Application of Cluster Analysis for Condition Assessment of Banks in Ukraine

Hrygorii Hnatiienko[a], Volodymyr Domrachev[a], Tetiana Semenenko[b], Volodymyr Saiko[a] and Violeta Tretynyk[c]

[a] *Kiev National University named by Taras Shevchenko, Volodymyrska St, 60, Kiev, 01033, Ukraine*
[b] *Sumy State University, Ryms'koho-Korsakova St, 2, Sumy, 40000, Ukraine*
[c] *Igor Sikorsky Kyiv Polytechnic Institute, Peremohy Ave, 37, Kiev, 03056, Ukraine*

Abstract

The International Monetary Fund estimates that the coronavirus pandemic could cause a deeper global recession than the economic downturn triggered by the 2008-2009 financial crisis. Uncertainty about the duration of the pandemic and unpredictability of the scale of its consequences provokes the search for ways not only to counter the threats of economic downturn, but also ways to economic growth and promote innovation in the difficult times of the pandemic. With this in mind, this article will analyze the application of cluster analysis to assess the state of banks. The problem of bank clustering is classified as ill-structured. Expert technologies and tools of artificial intelligence should be used to solve it. At the preliminary stage of the research, expert technologies are used, on the basis of which a subset of banking performance indicators is determined, which are essential for the decision on clustering. In addition, the characteristics of the banks that most influence the cluster analysis are selected.The authors propose to use an analysis based on the construction of clusters from the main indicators that characterize the activities of banks instead of analyzing the risks of banks, based on the calculation of economic standards. Prospects for improving methods of regulating the activities of banks in Ukraine are considered.

Keywords[1]

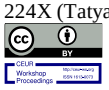
banking operations, cluster analysis, risk, liquidity, capital adequacy, economic standard, expert technologies, ill-structured problem

1. Introduction

The current state of Ukraine's economy is characterized by growing economic risks. For the second year in a row, the world is in a state of quarantine, which is replaced from time to time by stricter restrictive measures - national or local lockdowns, or, conversely, short-term mitigation when schools, kindergartens, restaurants, cinemas, etc. open. Banks, as a result of non-repayment of loans provided by firms for the purchase of goods, significantly reduced profits, reduced return on assets and capital. The liquidity of the banking sector decreased. In order to maintain the liquidity of banks, the National Bank began to fill the economy with money supply, which, in turn, provoked rising inflation. Creating a developed and perfect model of state regulation of the national banking system occupies a prominent place in the set of tasks for effective management of the banking sector and the economy as a whole. The search for new tools aimed at improving the efficiency of the banking system is becoming especially relevant today. Recently, there has been an adaptation of the banking system to the economic situation through the use of regulatory mechanisms, which are due to the limitation of risks due to economic standards. The most modern mathematical methods are used to analyze banking risks. Information is the 21st Century gold, and financial institutions are aware of

Information Technology and Implementation (IT&I-2021), December 01–03, 2021, Kyiv, Ukraine

EMAIL: g.gna5@ukr.net (Hrygorii Hnatiienko); mipt@ukr.net (Volodymyr Domrachev); t.semenenko@uabs.sumdu.edu.ua (Tetiana Semenenko); vgsaiko@gmail.com (Volodymyr Saiko); viola.tret@gmail.com (Violeta Tretynyk)
ORCID: 0000-0002-0465-5018 (Hrygorii Hnatiienko); ORCID: 0000-0002-0624-460X (Vladimir Domrachev); ORCID: 0000-0002-1308-224X (Tatyana Semenenko); ORCID: 0000-0002-3059-6787 (Vladimir Saiko); ORCID: 0000-0002-3538-8207 (Violeta Tretynyk)



this. Armed with machine learning and artificial intelligence technologies, they have the opportunity to analyze data that originates beyond the bank office. Financial companies collect and store more and more user data in order to revise their strategies, improve user experience, prevent fraud, and mitigate risks [1-4]. In this article, we will talk about how Artificial Intelligence and Machine Learning are used as well as the benefits and risks of these solutions [5-8].

The purpose of the paper is to analyze the possibility of using cluster analysis to assess the state of banks. In addition, the possibilities of using expert decision-making technologies [9-11] to increase the efficiency of the mathematical apparatus of data clustering [12-14], which is planned to be used to determine the similarity of banking institutions [15, 16].

