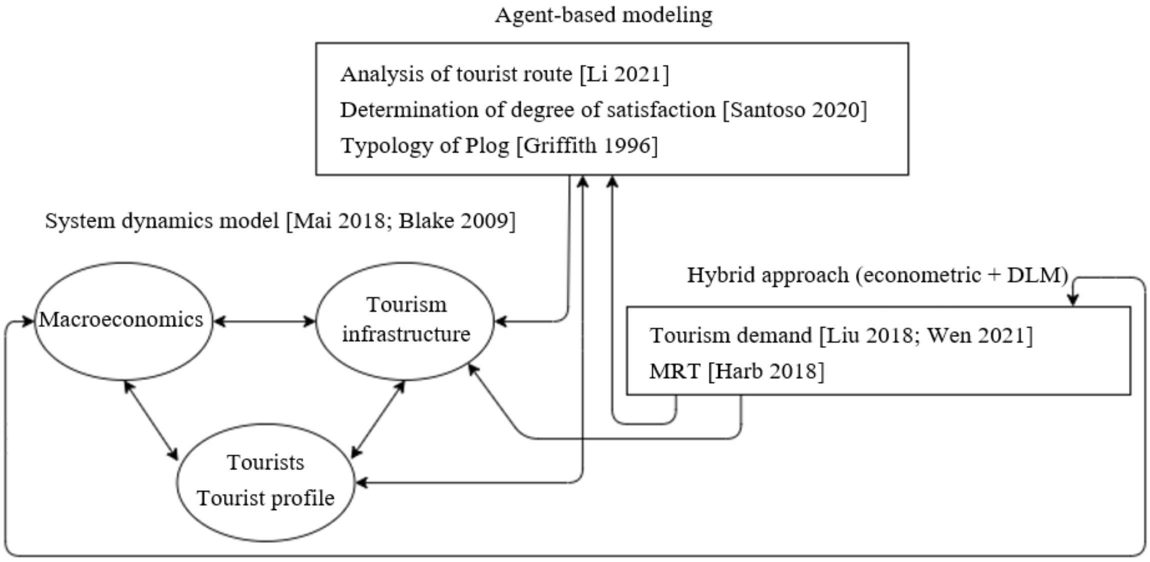

Figure 1. A possible approach to modelling domestic tourism

Consider the block with the system dynamics model. It is proposed to use the CGE model as a basis for modelling the tourism industry in the context of the region's sustainable development (Blake, 2009; Gintciak, 2022).

CGE models for the tourism sector

CGE models (computable general equilibrium models) are used to ensure the equilibrium between industries in economic modelling. The more industries, regions, and consumer types appear in the model, the more difficult it is to analytically solve the model, and numerical methods processed by computer capacities are used. CGE models are used in various economic sectors to assess the impact of investments on individual economic products (Blake, 2009). Among the most significant models based on the concept of CGE models, we can single out the MONASH model of the Australian economy and the similar USAGE model of the US economy.

Gül (2015) used a static CGE model to analyse the growth of demand in Turkey's tourism industry and detected the established prices, which made it possible to equalise supply and demand. The author was thus able to find that the data obtained showed an increase in the real runway with an increase in inbound tourism. Similarly, Blake (2006) showed that the CGE general equilibrium model, as it allows one to study the demand for tourism under various assumptions, can be used to measure the macroeconomic effects of internal and external shocks in a country. The authors found this model particularly useful for quantitatively assessing the effects of changes in demand or other possible scenarios. In contrast, the CGE model, Van Truong and Shimizu (2017) demonstrated, rarely detected the transport network's influence on the demand in tourism activities. However, the authors maintained that the CGE model is still quite effective despite this, which the authors advised to investigate in future studies. Since each of the above studies proved that it is reasonable to use general equilibrium models to analyse the processes of the tourism industry, we assume that this model can be successful used for the entire industry.

Review and classification of production functions

As part of the development of the prototype of the CGE model, we analysed international experience with using various production functions to describe economic processes using the model. In the course of the study, the most frequently used production functions for modelling the economic growth of the tourism industry were identified and classified.

