REPUBLIC OF AZERBAIJAN

On the rights of the manuscript

ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF NEURO-FUZZY MODELS AND INSTRUMENTAL TOOLS FOR RISK ASSESSMENT AND MANAGEMENT IN COMMERCIAL BANKS

Speciality:	3338.01 – “System analysis, control and information processing”
Field of science:	Technical sciences
Applicant:	**Jamirza Hormat Aghajanov**

Baku - 2025

The work was performed at the department of "Information technologies and programming" of Baku State University,

Scientific supervisor: Doctor of Technical Sciences, professor
Ramin Rza Rzayev

Official opponents: Doctor of Technical Sciences, Professor
Latafat Abbas Gardashova

Doctor of Technical Sciences, Associate Professor
Gambar Aghaverdi Guluyev

Doctor of Philosophy in Technical Science,
Ramin Bakhtiyar Samadov

Disseration council ED 1.20 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Institute of Control Systems of the Ministry of Science and Education of the Republic of Azerbaijan

Chairman of the Dissertation Council: Academician of ANAS, Doctor of Technical Sciences, Professor
Ali Mahammad Abbasov

Scientific Secretary of the Dissertation Council: Doctor of Philosophy on Engineering, Associate Professor
Tahir Ali Alizada

Chairman of the Scientific seminar: Doctor of Technical Sciences, Associate Professor
Fahrad Haydar Pashayev

GENERAL CHARACTERISTICS OF THE JOB

The relevance of the topic and the degree of its development. Risk management is one of the most relevant scientific and practical problems of modern banking. As technology advances and the world economy becomes globalized, the risks surrounding human activity only increase. The consequences of economic, political and natural crises are becoming more and more serious for individuals, legal entities, and the entire world economy.

The rapid growth of the volume of financial services, as well as the global financial crisis that occurred in 2008, have made important changes in the understanding of the need to consider the impact of risks during the development and implementation of any bank's development strategy, and therefore, both local and foreign commercial banks have to develop risk management. they should reconsider their approach to the process.

Unlike developed foreign countries, where the risk management system has been actively used for a long time, the risk management system in modern Azerbaijan banking practice is at the initial stage of development. Currently, the largest commercial banks of Azerbaijan are making efforts to approach Western standards of risk management, but medium and small commercial banks do not have the opportunity to implement expensive risk management systems. In this regard, there is a need to develop a risk management system for medium and small commercial banks that is most suitable for their needs and capabilities.

The risk management system should contribute to the further improvement of the risk management process in order to increase the efficiency of the activity of medium-sized commercial banks, ensure the continuity of the risk management process, respond promptly to risky situations, reduce the level of risks, and prevent risks and crisis situations. All this determines the relevance of the research topic.

Among the studies of foreign scientists in terms of the degree of scientific and practical development of the problem, E. Altman, F. Black, S. Brayovic-Bratanovic, X. Grüning, G. Kramer, F. Lundberg, G. Markowitz, R. Merton, M. Miller, P. Rose, P. Samuelson, D. Sinkey, W. Sharpe, M. Scholes, NA Amosova, AB Belyakov, SN

Kabushkin, GG Korobova, OI Lavrushin, MA Rogov, YA Sokolov, AM. The works of Tavasieva, NV Khokhlova, AS Shapkina have significant value. Here, the theoretical foundations of risk assessment and management and the establishment of a risk-management system are considered. MA Bukhtina and I. in the field of practical development of risk management problems. Farrakhovan's works can be mentioned.

The main purpose and objectives of the research. The main goal of the study is to develop theoretical and practical recommendations for increasing the quality and efficiency of risk management in medium-sized commercial banks.

In order to achieve the set goal, the following main issues have been defined within the framework of the dissertation:

- analysis of the risk management system and its components in a commercial bank;
- Clarification of the concept, parameters, and specializations of a medium-sized commercial bank;
- formulation of methodological recommendations for evaluating the risk-management system of a medium-sized commercial bank;
- development of a risk management mechanism for a medium-sized commercial bank, including multi-criteria evaluation methods and an expert system for evaluating decision efficiency in a fuzzy paradigm.

Object and subject of research. The object of the research is the market risks affecting the activity of the average commercial bank. The subject of the study is the methodology of building a complex system of risk management in an average commercial bank.