2. Research results

All manifestations of financial instability can be classified into three types: banking crises; currency crises; crises in financial markets [5]. By instability we mean the ability of the financial system to influence the amplitude of the economic cycle. There are a number of reasons for this, not the least of which are credit issues. As in the theory of macroeconomic analysis, and in practice, there is a simple trend of active growth of loans during periods of economic recovery and a sharp decline during periods of decline. Scientists identify a number of reasons that cause banking crises. These are market risks, liquidity shocks, asset quality, and so on.

Active state intervention remains a bottleneck for the Ukrainian banking system. There are two forms of state regulation: direct - the direct influence of the state on aggregate supply and demand through the creation of the public sector and redistribution of income; indirect - indirect influence of the state through the functioning of credit, financial and tax systems. One way or another, the government is responsible for all the processes taking place in the country. In terms of the studied problem, we note that the regulation of the financial stability of the banking system involves the use of a special set of tools at the stage of responding to negative trends in the functioning of the banking system. This is especially important in times of financial instability in the world economy. Almost all banking operations are risky. There are both general and specific reasons for this.

Analysis of current risks of commercial banks in Ukraine shows that their condition is affected by the general economic crisis, unstable political situation in the country, incomplete formation of the banking system, as well as the absence or imperfection of some basic legislation and even the discrepancy between the legal framework and the real situation. Among the most significant external factors are changes in bank interest rates, inflation, changes in lending conditions, changes in tax rates and customs duties, changes in labor laws and more.

The ability to adequately respond to risk leads the bank to make a profit in the future and, conversely, the desire to make a profit puts the bank in a condition of acceptance of a risk. If one risky operation is successful, the profit from it can be so significant that it covers the losses from other small risky operations for a long time. The Basel III standard (2010) offers an international system for assessing liquidity risks, standards and monitoring and strengthens banks' capital requirements in order to prevent an international credit crisis.

2.1. Systematic assessment of banking risks

According to the Guidelines for Banking Inspection "Risk Assessment System" [17], banking risks are defined as the probability that events, expected or unexpected, may have a negative impact on the capital and / or income of the bank. These risks arise from the specifics of banking activities carried out in market conditions, and mean the probability of receiving income less than expected, a decrease in the value of assets. Increased banking risks lead to significant financial losses and, as a consequence, to the bankruptcy of banks. From the bank's point of view, risk is the potential for loss of income or a reduction in the market value of a bank's capital due to the adverse effects of external or internal factors. Such losses may be direct (loss of income or capital) or indirect (restrictions on the bank's ability to achieve its business goals). In order to conduct banking supervision, the National Bank of Ukraine has identified nine categories of risk, namely: credit risk, liquidity risk, interest rate risk, market risk, currency risk, operational and technological risk, reputation risk, legal risk and

strategic risk. These types of risks are not mutually exclusive. Any banking product or service can expose a bank to several risks.

According to the Instruction on the procedure for regulating the activities of banks in Ukraine [18], the bank's liquidity is the bank's ability to ensure timely fulfillment of its monetary obligations, which is determined by the balance between maturity and amount of placed assets and terms and amounts of bank obligations. also terms and amounts of other sources and directions of use of means (granting of loans, other expenses).

The Committee on Supervision and Regulation of Banking, Supervision (Oversight) of Payment Systems has defined new criteria for certain groups of banks for 2016. This is stated in the decision of the Committee of December 31, 2015 № 657. According to the document, the following groups are provided: banks with a state share (in which the state owns a share of more than 75%); banks of foreign banking groups (banks, owners of controlling stakes in which are foreign banking institutions); group I (banks, the share of assets of which is more than 0.5% of the assets of the banking system); group II (banks whose share of assets is less than 0.5% of the assets of the banking system).

One of the main indicators of the state of the bank is capital adequacy. This indicator reflects the possibility of covering the share capital of the credit institution's risky assets. The amount of capital determines the volume of active operations of the bank, the size of the deposit base, the ability to borrow funds in financial markets, maximum loans, the size of the open currency position and a number of other important indicators that significantly affect the bank [19].

Under Basel II, capital, which has been identified by supervisors as a source of contingency losses, consists of three levels of capital. Tier 1 capital, so-called fixed capital, includes share capital and retained earnings, and tier two capital includes additional capital. Banking institutions can also attract short-term subordinated borrowings, ie third-tier capital, which they can use to meet the requirements of bank capital adequacy.