The production functions were divided into the following:

- Microeconomic and macroeconomic;

- Static and dynamic;

- Single-factor and multi-factor;

- Additive and multiplicative.

According to the type of analytical forms, the production functions were divided into linear (additive) and nonlinear (multiplicative).

1. Leontief function (Yankovyi, 2021; Hu et al., 2020; Blake, 2006)

Characteristics: microeconomic, static, two-factor, and additive.

The Leontief function is a CES function with fixed proportions of factors and with an elasticity of substitution equals to 0, which means that it is impossible to replace the factors of production with each other. There is thus a restriction on deviating from the initial number of factors, which are strictly fixed for the production of a unit of output.

This function is determined by the minimum ratio of the number of resources spent to the constant values of production. Since it belongs to the static type of production functions, this function is intended to model certain technologies. It is thus often used to describe small-scale or fully automated productions.

2. Cobb-Douglas function, Cobb-Douglas-Tinbergen function (Sancho, 2009; Antoszewski, 2019; Chen and Haynes, 2015; Timilsina and Shrestha, 2008; Daniels and Kakar, 2017; Pratt, 2013)

Characteristics: macroeconomic, static, two-factor, and multiplicative.

The Cobb-Douglas function depends on the number of factors of production, their elasticity coefficients, as well as the scale of production and NTP. There is an addition called the Cobb-Douglas-Tinbergen function. It differs from the source in that it is dynamic, i.e. time-dependent.

It turns out that time dependence is added to the expression of the Cobb-Douglas-Tinbergen function. Moreover, the final number of products is influenced by the growth rate of other industries and factors that are not explicitly considered.

In this function, the NTP is stationary, which means that, every year, the final result will change the same number of times.

The Cobb-Douglas (Cobb-Douglas-Tinbergen) function is usually used to describe medium-scale or large-scale objects characterised by stable functioning. It is closest to real economic phenomena and processes (relative to the Leontief and Allen functions) and is easy to obtain the estimates of unknown parameters (relative to the CES function), although it is a CES function, which means a single elasticity of substitution.

The function has a small drawback, like the linear function: when capital intensity converges to infinity, labour productivity also tends to infinity, which is unrealistic.

3. Linear function (Yankovyi, 2021)

Characteristics: macroeconomic, static (dynamic), two-factor (multifactorial), additive, and heterogeneous.

The linear function, in addition to the number of factors of production, has dependencies on the time and coefficients of the marginality of products related to the resources used. Most often, the linear function is used in large-scale systems where income or output is the result of the simultaneous interaction of a large number of different technologies or where the number of costs will be proportional to the final result.

An important role in the production linear function is played by the hypothesis of the constancy of marginal production factors or unlimited elasticity of substitution, which is not the most realistic scenario. Of course, the factors may be interchangeable, but most likely not in the tourism industry.

4. The Allen function (Yankovyi, 2021)

Characteristics: microeconomic, static (dynamic), two-factor, and multiplicative.

The Allen function is used to describe the processes in which the excessive growth of one of the factors of production leads to a negative change in output or income. This production function is usually intended for small production systems in which there exists no possibility of replacing the resources used because the elasticity of substitution is 0. Moreover, if the model is based on data that changes over time (for example, several years at the same enterprise), the Allen dynamic production function is used. It depends on time, factors of production, various coefficients, and has a degree of uniformity equal to 2.

5. CES function or constant elasticity substitution function (Sancho, 2009; Chen and Haynes, 2015; Daniels and Kakar, 2017; Pratt, 2013; Willenbockel, 1999; Klump and Preissler, 2000)

Characteristics: macro-and microeconomic, dynamic (static), two-factor (three-factor), and multiplicative.

There are various specifications of the CES function: the Solow specification, the Pitchford generalisation, and the Barro and Sala-y-Martin specification, which, since it is inconsistent and redundant, is rarely used in practice.

The CES function is used when there exists no accurate information about the level of interchangeability of production factors, i.e. the exact value of the elasticity of substitution is unknown but greater than 0. However, it is assumed that this level will not change much if the resources used are increased or decreased, i.e. there is a property of stability at certain proportions of factors.

