Algorithmization of Intellectual Data Analysis for Measuring the Country's Innovation Potential

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Abstract

The article examines the key principles of using applied intelligent systems in the economic analysis of Ukraine's innovation potential, which significantly improves the processes of management algorithm construction and, as a result, creates a favorable environment for innovative development. It presents an algorithm for measuring the country's innovation potential, which is based on basic methods applied for the analysis, distribution, and classification of input data space. The advantages of applying the principal component method are identified, along with a procedure for using it to determine key indicators for assessing the country's innovation potential. An approach to determining innovation potential is formed based on intelligent data processing, allowing for the analysis and visualization of large volumes of data, as well as the identification of trends, key factors, and indicators influencing innovation activity in Ukraine. The research also justifies the feasibility and proposes an approach to using modern intelligent systems for continuous monitoring and control of the level of innovation activity, as well as for identifying and forecasting risks and issues, and determining possible ways to address them.

Keywords
Distribution of input data space, applied intelligent systems, principal component method, innovation potential.

1. Introduction

In modern conditions of globalization and rapid technological development, the use of applied intelligent systems (AIS) is of paramount importance. They enable more accurate, faster, and more comprehensive analysis of large amounts of data. AIS facilitates the automation of economic and legal data analysis processes, providing fast access to information and conducting complex analysis, thereby enhancing effectiveness. Leveraging machine learning algorithms and big data analysis, AIS can identify trends in economic and legal processes and forecast the country's innovation potential.

The complexity of processes determining the country's innovation potential is driven by high dimensionality, multi-level structure of mathematical models, and the number of interrelations between input and output variables. This necessitates the application of advanced approaches

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to processing analytical data to support optimal managerial decision-making. This justifies the relevance of conducting this research.

The purpose of the research is to develop an algorithm for determining the country's innovation potential using applied intelligent systems based on identifying influencing factors and uncovering hidden relationships between variables in statistical data.

To achieve the stated goal, the following tasks were addressed:

1) formulation of the initial set of indicators of innovation potential based on analysis of literature sources;

2) proposal of an algorithm for determining the level of innovation potential, which includes a) identification of hidden relationships between variables by constructing a correlation matrix; b) selection of the most representative indicators using the principal component analysis method; c) calculation of the resulting integral indicator using the taxonomic indicator of development method.

2. Analysis of publications

The research papers of Ukrainian and foreign scientists are devoted to determining the innovation potential based on the use of applied intelligent systems.

In the article by Vakaliuk V. A. [1], it is to define the organization's innovation potential using coefficient, index-integral, comparative methods, as well as system analysis, and to consider it through the prism of organizational, managerial, and financial-economic factors.

Riabovolyk T. F. [5] studied issues related to the innovative development of the country's economy, the necessity of forming corresponding policies, and evaluating the innovation potential at the regional level. The scientist [5] also proposed an algorithm for the integral assessment of the effectiveness of using the innovation potential of regions and identified blocks of indicators of stimulating and de-stimulating influences on the formation of an aggregate indicator.

The article by Hryhoruk P. M. And Khrushch N. A. [2] analyzes the main statistical indicators reflecting the innovative development of the region and calculates the integrated indicator of innovation potential based on block convolution, exploring its dynamics.

Scientists Yepifanova I. Yu. and Hladkova D. O. [3] systematize and summarize the experience, analyze existing methods, and approaches to evaluating the innovation potential of an enterprise. Their key characteristics are identified, the most common ones are highlighted, and examples of calculation mechanisms are provided for a detailed assessment of the enterprise's innovation potential. It is proposed to evaluate the innovation potential of the enterprise based on determining indicators from the following components in a certain sequence: innovation competencies, innovation capabilities, innovation resources, and innovation projects.

As a result of the research by Semenchenko N. V. and Moroz O. S. a system of primary indicators for assessing the level of innovative development of an enterprise was formed, which allows to analyze it in terms of its components (innovative potential and innovative process). Furthermore, this system serves as the foundation for a hierarchical model aimed at analyzing the innovation development of the enterprise.