The National Bank of Ukraine issued a Resolution “On Approval of the Regulations on the Organization of the Risk Management System in Banks of Ukraine and Banking Groups”, in which it recommended banks to introduce internal bank documents on risk management, implement measures to implement requirements and develop appropriate software. The main risks of banks are the risk of insufficient capital to cover possible losses and liquidity risk, which is associated with the inability of the bank to meet its obligations to customers.

During the COVID-19 pandemic in Ukraine, the liquidity of the banking sector decreased. In order to maintain the liquidity of banks, the National Bank began to fill the economy with money supply, which, in turn, provoked rising inflation. The prices of monopoly producers reacted especially actively. The question now is whether and how the Ukrainian economy will be able to keep up with moderate inflation. How will the price of the national currency react, because our consumer sector is too sensitive to inflation spikes. Which goods of Ukrainian exports will become a "lifeline" for the trade balance of Ukraine. Prices in Ukraine during the pandemic are actively growing in almost all categories of goods: only in the first quarter of 2021 inflation exceeded 4 percent, and in March this year compared to March 2020, consumer prices rose to 8.5 percent, accelerating from 7.5 percent in February. This is especially true of food products, whose prices, along with soft drinks, have risen by more than 10 percent. It is also noticeable that fares in scheduled transport have risen by almost 8 percent.

For the second year in a row, the world is in a state of quarantine, which is replaced from time to time by stricter restrictive measures - national or local lockdowns, or, conversely, some mitigation when schools, kindergartens, restaurants, cinemas, etc. open. Businesses are closing, investment costs are falling, people who have lost their jobs are losing skills and motivation for many months. In the first wave of the pandemic responded, the so-called contact industries (industry of culture, leisure, tourism, hotel, restaurant business, trade), the closure of restaurants and bars could affect farms. Warehouses and shops are full of unsold products, which lose their meaning with the change of seasons. As we can see, a short period was enough for the wave of economic downturn to overwhelm such system-forming industries as agriculture, light industry, energy, and further - mechanical engineering. Compared to past world crises, the economic downturn has been sudden and profound. The GDP indicator is increasingly demonstrating its inability to be an adequate measure of economic

development indicators; new aspects arise in questions about the nature and role of money in the functioning of a market economy. Banks, as a result of non-repayment of loans provided by firms for the purchase of goods, significantly reduced profits, reduced return on assets and capital.

2.2. Credit risk prevention

The NBU has set the economic standard H2 in order to prevent excessive transfer of credit risk by the bank and the risk of non-return of bank assets to creditors and depositors of the bank. The regulatory capital adequacy ratio is defined as the ratio of regulatory capital to total assets and certain off-balance sheet instruments, reduced by the amount of created relevant reserves for active operations and the amount of loan collateral (investments in debt securities) by unconditional liability or cash collateral. and weighted by the degree of credit risk. To calculate the regulatory capital adequacy of a bank, its assets are divided into five groups according to the degree of risk and summed up taking into account the relevant weighting ratios.

The normative value of the H2 coefficient for existing banks must be at least 10%. For banks that start operating, this standard should be: during the first 12 months of operation from the date of obtaining a license - not less than 15%; during the next 12 months - not less than 12%; in the future - not less than 10% [18]. In 2017, the National Bank of Ukraine switched to the classification of banks not by the size of assets, but on the basis of cluster analysis, in which all banks are divided into separate groups - clusters. One cluster includes banks with similar business models, risk profiles, nature of operations, etc. Banks of different sizes, but with joint owners, will also be merged. For each such cluster, specific monitoring modes will be defined and appropriate monitoring groups will be selected.

The largest banks (groups 1 and 2) are divided into three clusters: state-owned banks, large private banks and banks that are part of international banking groups. Clusters of small banks (groups 3 and 4) are not reported and the affiliation of a bank to the cluster will be considered a banking secret.