Research methodology used. The theoretical and methodological basis of the dissertation research was formed by the works of foreign scientists dedicated to the analysis of the theoretical issues of risk management and their practical application features; published works of risk management practitioners; legislative and normative legal acts of the Republic of Azerbaijan and the Central Bank; state and international risk management standards; materials of scientific-practical conferences and studies on risk management issues.

Comparative analysis, generalization, systematic and logical analysis methods, classical methods of decision-making under conditions of uncertainty, expert evaluation methods and fuzzy methods of multi-criteria analysis were used in the dissertation work.

The empirical basis of the research was made up of the materials of the Basel Committee on Banking Supervision, normative documents and analytical reviews of the Central Bank of the Republic of Azerbaijan, statistical research data of leading rating agencies and internal development of the commercial bank.

Main clauses defended. The scientific novelty of the study is the development of a complex risk management mechanism in an average commercial bank. The main scientific results of the dissertation submitted for defense and containing elements of scientific innovation are as follows:

1. The concept of "Risk management" system for commercial banks was developed based on fuzzy cognitive model.
2. A balanced approach based on the combined use of traditional and fuzzy methods for bank decision-making in the field of risk assessment is proposed.
3. An expert system that takes into account the influence of relevant subcomponents has been developed for market risk assessment.
4. An algorithm was designed based on the application of the fuzzy Minimax convolution method for market risk assessment (with equal and different degrees of importance of influencing subcomponents).
5. An algorithm based on the application of the Fuzzy Extraction System was designed for the numerical assessment of market risks.
6. An algorithm was designed based on the application of the neuro-fuzzy hybrid modeling system, which ensures the compilation of expert knowledge for the numerical assessment of market risks.

Scientific novelty of the research. The theoretical importance of the research consists in the generalization of modern risk management methods and procedures used in foreign practice. The main scientific innovations include the following:

1. Adaptation of fuzzy multi-criteria evaluation methods for market risk assessment.
2. Development of the methodology for establishing an appropriate expert system for the assessment of market risks.
3. Compilation of expert knowledge obtained in the assessment of market risks with the help of neuro-fuzzy methods.
4. Development of fuzzy cognitive model providing analytical support for risk management system in commercial banks.

Practical significance of research. The practical significance of the study is the development of a practical model designed for the development of risk management policies and their effectiveness assessment for bank managers and risk managers. The proposed step-by-step scheme will enable a comprehensive assessment of banking risks and timely adoption of management decisions aimed at minimizing risks and achieving optimal profitability while complying with regulatory requirements.

The methodology explained in the thesis work can be used in the education of students in economic specialties and in the further improvement of the professionalism of bank specialists.

Approbation and implementation of work. The main provisions and results of the dissertation work were presented and discussed in institute-wide seminars with the participation of relevant specialists and scientists. The materials and main results of the dissertation were presented in reports at international and republican scientific-practical conferences at various levels, including:

- 8th International Conference on Control and Optimization with Industrial Applications (COIA – 2022) 24-26 August 2022, Baku, Azerbaijan;
- 5th International Conference on Problems of Cybernetics and Informatics (PCI 2023) August 28-30, 2023, Baku, Azerbaijan;
- International Conference on Intelligent and Fuzzy Systems (INFUS – 2024), July 16-18, 2024, Çanakkale Onsekiz Mart University, Çanakkale, Turkish;

The organization where the dissertation work was performed. The dissertation work was performed at the "Information Technologies and Programming" department of the "Applied mathematics and cybernetics" faculty of Baku State University.

Publication of the results of dissertation work. A total of 9 scientific works were published based on the materials of the dissertation work (6 articles, 3 conference materials): 3 scientific works in Web of Science and Scopus, 1 scientific work of Ukrainian EAC, 1 scientific work of Russian EAC and 4 scientific works of Azerbaijan EAC was published in the journals included in the list of

The structure and scope of the dissertation work. Dissertation consists of introduction, 4 chapters, conclusion and list of used literature. The total volume of the work consists of 129 pages of typewritten text, 13 pictures, and 23 tables. The bibliography includes 75 titles.