Additionally, research into the innovation potential of regions was undertaken by Zhykhor O. B. [4]. In his work [4], the scientist proposed and substantiated the use of a generalized utility function (or Harrington's scale) to determine the level of innovation activity of the region (the realized part of the innovation potential of the region).

In J. Gladevich's article [6], an approach to evaluating innovation potential using the sum method is proposed. The obtained results are depicted on maps for enhanced comprehension and visualization.

Furthermore, the issue of modeling economic processes, including indicators of innovation potential, has been addressed by foreign scientists: Atashbar, T. [8, 9] developed an algorithm for determining macroeconomic indicators using automated artificial intelligence systems;

Zeleznikow, J. [10] suggested applied decision support systems to automate data exchange between clients and firms; Fulcher, J., Jain, L.C. [11] proposed considering artificial intelligence in the provision of financial services, while another group of scientists, Veloso, M., Balch, T., Borrajo, D., Reddy, P., & Shah, S. [12, 13], in their works, emphasize the need for its consideration in the management of any financial company.

Thus, contemporary economic trends indicate the necessity of algorithmizing economic processes for their further enhancement through the application of artificial intelligence. In the context of analyzing innovation potential in scientific works, the problem of identifying hidden relationships between indicators of innovation potential and justifying the selection of the most representative among them remains insufficiently explored, which is the aim of this research.

3. Methods

To compute the composite index of a country's innovation potential, it is proposed to devise a procedural algorithm that encompasses various combinations of statistical analysis methods aimed at obtaining an overarching assessment of a substantial volume of data (Figure 1).

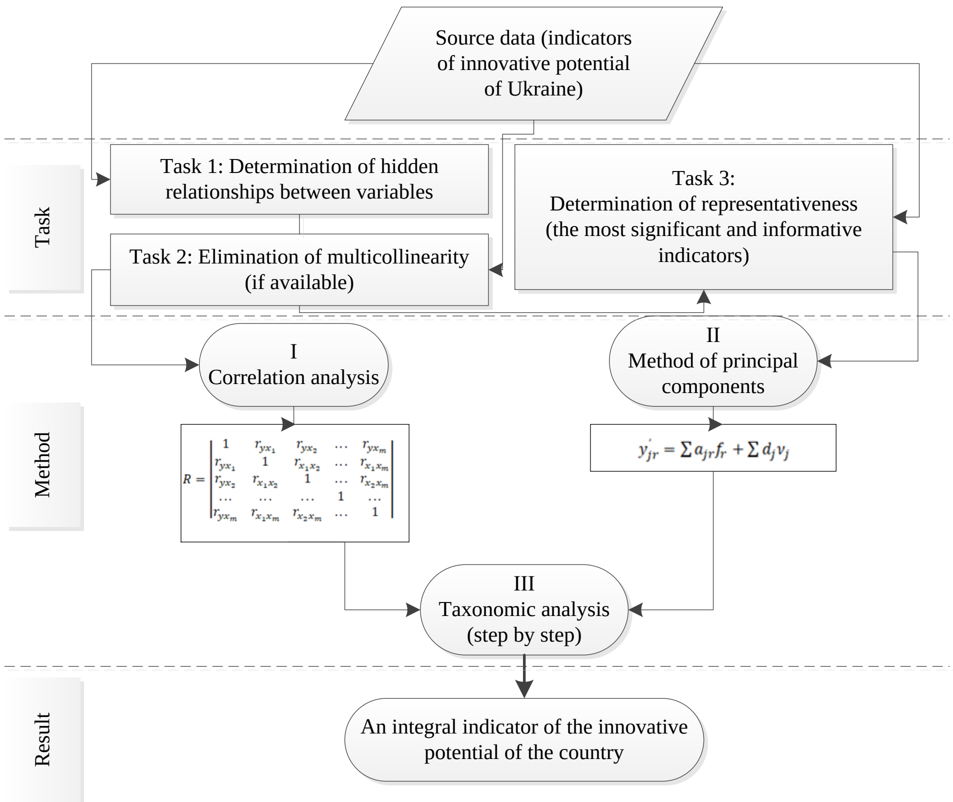


Figure 1: Algorithm for determining the integral indicator of Ukraine's innovation potential
Source: compiled by the authors

As illustrated in Figure 1, the following methods were employed in this study to achieve the research objective: correlation analysis [14] to identify latent relationships between variables and to mitigate multicollinearity among them; principal component analysis [18] to determine the most significant and informative indicators; and a taxonomic development index [19] for calculating the integrated indicator of the country's innovation potential.