Note that in 2015 the NBU used the division of banks into groups according to the size of assets. The first group of the largest banks included PrivatBank, Oschadbank, Ukreximbank, Prominvestbank, Raiffeisen Bank Aval, Ukrsotsbank, Alfa-Bank, VTB Bank, Finance and Credit, Ukrsibbank, FUIB, UkrPasbank. The second group of large banks included Credit Agricole, Pivdenny, ING Bank, Citibank, Khreschatyk, Fidobank, Megabank, Kredobank, Credit Dnipro, PlatinumBank, Ukrinbank, Universal Bank and Diamantbank. Then it was decided to move to the classification by owner.

Cluster analysis is, by excellence, an unsupervised learning technique, that identifies the complex relationships between variables, without imposing any restriction [20. 21]. Cluster analysis focuses on the examination of the interdependencies between variables [22, 23], its finality consisting in gathering similar entities into more homogenous groups, named clusters [24-27].

Clustering analysis is currently one of the most popular and advanced mathematical grouping methods both in finance and other existing sciences [28-34]. The purpose of cluster analysis is to determine the units similar to each other in terms of their characteristics studied, and to define their clustering structures. The banking sector is the most important partner of organizations and countries against developing world economy and fluctuations in global competitive environment. Specifically, cluster analysis, a classification technique, is run on the sample of Ukrainian commercial banks to test the ability of cluster analysis to recognize vulnerable banks before they break down, as well as find out which characteristics they have in common.

It should be noted that the assessment of financial stability, as well as the efficiency of banks is carried out, traditionally, with the help of analytical tools, the main disadvantage of which is inability to take into account internal dependencies that can be hidden in analytical data. In contrast, we propose to use the tools of artificial intelligence and machine learning, which feature it is the search for such dependencies [6].

The goal of the present study is to identify resembling credit institutions, which can be included into homogenous groups, according to a series of prudential and profitability indicators. Our study aims to provide an alternative to the peer group techniques, implemented by supervisory authorities in the process of off-site surveillance. According to this technique, credit institutions are, firstly, grouped

by size or volume of activity, and then, for each group, are made comparative analyses between the current values of financial indicators and the previous ones. The disadvantage stems from the fact that this method cannot signal the impairment in the financial condition of the whole group, but only the distress of a particular credit institution in that group.

2.3. Application of expert technologies for preparation of cluster analysis of banks

For effective and adequate application of cluster analysis in the banking sector, it is appropriate and even necessary to use expert technology [35, 36] in the previous stages of the study. Expert technologies are characterized by a wide range of areas and are used, as a rule, in situations where the use of other methods is ineffective or even impractical [37, 38].

In order to systematically assess banking risks and successfully prevent credit risks, attention should be paid to at least the following aspects of the application of expert technologies in the banking sector:

- Selection of banking experts and formation of an expert group;
- Determining the coefficients of competence of experts in the selected field;
- Selection of performance indicators of banks that significantly affect the adequacy of the division of many banks into clusters;
- Selection of characteristics from the whole set of characteristics used, which will be used to evaluate banks for their further clustering;
- Choice of clustering method for adequate division of banks into groups according to selected criteria.

Expert technology is a tool to support decision-making in poorly structured subject areas where it is not possible to obtain reliable numerical information.

In [39, 40] the classification of decision-making methods according to the content of expert information, the type of information obtained in conditions of uncertainty and risk is given. In [41], a classification of decision-making problems according to the degree of their complexity is proposed. All problems are divided into three classes:

- well-structured or quantified problems in which significant dependencies can be expressed by numerical estimates;
- ill-structured or mixed problems, which are characterized primarily by qualitative (verbal), as well as quantitative relationships between elements;
- unstructured or qualitatively expressed problems that contain only a description of the most important resources, features and characteristics, the quantitative relationships between which are unknown.

2.3.1. Problem statement and its formalization

Note that the performance of banks can be measured on different scales. This fact should be taken into account when using expert technology. In particular, the performance of banks can be set in:

- nominal scales;
- dichotomous form;
- discrete form on scales with several gradations;
- in the form of fixed weights, which are real numbers;
- in the form of intervals of real numbers;
- in the form of functions of belonging to a fuzzy set;
- in the form of various combinations of the given ways of representation.

Thus, the problem of bank clustering can be classified as poorly structured. To solve it we will use mathematical modeling, expert technologies and tools of artificial intelligence.