The CES function is more reasonable, because with capital intensity tending to infinity, labour productivity will be limited. This indicates a more realistic description of economic systems. However, it is difficult to obtain the estimates of unknown parameters. To do this, one needs to conduct a logarithm analysis, and the estimates will most likely be only approximate. The CES function can be used to model systems of any level and is universal.

6. LES function or function with linear elasticity of factor substitution (Gül, 2015)

Characteristics: macro-and microeconomic, static, multifactorial, multiplicative.

The LES function, also called the consumer utility function, is a measure of the ratio between the volumes of goods consumed and the level of utility, i.e. the satisfaction obtained from the consumption of a specific set of goods by a specific consumer. Its final result is influenced by the minimum required amount of each of the factors and the coefficient of the importance of the product for the consumer.

This production function is most often used to describe processes in which the possibility of replacing the factors used strongly depends on their proportions.

Macroeconomic production function (MPF) (Kamaletdinov and Ksenofontov, 2018).

Characteristics: macroeconomic, static, two-factor, and multiplicative.

The macroeconomic production function is similar to the Cobb-Douglas function, but instead of the labour factor, labour productivity is used, which is the ratio of GRP and the number of the employed population.

The MPF can be used for a formalised description of the work of the state, taking into account various taxes, investments, and other expenses and fees.

7. Solow or Hilhorst function (Miao and Vinter, 2021; Attar, 2021; Ilyash, 2021)

Characteristics: macro-and microeconomic, static, multifactorial, multiplicative, and heterogeneous.

The Solow function differs from the CES function only in the property of uniformity (this function is inhomogeneous). Due to this fact, the Solow function is used when the uniformity property appears optional. Since the Solow function differs from the CES function in terms of the assumptions about uniformity, it can similarly be used in modelling systems of any scale.

8. Quasi-linear production of functions (Wu, 2021; Tanaka, 2022)

Characteristics: macro-and microeconomic, static, multifactorial, multiplicative, and heterogeneous.

In a quasi-linear function, one parameter changes linearly and the other non-linearly. If there is no linearly changing factor, i.e. its quantity will be equal to 0, then production will continue, despite the lack of linear resources.

This function is typical for firms with large volumes of nonlinear factors. Such productions can use a larger or smaller amount of linear factor, i.e. they do not particularly depend on their quantity. Small fluctuations in the value of the linear factor will not affect the final result, while fluctuations in the value of the nonlinear parameter change the output values.

9. The Tornquist function (Issin, 2017)

Characteristics: macro-and microeconomic, static, multifactorial, and multiplicative.

The Tornquist function is called the demand function; it shows the dependence of the volume of production on goods and services.

This function has three types. Its basic formula reflects that the amount of demand for essential goods decreases with income growth and has a limit. The formula for the demand for secondary goods and services is used when income reaches a certain mark. However, the volume of demand also has a limit. As a result, the formula for elite services or luxury goods is used when an even higher threshold in affluence is reached. However, it no longer has a limit – only the rapid growth of the function graph.

To solve the selected problem, the CES function was selected from the other considered functions.

This function offers the most realistic description of economic systems. It is also used when there exists no accurate information about the level of interchangeability of the factors of production.

Consider the general view of the CES function (formula 1):

$$Y = \left(A0 * e \wedge (wt)\right) * \left(A1 * K \wedge (-p) + (1 - A1) * L \wedge (-p)\right) \wedge \left(-\frac{\gamma}{p}\right), \tag{1}$$

where *Y* – quantity of output; *K* – capital; *L* – labour; *A0* – factor productivity; *A1* – weighting; *p* – replacement ratio; *γ* – uniformity; *w* – production growth rate due to all other factors except *K* and *L*; *t* – time.

Calculation formula (2) of *p*:

$$p = \frac{1-\sigma}{\sigma}, \tag{2}$$

where *σ* is the elasticity of substitution.