The construction of the pairwise correlation coefficient matrix is a common method within the framework of applied intelligent systems. Calculating correlation coefficients allows for the for the identification of the strength and directions of relationships between the variables under investigation, as the key issue in building adequate mathematical models is the presence of correlated independent variables, i.e., the absence of multicollinearity effects [14]. Multicollinearity effects signify that at least two independent variables influencing the predicate exhibit a strong correlation. A series of scientific studies [14, 15, 16] are devoted to the adverse impact of multicollinearity on the entire research process. The primary issue arising from multicollinearity is the unstable and biased parameter errors in data analysis models, leading to ineffective estimates that preclude an adequate analysis of the process.

Based on the calculation of pairwise correlation coefficients for a set of indicators, a matrix is constructed (Formula 1). If the entire dataset consists of m variables (factors) X, each containing n observations, then the matrix of pairwise correlation coefficients R is calculated, which will be symmetric with respect to the main diagonal.

$$R = \begin{vmatrix} 1 & r_{yx_1} & r_{yx_2} & \cdots & r_{yx_m} \\ r_{yx_1} & 1 & r_{x_1x_2} & \cdots & r_{x_1x_m} \\ r_{yx_2} & r_{x_1x_2} & 1 & \cdots & r_{x_2x_m} \\ \cdots & \cdots & \cdots & 1 & \cdots \\ r_{yx_m} & r_{x_1x_m} & r_{x_2x_m} & \cdots & 1 \end{vmatrix} \quad (1)$$

For the purpose of interpreting the calculated coefficients of pairwise correlation, the Chedoke scale [11] is utilized, according to which a coefficient of pairwise correlation with a value of 0.7 represents a strong association. Therefore, if the coefficient of pairwise correlation between two indicators equals or exceeds 0.7, one of the indicators should be excluded from the model to mitigate the multicollinearity effect.

After eliminating the multicollinearity effect, there arises the need to determine the most representative indicators using the principal component method of factor analysis. The essence of the factor analysis method lies in identifying hidden interdependencies between indicators that characterize various aspects of the country's innovation potential over a certain period of time and have different natures, reducing them to a smaller set and using new, most important characteristics that explain a significant portion of the variation in the values of the analyzed data. The essence of the factor analysis method consists of uncovering hidden interdependencies between indicators that characterize various aspects of the innovation potential over a certain period and have different natures, reducing them to a smaller set and using new, most important characteristics that explain a significant portion of the variation in the values of the total sample data.

The principal component method allows for the extraction of m principal components or generalized features from m original features. The mathematical model of the principal component method is based on the logical assumption that the values of a set of interdependent features generate some common outcome and has the following form [12]:

$$y_{jr}^{'} = \sum a_{jr} f_r \quad (2)$$

where y_{jr}' is centered (normalized) value of the j-th feature; a_{jr} is the weight of the r-th component in the j-th feature; f_r is r-th principal component.

The basic factor analysis model is determined by the formula:

$$y_{jr}^{'} = \sum a_{jr} f_r + \sum d_j v_j \quad (3)$$

where y_{jr}' is centered (normalized) value of the jth feature; a_{jr}– the weight (or loading) of the j-th feature on the r-th common factor; f_r – r-common factor; d_j – the weight (or loading) of the j-th feature on the r-characteristic individual factor; v_j – characteristic (individual) factor related only to this j-characteristic.

As evident from formulas (2) and (3), the principal component analysis method does not consider characteristic factors, and the number of components equals the number of features. Consequently, after excluding components based on the smallest proportion of total variance, the remaining components will be significantly fewer than the number of features.