Suppose a set A, consisting of n objects (in our case - banks), which must be compared with each other:

$$a_i \in A,\ i \in I = \{1,...,n\}. \quad (1)$$

Objects (banks) (1) are described by a set of m parameters (indicators), are points of parametric space Ω^m :

$$a_i = (a_i^1,...,a_i^m),\ a_i \in A,\ i \in I,\ A \subset \Omega^m, \quad (2)$$

where $a_i^j,\ i \in I,\ j \in \{1,...,m\} = J,$ – the value of the $j-$th indicator of the $i-$th bank.

On the basis of a survey of k experts there is a narrowing of the parametric space of the species (2):

$$\Omega^{m'} \subset \Omega^m,\ m' < m. \quad (3)$$

That is, among the whole set of parameters (1) are selected only those that are important for further clustering of a given set of banks

$$a_i^j \in A,\ i \in I,\ j \in J' \subset J,\ A \subset \Omega^{m'}. \quad (4)$$

The next step in the application of expert technology is the selection of characteristics by which objects of the species are evaluated (4). In our case, these are banks of the whole set of Ukrainian banks that should be clustered, or banks of a certain subset.

The characteristics of banks are well developed and sound. We will mark them through

$$f_i(a) \to extr,\ i = 1,...,s, \quad (5)$$

where $s-$ the number of characteristics that, in principle, can evaluate the activities of banks.

After the application of expert technologies, the set of characteristics of banks of type (5) decreases, $s' < s$. Thus, the set of characteristics that are essential for solving the problem of clustering of banks will look like:

$$f_i(a) \to extr,\ i = 1,...,s'. \quad (6)$$

2.3.2. Determination of coefficients of competence of experts

Today, the weights of competence of experts, defined in various scales of measurement, are widely used. The most common are the following ways of representing the values of weights:

- arbitrary real or natural numbers $-\infty < \rho_i < \infty,\ i \in I;$
- real numbers subject to unilateral or bilateral restrictions:

$$\rho_i > 0,\ i \in I;\ -5 \le \rho_i \le 5,\ i \in I;\ 0 < \rho_i < 1,\ i \in I;$$

- real or natural numbers, taking into account the condition of centering:

$$\sum_{i \in I} \rho_i = 0,\ -\infty < \rho_i < \infty,\ i \in I;$$

- real numbers taking into account the condition of normalization:

$$\sum_{i \in I} \rho_i = 1,\quad \rho_i > 0,\ i \in I;$$

- idealized weights:

$$\max_{i \in I} \rho_i = 1,\ \rho_i > 0,\ i \in I.$$

- interval form of weights:

$$\rho_i \in [\rho_i^H, \rho_i^B],\ 0 < \rho_i^H < \rho_i^B,\ i \in I.$$

- weights in the form of a function of belonging to a fuzzy set.

The problem of determining the importance of banks, the importance of performance indicators of banks and the competence of experts in most cases are similar and differ only in interpretation. Therefore, the definition of weights in general should be considered, bearing in mind that this problem can be interpreted in any of these aspects.

2.3.3. Selection of characteristics by which banks will be evaluated for their further clustering

Characteristics that are calculated to formally determine the financial condition of banks are used in a variety of practical situations. To solve a specific problem, in particular, the clustering of banks, an additional expert survey should be organized. Based on the use of expert technologies, the analysis of bank valuation tools is carried out. As a result of the application of this toolkit, from the set of all possible characteristics of banks (5), only those (6) are selected that are essential for the decision to combine subsets of banks into clusters.

The methods of conducting the relevant examination and the methods of aggregating expert information depend on many factors. These procedures require further research and will be described in future research.

2.3.4. Choice of clustering method for adequate division of banks into groups

To date, a wide range of clustering methods has been developed. These methods are characterized by different approaches, have different conditions of application and can lead to clustering results that do not coincide with each other. Therefore, for the situation of application of cluster analysis on many banks, it is necessary to conduct a preliminary study of the suitability of the use of effective clustering methods among the full range of such methods. The admissibility of the application of specific methods of cluster analysis to the study of many banks is determined by the use of expert technology. In the future, relevant research will be carried out and procedures will be described, which substantiate the feasibility of using certain approaches.

Research on the feasibility of using different methods of clustering in the banking sector requires a lot of effort and is not the subject of description in this paper.