4. Results

Improvement of the traditional CES function

It is worth considering that the production functions were not initially adapted for calculating the tourist indicators. However, we decided to consider the possibility of using them when calculating the possible revenue from domestic tourism. Since the incomes of the different population groups of a country can differ significantly, we decided to divide the population into four groups according to the data found in open sources. We assumed that the financial capabilities of tourists can be considered as the difference in their income after taxes and spending on rent and the consumer basket, considering elasticity. It is obvious that tourists do not spend this amount entirely on trips but we assumed that the calculation aimed to estimate the maximum possible income from tourism.

Therefore, our next task was to calculate a tourist's maximum possible spending. This required adapting the production function to the tourism industry. We calculated the financial opportunities for each tourist separately depending on their standard of living.

If, for production in the CES function, the important parameters were K (capital) and L (labour) and Y (the quantity of products produced), then, for the tourism industry, the parameter Y will be responsible for the total income of a person, K for constant and necessary expenses, including spending on housing area, food, transport, and other necessities, and L for the final part of the funds that the agent can set aside for future travel.

The following formula (3) was used to calculate the data on the tourism industry.

$$Y = \left(K \wedge (-p) + L \wedge (-p)\right) \wedge \left(-\frac{\gamma}{p}\right), \tag{3}$$

where *K* – permanent (necessary) expenses, which include spending on rental housing and the consumer basket; *L* – the maximum possible amount of money a person is willing to save (postpone) for travel; and *Y* – annual income, including taxes. In this case, the unknown parameter will be *L, and the distribution of funds will depend on the trend of spending tourists.*

Accordingly, the formula 4 for obtaining an estimate of the maximum possible expenses of one tourist, taking into account their standard of living, is as follows:

$$L = Y\left(\tfrac{1}{\gamma}\right) - K, \tag{4}$$

The calculation formula (5) of σ using the ratio of the number of tourists in different years to their tourism expenses is as follows:

$$\sigma = (L0 - L1) / (population0 - population1), \tag{5}$$

where *L0, L1* – travel expenses of tourists in 2018 and 2019, respectively; population0, population1 – the number of tourists in 2018 and 2019, respectively.

Unfortunately, at this stage, we were limited by the lack of high-quality source data necessary for validating and refining the formula. Since work is currently underway to collect and analyse data on the tourism industry as part of a project to develop a model of domestic tourism, at the next stage, all the results obtained will be verified based on real data.

Initial data

The process of data collection and analysis requires separate coverage. No single unified system exists in any country for collecting and analysing the tourism industry data. The methodological recommendations for collecting and analysing the data on the tourism industry are presented in the Methodology of the United Nations World Organisation from 2008. However, each country follows its own approach to this process. Therefore, within the framework of this model, the data obtained from various open sources were used (Botavina et al., 2020), which could affect its quality. It is difficult to find real, openly accessible data to make calculations. Real data, in most cases, has private access. In turn, open sources contain data that differ in its content, since collecting tourist data is not bound by any uniform requirements. Since we considered only the first experiments within the framework of the project on modelling domestic tourism, we made assumptions about the possibility of using synthetic data, which is close to real data.

It is worth noting that, during the development and testing of the prototype model, no emphasis was placed on the use of data on any particular country, as the model is assumed to be a unified solution for any object of research. In this case, it was necessary to focus on a developed country with stable economic indicators and with a minimum number of tourist zones. The latter requirement was due to the inability to obtain reliable results based on the average for different points of attraction. Based on the stated requirements, the choice of the country for the study settled on Austria for a number of the following reasons:

- Relative completeness of data in comparison with other countries;
- Stable contribution of the tourism industry to the country's GDP (about 6%);
- Developed domestic tourism (at least 40% of the tourist flow);
- Stability of economic indicators;
- Relative limitations at the tourist points of attraction.

Experiments

Considering pensioners, the working population was divided into four income groups. For each group, the maximum amount of money that could be spent on holidays in the country was calculated. It is worth noting that the results turned out to be logically acceptable, as they did reveal an increase in the difference in income after taxes and spending on rental housing and grocery baskets. Elasticity smoothed the distribution of funds between the necessary expenses and tourist products, allowing us to count on high-quality results after experimenting with real data.