The final stage in determining the innovation potential of a country is the formation of an approach for its integral evaluation. There are several methods for constructing an integral indicator for analyzing complex phenomena, among which taxonomic analysis has been chosen for this study. This method allows for the systematization of multidimensional statistical information and obtaining a single comprehensive assessment. The universality of taxonomic analysis enables its use for analyzing the properties of a single unit characterized by feature values specified in the form of time series, which forms a generalized picture of changes. The sequence of steps in calculating the taxonomic indicator of innovation potential is presented in Table 1.

Table 1
Stages of taxonomic analysis of the innovative potential of the country

Stage	Characteristic	Calculation procedure
Stage 1	Forming a matrix of observations	$X = \begin{vmatrix} x_{11} & x_{1j} & \cdots & x_{1k} \\ \cdots & \cdots & \cdots & \cdots \\ x_{i1} & x_{ij} & \cdots & x_{ik} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{nj} & \cdots & x_{nk} \end{vmatrix}$
Stage 2	Standardization of the values of the elements of the observation matrix	$z_{ij} = \frac{x_{ij}-\bar{x}}{\sigma_i}$, where z_{ij} is standardized value of indicator i in time period j; x_{ij} is value of indicator i in time period j; $\bar{x}$ is arithmetic mean value of indicator i for all periods; σ is standard deviation of indicators.
Stage 3	Definition of the reference vector	$z_{0k} = \begin{cases} max\ z_{ik}, \text{if the stimulus indicator} \\ min\ z_{ik}, \text{if the indicator is a disincentive} \end{cases}$ $z0k$ is reference value of the indicator.
Stage 4	Calculation of the distance between individual observations and the reference vector (C_0)	$C_{i0} = \sqrt{\sum_{i=1}^{n}(z_{ij} - z_{0j})^2}$
Stage 5	Definition of a taxonomic indicator of development	$S_0 = \sqrt{\frac{1}{m}\sum(C_{i0} - \bar{C})^2}$, where S_0 is standard deviation; $\bar{C}$ is average distance between observations. $C_0 = \bar{C} + 2S_0$, where C_0 is the maximum possible deviation from the standard. $d_i = \frac{C_{i0}}{C_0}$, where d_i is dynamic indicator of development. $K_i = 1 - d_i$, where K_i is taxonomic indicator of development.

The analysis conducted using the taxonomy method (Table 1) allows us to establish the scale and directions of changes, forecast their impact on the main parameters of innovation potential, identify the most important growth factors, and make appropriate management decisions or directions for state policy based on this.

4. Output date

For the formation of the initial set of indicators that can be used for the analysis of the country's innovation potential, a number of scientific studies have been analyzed [1,2,3,4,5,6,7]. As a result, 13 indicators of innovation potential have been selected, including: the volume of exports of telecommunications, computer, and information services (X1), the volume of exports of scientific and research and development services (X2), the expenditure on innovation (X3), the share of funds from non-resident investors to the total expenditure on innovation (X4), the share of enterprise own funds to the total expenditure on innovation (X5), the number of employees engaged in scientific research and development (X6), the number of employees with scientific degrees engaged in scientific research and development (X7), the share of the number of industrial enterprises that implemented innovations (products and/or technological processes) in the total number of industrial enterprises (X8), the number of types of innovative products (goods, services) implemented in the reporting year (X9), the share of the volume of implemented innovative products (goods, services) in the total volume of sold products (goods, services) of industrial enterprises (X10), the expenditure on scientific research and development (X11), the expenditure on the purchase of machinery, equipment, and software (X12), the share of the number of innovation-active enterprises in the total number of industrial enterprises (X13).

In the next stage of the research, selected indicators of Ukraine's innovation potential for the years 2000-2021 were calculated based on data from the State Statistics Service of Ukraine [20] and the National Bank of Ukraine [21], as identified through analysis of literature sources (Table 2).