2.4. Application of cluster analysis to many banks

The cluster approach (analysis) is a component of classification methods and consists in splitting a given sample of objects (situations) into subsets - clusters so that each cluster consisted of similar objects, and objects of different clusters differed significantly. The application of cluster analysis involves the following steps:

- sampling for clustering, in our case these are indicators of banks' activity;
- determination of the characteristics by which the objects in the sample will be evaluated. (We choose the indicators of return on assets and capital, as well as the indicator of capital adequacy);
- selection of the method of calculating the values of the degree of similarity between objects - application of the method of cluster analysis of k-means (ordering a set of objects into relatively homogeneous groups).

The goal is to divide n observations into k clusters so that each observation belongs to the cluster with the closest average value. The principle of the algorithm is to find the centers of such clusters. Clustering can be considered as a task of constructing the optimal division of objects into groups. Each object is identified by a vector of characteristics. X = (x1 ..., xd). The optimality can be defined as the requirement to minimize the root mean square partition error:

$$e^2(X,L) = \sum_{j=1}\sum_{i=1} ||x^{(j)}_i - c_j||^2,$$

where c_j is the "center of mass" of the cluster j.

"Center of mass" of the cluster is a point in the space of characteristic vectors with the average for this cluster values of characteristics.

2.5. Algorithm for clustering banks based on financial indicators

Let us describe the k-Mean algorithm [22]. This algorithm consists of the following steps:

1. Randomly select k points that are the initial "centers of mass" of clusters (any k of n objects, or random points in general).
2. Assign each object to the cluster with the nearest "center of mass".

3. List the "centers of mass" of clusters according to the current membership.
4. If the algorithm stop criterion is not satisfied, return to step 2.

As a criterion for stopping usually choose one of two:

1. No transition of objects from cluster to cluster in step 2.
2. Minimum change of the root mean square error.

The algorithm is sensitive to the initial selection of "centers of mass".

Let us analyze some indicators of Ukrainian banks for the first half of 2021 (according to the NBU) using cluster analysis (Tables 1, 2 and 3). Our goal is to cluster banks using their financial data. The data can be obtained from reports (or site) of the National bank of Ukraine.

Table 1

The result of the analysis of the capital adequacy ratio

№	Claster							
	1	2	3	4	5	6	7	8
Centers	297	414	21	653	158	105	61	459
Number of banks	2	1	49	1	2	4	11	1

An important part of cluster analysis is to identify outliers, objects that do not naturally fall into any larger cluster.

It is important to identify the number of banks with a low value of H2. To do this, we further divide the banks from cluster №3 into subclusters (Table 2).

Table 2

The result of the analysis of the capital adequacy ratio

№	Separately Cluster №3 from Table 1							
	1	2	3	4	5	6	7	8
Centers	29	18.9	11.7	14	23	33	38	41
Number of banks	6	10	3	14	11	1	3	1

Table 3

The result of the analysis of the bank liquidity ratio

№	Claster									
	1	2	3	4	5	6	7	8	9	10
Centers	185	239	69	84	101	145	523	600	118	216
Number of banks	1	1	16	19	17	4	1	2	7	3

The analysis allows us to effectively identify problem banks in the early stages.

The division of banks into groups based on cluster analysis not by type of ownership or size of capital, but by clustering according to economic standards is more appropriate to determine the risks of banking. Economic standards are indicators of the risk of the bank.

Problematic should be those banks that for two or more indicators of economic standards fell into the clusters responsible for riskier activities. This approach defines a new method of regulating banks based on the division of banks into clusters according to the values of economic standards. Based on the above analysis, it can be concluded that in the near future, at least two or three Ukrainian banks will leave the market.

3. Results and Interpretations

A very large number of bank failures in last years triggered a financial crisis. Although unprecedented intervention of central banks and governments helped economies to recover, the global financial systems remains at risk. As we have previously mentioned, cluster analysis, as part of maching learning, is an exploratory technique which organizes large amounts of observed data into a reduced-size meaningful structure. In order to discover the hidden information in our set of financial indicators, we have applied the clustering technique for each of the economy normatives.

4. References

[1] M. P. Deisenroth, A. A. Faisal, C. S. Ong, Mathematics for Machine Learning, Cambridge University Pres, UK, 2021.

[2] Luis G. Serrano, Grokking Machine Learning, Manning Pub., 2021, 512 p.

[3] Artificial Intelligence in Data Mining. Theories and Applications / [edited by] D. Binu, B. R. Rajakumar. Academic Press is an imprint of Elsevier, 2021, 271 p.