THE CONTENT OF THE WORK

At the entrance the relevance of the work is noted, a list of tasks and approaches necessary to achieve the goal of the dissertation research is provided, the structure and content of the work, as well as the expected results submitted to the defense are explained.

In the first chapter present problems of risk management in a commercial bank, which is the most important element of the general banking management system. Banking risk means the possibility of losses specific to banking, as well as the occurrence of unpleasant events related to internal factors (for example, the complexity of the organizational structure, the level of qualifications of employees, organizational changes, personnel changes, etc.), causing losses and/or deterioration of the liquidity of the credit organization. A number of possible actions should be understood.

The bank's risk management system (risk-management system) is a set of methods used by bank employees in conditions of uncertainty in the bank's activities, to predict risky events and to take appropriate measures to eliminate or reduce negative consequences. Schematically, the structure of the bank's risk management system is shown in Fig. 1 was presented.

Assessed bank risks and capital adequacy of banksforeign methodologies in the field of science are represented by the following:

- rating evaluations – examples of this system are the Italian PATROL system, the French ORAP system, the US CAMEL system;
- analysis of coefficients - an example of such a system is the German BAKIS information system;
- A comprehensive banking risk assessment system, called RATE, operating in Great Britain;
- statistical models: the French SAABA model of early prevention of risks and the US FIMS system;
- separate rating systems of famous international rating agencies: Moody's Ratings, Fitch Ratings, S&P Global Ratings

Fig. 1. The structure of the bank's risk management system

Mathematical matrices are usually used to assess bank risk. Consider an existing model for using matrices in risk assessment. In particular, a similar model is proposed in the Australian and New Zealand risk management standard based on qualitative and quantitative risk assessment. However, it is more correct to talk about mapping, because in this case risks can be assessed when the risk map is analyzed and not the matrix drawn up. The compiled risk map (matrix) is the main information base for making decisions on the further processing of risks. The current map appears as shown in Table 1. Experience shows that such cartography allows for easy and quick assessment of bank risks, on the basis of which management decisions are made.

Table 1. Risk matrix in accordance with the international standard

A	Y	Y	E	E	E
B	He	Y	Y	E	E
C	K	He	Y	E	E
D	K	K	He	Y	E
E	K	K	He	Y	Y
	1	2	3	4	5

In this map, the abscissa axis shows the probability of risk occurrence, and the ordinate axis shows the consequences. Here, the qualitative and quantitative scale of risk probability is as follows:

- A – almost certain, i.e. expected under any circumstances;
- B – highly likely, that is, it is almost always possible;
- C – maybe, that is, it happens from time to time;
- D – unlikely, that is, it can happen sometimes;
- E – can happen in rare cases, that is, in exceptional cases.

The map shown in Table 1 uses the following 4 degrees of danger risk: Ex – extreme risk, that is, a risk that requires immediate action; Y – high risk, that is, a risk that requires the attention of top managers; O – medium (moderate) risk, i.e. the risk that requires formalization of the responsibility of managers; K – small risk, i.e. the risk when the daily procedure is managed.

The risk-management system must fully comply with the bank's policy in the field of bank risk management, this policy must clearly define the procedures for identifying, measuring (estimating), monitoring and controlling various types of risks, as well as their management strategy. As a rule, the bank's risk management system includes the following stages:

- identification of risk and factors affecting it;
- risk assessment (risk measurement);
- determining the acceptable level of risk;
- monitoring the level of risk and developing measures to reduce it.

Based on this paradigm, it is necessary to use and collect expert opinions, as a result, fuzzy analysis and decision-making methods related to banking operations at each localization point to form heuristic knowledge from the date of conclusion of various contracts in the bank. That is why it is considered necessary to develop a fuzzy cognitive map for the assessment of internal and external banking risks.

In the second chaptera combined approach to solving the problem of multi-criteria assessment of market risk is discussed in the presence of alternative expert assessments of the probability of occurrence of certain events that have a critical impact on the level of market risk.The methodology of decision-making under conditions of risk and uncertainty uses a "decision matrix" in the process of justifying risky decisions. Its example is presented in Table 2.