Table 2
Indicators of Ukraine's innovation potential

Year	The volume of export of telecommunication, computer and information services (X1), million dollars. USA[1]	The volume of costs for innovation (X3), UAH million.	The share of funds of non-resident investors to the total volume of innovation costs (X4)	The share of the company's own funds in the total volume of innovation costs (X5), %	Share of the number of industrial enterprises that introduced innovations (X8), %	The number of types of innovative products introduced in the reporting year (X9), units
2000	175	1757,1	7,6	79,6	14,8	15323
2001	190	1971,4	3,0	83,9	14,3	19484
2002	200	3013,8	8,8	71,1	14,6	22847
2003	210	3059,8	4,2	70,2	11,5	7416
2004	300	4534,6	2,5	77,2	10,0	3978
2005	375	5751,6	2,7	87,7	8,2	3152
2006	400	6160,0	2,9	84,6	10,0	2408
2007	498	10821,0	3,0	73,7	11,5	2526
2008	600	11994,2	1,0	60,6	10,8	2446
2009	718	7949,9	19,0	65,0	10,7	2685
2010	719	8045,5	30,0	59,4	11,5	2408
2011	1040	14333,9	0,4	52,9	12,8	3238

2012	1321	11480,6	8,7	63,9	13,6	3403
2013	1782	9562,6	13,1	72,9	13,6	3138
2014	2042	7695,9	1,8	85,0	12,1	3661
2015	2105	13813,7	0,4	97,2	15,2	3136
2016	2310	23229,5	0,1	94,9	16,6	4139
2017	2760	9117,5	1,2	84,5	14,3	2387
2018	3473	12180,1	0,9	88,2	15,6	3843
2019	4331	14220,9	0,3	87,7	13,8	2148
2020	5181	14406,7	0,9	85,4	14,9	4066
20212	7107	14220,0	6,1	84,9	15,0	2130

1 forecast data for 2000-2009;
2 forecast data for 2021.

Table 2 shows that only indicators that correlate with each other and may have a close relationship have been selected due to their heterogeneity and scale of values. Therefore, the presented indicators have been chosen for further factor analysis.

5. Experiment

For eliminating the multicollinearity effect between the indicators, a matrix of pairwise correlation coefficients was calculated, which is presented in Figure 2.

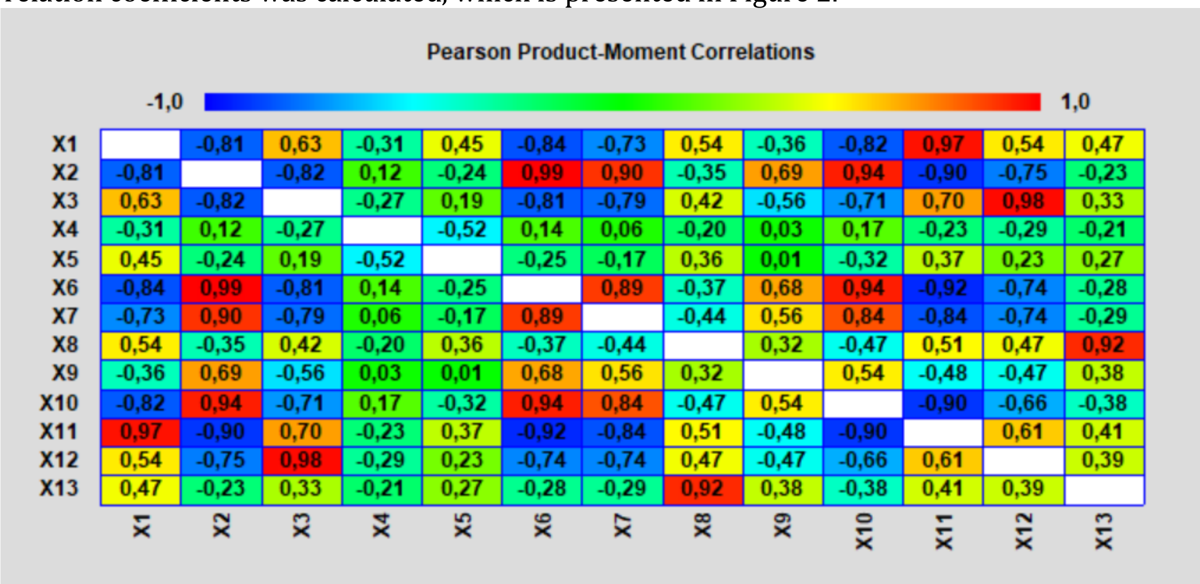
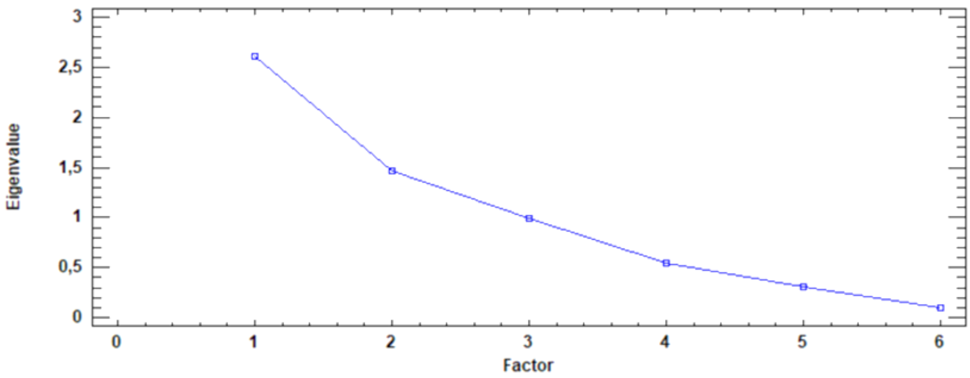