[4] Peter Flach, Machine Learning. The Art and Science of Algorithms that Make Sense of Data, Cambridge University Press, 2012, 400 p.

[5] Brett King, BANK 4.0. Banking Everywhere, Never at a Bank, John Wiley & Sons Ltd, 2019, 347 p.

[6] M. Shchoholiev, O. Andriichuk, V. Tsyganok, V. Tretynyk, Decision-making and Computational Linguistic Tools Application for Overall Estimation of the Level of Social Tension, Journal of Physics : conference series , volume 1780, 2021, doi:10.1088/1742-6596/1780/1/012017.

[7] Hnatiienko, H., Domrachev, V., Saiko, V. Monitoring the condition of agricultural crops based on the use of clustering methods // 15th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment, Monitoring 2021, Nov 2021, Volume 2021, Pp.1-5, DOI: https://doi.org/10.3997/2214-4609.20215K2049.

[8] Hnatiienko H. Choice Manipulation in Multicriteria Optimization Problems / Selected Papers of the XIX International Scientific and Practical Conference "Information Technologies and Security" (ITS 2019), pp. 234–245.

[9] Cooke, R. M., Experts in Uncertainty: Opinion and Subjective Probability in Science (Oxford University Press, 1991).

[10] Galanis, P. (2018) 'The Delphi method', Archives of Hellenic Medicine. doi: 10.4324/9781315728513-10.

[11] Bozóki Sándor & Tsyganok Vitaliy The (logarithmic) least squares optimality of the arithmetic (geometric) mean of weight vectors calculated from all spanning trees for incomplete additive (multiplicative) pairwise comparison matrices International Journal of General Systems. 2019. vol.48, No.4. P.362-381.

[12] Czamanski S. and Ablas L. A. Identification of industrial clusters and complexes: a comparison of methods and findings // Urban Studies. –1979. – V. I6 . – P. 61-80.

[13] Seetha Hari, Murty Narasimha, B.K. Tripathy. Modern Technologies for Big Data Classification and Clustering. – IGI Global, 2015 – 360 p.

[14] Hnatiienko H.M., Suprun O.O. Fuzzy Set Objects Clustering Method Using Evolution Technologies // Selected Papers of the XVIII International Scientific and Practical Conference "Information Technologies and Security" (ITS 2018). Kyiv, Ukraine, November 27, 2018. Pp.330-337.

[15] Abbas, O. A., Comparisons Between Data Clustering Algorithms, The International Arab Journal of Information Technology, Vol. 5, No. 3, 2008, pp. 320-325.

[16] Bacao, F., Lobo, V., Painho, M., 2005. Self-Organizing Maps as Substitutes for KMeans Clustering, Proceedings of the ICCS, 476-483.

[17] Methodical instructions on inspection of banks "Risk assessment system". Resolution of the Board of the National Bank of Ukraine dated 15.03.2004, № 104, URL: http://zakon3.rada.gov.ua/laws/show/v0104500-04 (in Ukrainian).

[18] Instruction on the procedure for regulating the activities of banks in Ukraine. Resolution of the National Bank of Ukraine dated 28.08.2001, № 368, URL: https://zakon.rada.gov.ua/laws/show/z0841-01#Text. (in Ukrainian).

[19] Neumann G. Evolutionary business information systems / Gustaf Neumann, Stefan Sobernig, Michael Aram // Business and Information Systems Engineering. – 2014, February. – 6(1). – P.33-36/ – doi: 10.1007/s12599-013-0305-1.

[20] Wu, J., Chen, Y., Dai, D., Chen, S., Wang, X. (2017). Clustering-based geometrical structure retrieval of man-made target in SAR images. IEEE Geoscience and Remote Sensing Letters, 14, pp.279–283.

[21] Lakhno V. A., Kravchuk P. U, Malyukov V. P., Domrachev V., Myrutenko L.V., Piven O.S. Developing of the cyber security system based on clustering and formation of control deviation signs. Journal of Theoretical and Applied Information Technology 15th November 2017. Vol.95. No 21 p. 5778 – 5786.