Table 2.A matrix that supports decision-making under risk conditions

Alternative decision	Probabilities of impacts on market risk				Alternative decision	Probabilities of impacts on market risk			
	x_1	x_2	x_3	x_4		x_1	x_2	x_3	x_4
A_1	0.42	0.34	0.25	0.31	A_9	0.56	0.48	0.42	0.28
A_2	0.59	0.41	0.33	0.22	A_{10}	0.33	0.51	0.27	0.43
A_3	0.39	0.51	0.47	0.39	A_{11}	0.42	0.46	0.48	0.33
A_4	0.42	0.45	0.47	0.40	A_{12}	0.51	0.37	0.39	0.20
A_5	0.51	0.37	0.35	0.36	A_{13}	0.43	0.46	0.42	0.41
A_6	0.34	0.49	0.28	0.36	A_{14}	0.48	0.42	0.34	0.38
A_7	0.31	0.44	0.46	0.48	A_{15}	0.36	0.50	0.24	0.27
A_8	0.42	0.50	0.36	0.33					

A1, A2, ..., A15 in the decision matrix – characterize each of the decision-making alternatives; aij (i = 1÷4; j = 1÷15) is a specific level of effectiveness of the decision corresponding to a certain alternative in a certain situation.

The essence of classical methods of decision-making under conditions of uncertainty was analyzed on the example of market risk (BR) assessment, which is regularly carried out in commercial banks. According recommendations of the Basel Committee, BR has the following subcategories: x1) interest rate risk – is the risk of losses (damages) as a result of negative changes in interest rates; x2) currency risk – is the risk of losses (damages) as a result of unfavorable changes in foreign exchange rates; x3) capital risk – is the risk caused by negative changes in the price of capital and securities; x4) Commodity risk is a risk caused by negative changes in the value of goods in the market.

In the example of BR assessment, the following classic approaches to decision making under uncertainty are interpreted: MaxMin, MaxMax, Losses, Hurvitz and Laplace criteria, Pareto's rule and Bord's method. Table 3 presents the corresponding results of selecting different alternative decisions on BR evaluation with the help of the listed methods.

Table 3. Ranking alternative decisions using classical methods

No	MaxMin		MaxMax		Criterion of happiness		Hurwich criterion (α = 0.65)		Pareto rule	Bord method	
	Show.	Color	Show.	Color	Show.	Color	Show.	Color		Show.	Color
A_1	0.25	12	0.42	15	0.42	1	0.3605	15	15	17	15
A_2	0.22	14	0.59	1	0.59	15	0.4605	3	12	26	12
A_3	0.39	3	0.51	3	0.51	10	0.4680	1	1	45	1
A_4	0.40	2	0.47	13	0.47	3	0.4455	5	2	40	3
A_5	0.35	4	0.51	4	0.51	11	0.4540	4	10	32	10
A_6	0.28	9	0.49	9	0.49	7	0.4165	12	5	39	4
A_7	0.31	8	0.48	10	0.48	4	0.4205	11	7	34	7
A_8	0.33	6	0.50	7	0.50	8	0.4405	7	8	33	8
A_9	0.28	10	0.56	2	0.56	14	0.4620	2	4	39	5
A_{10}	0.27	11	0.51	5	0.51	12	0.4260	10	9	33	9
A_{11}	0.33	7	0.48	11	0.48	5	0.4275	9	6	37	6
A_{12}	0.20	15	0.51	6	0.51	13	0.4015	14	13	24	13

A_{13}	0.41	1	0.46	14	0.46	2	0.4425	6	3	41	2
A_{14}	0.34	5	0.48	12	0.48	6	0.4310	8	11	32	11
A_{15}	0.24	13	0.50	8	0.50	9	0.4090	13	14	21	14

The third chapterA new methodology based on fuzzy cognitive model of market risk assessment is explained. In banks, the concept and mechanisms of bank risk management are formed, which meet the requirements of risk management, express the need to take into account the important features of individual risks, and enable the formation of methods of influencing them. For this, the logical detail of bank risks based on fuzzy cognitive map (FCM) is shown in Fig. 2 is shown.