Figure 2: Matrix of pairwise correlation coefficients between indicators of Ukraine's innovation potential
Source: compiled by the authors

As seen from the data presented in Figure 2, a number of indicators exhibit a strong linear relationship with each other (the correlation coefficient exceeds the value of 0.7). To address multicollinearity, further factor analysis is conducted to determine the optimal set of indicators for assessing the level of innovation potential in Ukraine, incorporating 6 indicators.

For practical implementation of the principal component analysis method using the data provided in Figure 2, the Statgraphics Centurion 19 package was utilized. This package allows for the examination of individual and cumulative variance, the proportion of total variance explained by each component, and cumulative variance characterizing the selected principal components (Figure 3).



Factor	Eigenvalue of the factor	Percentage of total variance, %	Percentage of accumulated variance, %
1	2,61	43,47	43,47
2	1,47	24,45	67,92
3	0,99	16,49	84,40
4	0,54	8,97	93,37
5	0,31	5,11	98,48
6	0,09	1,52	100,00

Figure 3: Statistical Characteristics of the Obtained Principal Components for Assessing the Country's Innovation Potential
Source: compiled by the authors

The obtained results of the factor analysis for indicators of innovation potential are presented in Figure 3, where the necessary number of factors is determined by the magnitude of cumulative variance. A value of cumulative variance at the level of 70% is considered sufficient. This indicates that the formed factors explain 70% of the variability of the studied process, while 30% is explained by other factors. Thus, the results of the factor analysis demonstrate that it is advisable to conduct an assessment of the country's innovation potential based on three obtained factors, which explain 84.40% of the variability of the assessment.

In the next stage of the research, an assessment of the significance of indicators based on the size of the loadings was conducted to reduce the dimensionality of the number of indicators. Factor loadings were obtained following the varimax procedure (see Appendix 1), demonstrating the correlation between indicators and factors. Using the principal component method, five most representative indicators of the country's innovation potential were identified.

According to the previously developed algorithm, in the subsequent stage of the research, an integrated indicator of innovation potential was calculated using the taxonomy analysis method. Intermediate indicators and the resulting assessment of Ukraine's innovation potential for the years 2010-2021 are provided in Appendix 2. It was determined that the taxonomy development index presented in Appendix 2 can range from [0;1], with the closer the value of the composite index to one, the higher the country's innovation potential.

6. Results

Based on the developed algorithm, the research identifies the dynamics of Ukraine's innovation potential from 2000-2021, as presented in Figure 4.