[22] Sławomir T. Wierzchoń, Mieczysław A. Kłopotek. Algorithms of cluster analysis. Institute of Computer Science, Polish Academy of Sciences, 2015. Warsaw, 2015. 310 p.
[23] Data clustering: algorithms and applications / [edited by] Charu C. Aggarwal, Chandan K. Reddy. Chapman & Hall/CRC data mining and knowledge discovery series. 2014. 614 p.
[24] Constrained clustering: advances in algorithms, theory, and applications / editors, Sugato Basu, Ian Davidson, Kiri Wagstaff. Chapman & Hall/CRC data mining and knowledge discovery series, 2008, 470 p.
[25] Guojun Gan. Data Clustering in C++. An Object-Oriented Approach. 2011 by Taylor and Francis Group, LLC Chapman & Hall/CRC is an imprint of Taylor & Francis Group, an Informa business. 497 p.
[26] Nicolae Dardac, Iustina Alina Boitana, Cluster Analysis Approach for Banks' Risk Profile: The Romanian Evidence, European Research Studies, Volume XII, Issue (1) 2009, 109-118 p.
[27] Michael Negnevitsky, Identification of failing banks using Clustering with self-organising neural networks, International Conference on Computational Science, Procedia Computer Science 108C, Published by Elsevier B.V. 2017, 1327–1333 p.
[28] Caruso, G., Gattone, S. A., Fortuna, F., & Di Battista, T. (2021). Cluster Analysis for mixed data: An application to credit risk evaluation. Socio-Economic Planning Sciences, 73, 100850.
[29] Herrera-Restrepo, O., Triantis, K., Seaver, W. L., Paradi, J. C., & Zhu, H. (2016). Bank branch operational performance: A robust multivariate and clustering approach. Expert Systems with Applications, 50, 107-119.
[30] Negnevitsky, M. (2017). Identification of failing banks using Clustering with self-organising neural networks. Procedia Computer Science, 108, 1327-1333.
[31] Lagasio, V., & Quaranta, A. G. (2021). Cluster analysis of bank business models: the connection with performance, efficiency and risk. Finance Research Letters, 102640.
[32] Moldovan D., Mutu S. (2015). A cluster analysis on the default determinants in the European banking sector. BIS 2015 workshops LNBIP 228, pp. 64-74.
[33] Agarwal R. The information systems identity crisis: focusing on high-visibility and high-impact research / R.Agarwal, H.Lucas // MIS Quarterly. – 2005. – 29 (3). – P.381-398. – doi: 10.2307/25148689. – JSTOR 25148689.
[34] Ferstl, R., D. Seres (2014). Clustering Austrian banks' business models and peer groups in the European Banking Sector, Financial Stability Report, 24, pp. 79-95.
[35] Halaj G., Ochowski D. (2009). Strategic Groups and Banks' Performance, Financial Theory and Practice, 33 (2), pp. 153 – 186.
[36] Ferstl R., Seres D. (2012). Clustering Austrian Banks' Business Models and Peer Groups in the European Banking Sector. Financial Stability Report, No. 24, pp. 79-95.
[37] Kraevsky, V., Kostenko, O., Kalivoshko, O., Kiktev, N., Lyutyy, I. Financial Infrastructure of Telecommunication Space: Accounting Information Attributive of Syntalytical Submission / IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T). DOI: 10.1109/PICST47496.2019.9061494.
[38] Riabtsev, V., Kravchenko, Y., Salkutsan, S., Tyshchenko, M., Sharadkin, D., Bondarenko, V. Information model of decision support in the design of information and communication systems based on the customer's profile / ATIT 2020 - Proceedings: 2020 2nd IEEE International Conference on Advanced Trends in Information Theory, 2020, pp. 234–237, DOI: 10.1109/ATIT50783.2020.9349258.
[39] Kunal Sengupta. Fuzzy preference and Orlovsky choice procedure // Fuzzy Sets and systems. – 1998. – No. 93. – P.231-234.
[40] Oletsky, O.V., Ivohin, E.V. Formalizing the Procedure for the Formation of a Dynamic Equilibrium of Alternatives in a Multi-Agent Environment in Decision-Making by Majority of Votes / Cybernetics and Systems Analysis, 2021, 57(1), pp. 47–56. DOI: 10.1007/s10559-021-00328-y.
[41] Newell A., Simon H. A. Human Problem Solving. – Englewood Cliffs, NJ: Prentice-Hall, 1972. – 920 p.