Table 2 shows the results of calculating the possible revenue from tourists categorised by income groups. The income from one tourist is the share of the salary that remains with them after paying for all the vital needs. The data on the salary of one tourist per year, depending on the income group, is based on articles of a recommendatory nature. The approximate expenses of one tourist for the consumer basket and the cost of housing and other necessary expenses were also calculated depending on the income group. Knowing the values of the parameters Y and K, the elasticity variable γ was selected, which offered a realistic estimate of the residual amount for travel. The revenue from one tourist was calculated according to formula (4). The authors compiled the data using open sources.

Table 2. Revenue from one tourist based on the income group

Group	Predictable waste, €
1	1056
2	3796
3	7582
4	8657

In addition to revenue, it was necessary to calculate the maximum number of trips per year to predict tourist flow. For each of the profitability groups, the cost of vacation was determined depending on its class based on the studied materials from open sources. To unify the data for a unit of vacation, we took 14 days. We took the average cost of a vacation by category for 14 days from open sources. We then calculated the possible number of trips for each income group using the following formula:

$$Number\,of\;\; possible\,trips = Predictable\,waste\;\; / \,Recreation\,coast \quad (6)$$

We then rounded the resulting values to integers. Table 3 shows the results.

Table 3. Maximum number of trips per year for one tourist based on income group

Group	Predictable waste, €
1	1056
2	3796
3	7582
4	8657

It is worth noting that prices in Austria are among the highest, so tourists can afford a vacation in most other countries for a similar cost. For most countries, an additional reason for choosing domestic tourism instead of outbound tourism is to save money.

All the calculations were implemented in code written in the statistical programming language R.

5. Discussion

Modelling domestic tourism based on the concept of CGE models is not a new solution (Deepak et al., 2001; Blake, 2009; Gül, 2015; Blake, 2006; Van Truong et al., 2017). However, in the conditions of a pandemic (Hordofa et al., 2022), the development of a general equilibrium model is becoming relevant again, since it allows us to assess the object of the investigation from the point of view of the impact on this system, and it also takes into account the mutual influence of all elements of the system on each other. Thus, significant changes in the needs and opportunities of tourists correlate with changes at the state level, and the model continues to develop in a coordinated manner. Since increasing the scale of the research object increases the complexity of building a model, it is necessary to formalise the behaviour of all the elements of the system as much as possible. A mathematical description of the dynamics of consumer spending will allow us to assess the trends towards savings as well as to understand the natural limitations in the possible income from tourist products.

The resulting solution allowed us to assess the financial capabilities of the population and its propensity to spend on necessities and recreation and to divide the population groups by profitability, which is necessary at the next stage of developing the model to determine the revenue from one tourist. It is impossible to estimate the prospects of obtaining revenue from tourism without the distribution of profitability groups, indicating that it is impossible to predict tourism's contribution to the GDP.

6. Conclusion

In this article, we reviewed the approaches to modelling tourist flows and tourist processes. We classified the analysed models based on their type and scale. We also created a list of the most popular indicators for analysing the tourism industry: geotagged photos, the GDP, the annual tourist's income, the actual arrivals of tourists, the search queries (general information about the country), the search queries regarding planning (restaurants, hotels, and shops), and the psychotype and behaviour of tourists. After analysing the articles, we selected the most promising approaches to modelling domestic tourism. It formed the basis of a general model of domestic tourism, combining the advantages of mathematical methods for predicting tourist flow, neural networks for data processing, and simulation models for fully accounting for all the infrastructure elements and their mutual influence. Moreover, we analysed the production functions for the subsequent calculation of the income of tourists from various income groups. Based on our analysis, we selected the CES function to forecast revenue from the tourist products consumed by domestic tourists. We adapted this function to consider the profitability indicators, the cost of essential goods, and the elasticity of demand for tourist services for four income groups. We conducted the analysis on Austria's synthetic data, which was close to the real data. Our results reveal the estimated maximum amounts of revenue gained from one tourist for the four groups of profitability, as well as the estimated number of trips per year, considering the recommended type of vacation for each of the groups. Our study contributes to the initial stage of the development of the CGE model for modelling tourism processes by considering the relevance of general equilibrium models in the context of the economic crisis caused by the pandemic.

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