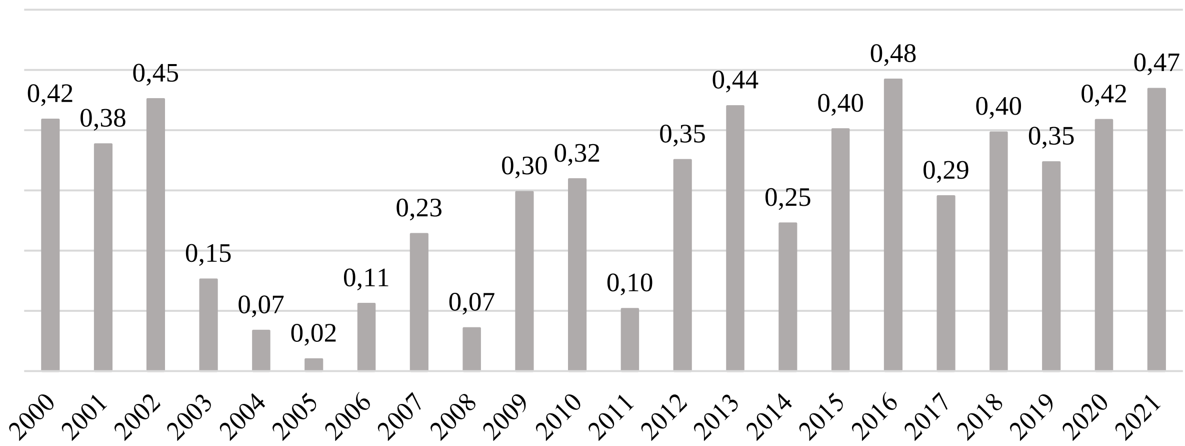


Figure 4: Dynamics of the Integrated Indicator of Ukraine's Innovation Potential
Source: compiled by the authors

As seen in Fig. 4, the highest values of Ukraine's innovation potential were in 2002, 2016, and 2021, while the lowest were in 2005, 2008, and 2011. The provided statistics allow for the identification of fluctuations in the country's innovation potential over time; however, for a qualitative interpretation of the assessment results, there is a need to develop a scale for distributing indicators at the level.

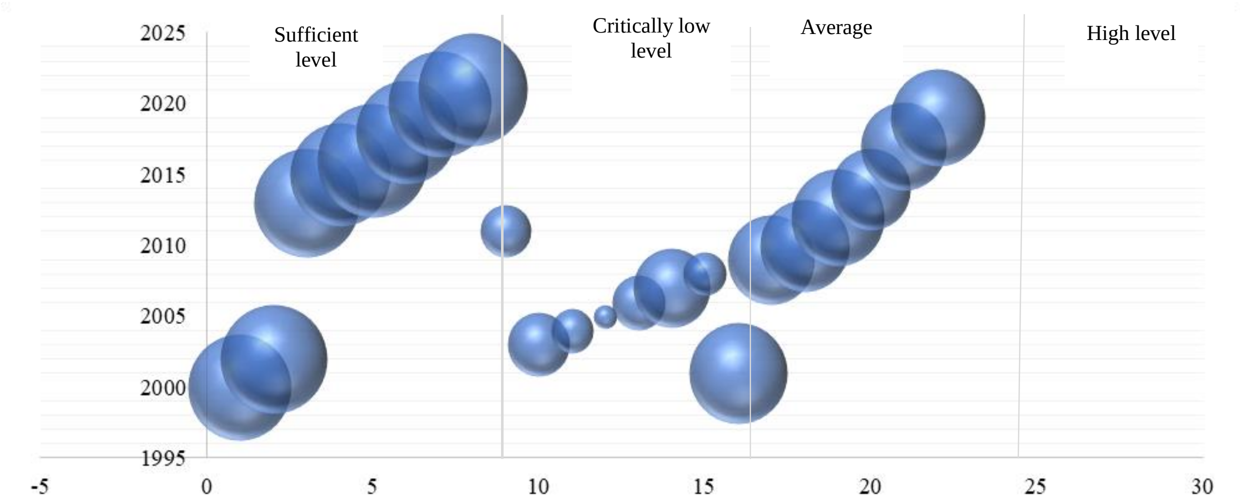
The research proposes a scale for determining the level of a country's innovation potential based on the Fibonacci ratio [22]. According to this ratio, changes in indicator values most often occur in the range between 38.2% and 61.8%. In this case, the scale for evaluating innovation potential takes the form [0;1]. According to the approach in [23], after multiplying this difference sequentially by 0.382 and 0.618 and subtracting each of the obtained sums from the «maximum», values of intervals were obtained within which changes are most likely to occur according to the Fibonacci ratio. The obtained interval [0; 0.382) is divided into 2 smaller intervals at the levels of 38.2% and 61.8% (0.236 and 0.382).

As a result of scaling according to the Fibonacci ratio, four ranges of the level of a country's innovation potential were obtained, which are presented in Table 3.

Table 3
Scales for determining the innovation potential of the country

Indicator	The level of innovative potential of the country			
	Critically low	Average	Sufficient	High
An integral indicator of the innovative potential of the country	[0; 0,236)	[0,236; 0,382)	[0,382; 0,618)	[0,618; 1]

Based on the scale in Table 3, the levels of Ukraine's innovation potential for the years 2010-2021 were determined, presented in the form of a distribution matrix in Figure 5.



Year	Integral indicator of innovative potential (average value)	The level of innovative potential
2000,2002,2013,2015, 2016,2018,2020,2021	0,42	Sufficient
2003,2004,2005,2006, 2007,2008,2011	0,15	Critically low
2001,2009,2010,2012, 2014,2017,2019	0,32	Average

Figure 5: Distribution of Ukraine’s Innovation Potential Level
Source: compiled by the authors

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7. Conclusions

Thus, the researchers developed an algorithm for determining the integral indicator of the country’s innovation potential through a system of quantitative indicators by: selecting the initial set of indicators based on the synthesis of methodological approaches in the scientific literature; eliminating high functional dependency between indicators using correlation analysis; reducing the number of coefficients using multidimensional factor analysis – principal component method. The initial data for conducting correlation and multidimensional factor analysis were derived from a sample of 22 observations (data for 2000-2021). Based on the results of factor analysis, it was established that it is advisable to assess the innovation potential based on three obtained factors, which collectively account for 84.4% of the variability of the initial variables. Among the set of indicators for each factor, diagnostic features were determined using the «weight center» method, which have the most significant properties of the set of output data. Based on the taxonomic indicator of development, integral indicators of Ukraine’s innovation potential for 2010-2021 were calculated and their qualitative interpretation was provided according to the scale developed based on the Fibonacci relationship. The proposed algorithm allows for continuous monitoring and control of innovation potential, identifying and forecasting risks and potential issues, as well as determining possible ways to address them.

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Additions

1. Matrix of factor loadings of the obtained principal components

Indicator	The value of factor loadings by components		
	Main component 1	Main component 2	Main component 3
The volume of export of telecommunication, computer and information services (X1), million dollars. USA	0,5127	0,6793	0,2297
The volume of costs for innovation (X3), UAH million.	**0,7447**	0,5069	0,1317
The share of funds of non-resident investors to the total volume of innovation costs (X4)	**-0,0840**	-0,0170	**-0,9013**
The share of the company's own funds in the total volume of innovation costs (X5), %	0,0178	0,3201	**0,7987**
Share of the number of industrial enterprises that introduced innovations (X8), %	-0,1309	**0,9488**	0,1584
The number of types of innovative products introduced in the reporting year (X9), units	**-0,9591**	0,1885	0,0091

2.Calculation of innovative potential of Ukraine

Year	An indicator of the distance between individual observations and the reference vector (C_{i0})	A dynamic indicator of development (d_i)	Taxonomic indicator of development (K_i)
2000	30,81	0,58	0,42
2001	32,97	0,62	0,38
2002	29,01	0,55	0,45
2003	44,85	0,85	0,15
2004	49,37	0,93	0,07
2005	51,87	0,98	0,02
2006	47,00	0,89	0,11

2007	40,86	0,77	0,23
2008	49,14	0,93	0,07
2009	37,16	0,70	0,30
2010	36,06	0,68	0,32
2011	47,44	0,90	0,10
2012	34,36	0,65	0,35
2013	29,62	0,56	0,44
2014	39,94	0,75	0,25
2015	31,66	0,60	0,40
2016	27,29	0,52	0,48
2017	37,55	0,71	0,29
2018	31,93	0,60	0,40
2019	34,55	0,65	0,35
2020	30,84	0,58	0,42
2021	28,10	0,53	0,47