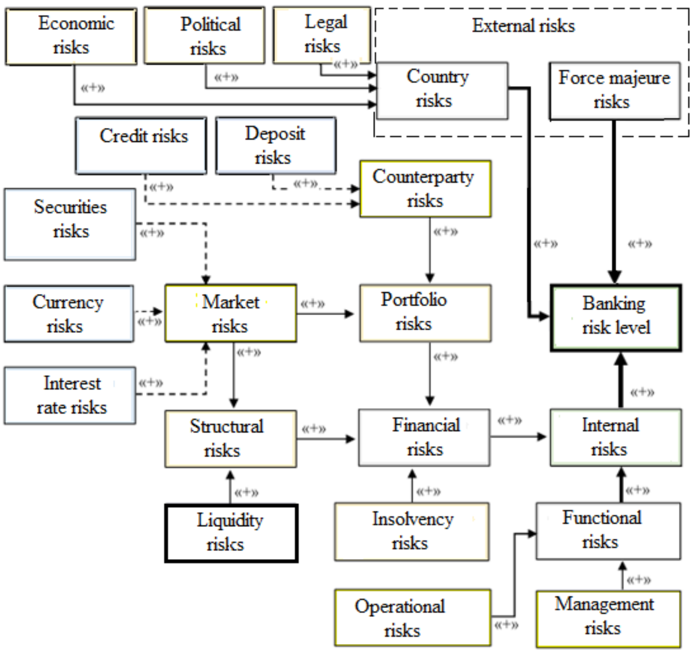

Fig. 2.A fuzzy cognitive map for bank risk assessment

In practice, the "interaction" of even two elements of the FCM occurs according to more complex functional laws, which are very difficult to formalize in traditional mathematical form. Therefore, it is necessary to apply the fuzzy inference mechanism and perform analysis based on the fuzzy cognitive model (FCMd - Fuzzy Cognitive

Model) to describe the cause-and-effect relationship between the conditions of commercial bank risk. At this time, the nodal factors (concepts) of the FCM are interpreted as fuzzy sets, and causal relationships between them are established based on a limited set of fuzzy linguistic rules, which are formed as follows:

"If xk1 is Ak1 and xk2 is Ak2 and …. and xkn is Akn, then y is Bk". (1)

Here xkj (j = 1÷n; k = 1, 2, …) are the input linguistic variables characterizing the influencing factors; y – is an output linguistic variable that characterizes the consolidated risk level; Akj and Bk are terms (values) of the corresponding input and output linguistic variables that can be described by corresponding fuzzy sets. A scale of probability of occurrence of the risk characterized by the following conditions is proposed:

A- an almost absolute, that is, a risky situation expected under any circumstances;

B- with high probability, that is, a risky situation is almost always possible;

C- maybe, that is, a risky situation arises from time to time;

D– with low probability, that is, a risky situation may occur sometimes;

E- sometimes, that is, in exceptional cases, a risky situation may arise.

The given conditions are the qualifying criteria for the assessment of risk situations that can be described by corresponding fuzzy sets. For this purpose, after choosing a discrete set U = {0, 0.25, 0.5, 0.75, 1} as the universe, the corresponding fuzzy sets can be described as follows:

A= {0/0, 0/0.25, 0/0.5, 0.5/0.75, 1/1};

B= {0/0, 0/0.25, 0.5/0.5, 1/0.75, 0.5/1};

C= {0/0, 0.5/0.25, 1/0.5, 0.5/0.75, 0/1};

D= {0.5/0, 1/0.25, 0.5/0.5, 0/0.75, 0/1};

E= {1/0, 0.5/0.25, 0/0.5, 0/0.75, 0/1}.

To assess the level of risk in the areas of localization of banking operations, a scale of terms described by fuzzy subsets of the discrete universe J = {0, 0.1, 0.2, …, 1} is used. Here, μ(j) (j∈J) is as follows:*TL*=QUİTE LOW: $\mu_{TL}(j)=\begin{cases}1, & j<1\\ 0, & j=1\end{cases}$; VL=VERY LOW: $\mu_{VL}(j)=(1-j)^2$; ML=MORE LOW: $\mu_{ML}(j)=\sqrt{1-j}$; L = LOW: $\mu_{L}(j)=1-j$;H=UP: $\mu_{H}(j)=j$; MH=MORE UP: $\mu_{MH}(j)=\sqrt{j}$; VH=VERY HİGH: $\mu_{VH}(j)=j^2$, TH=VERY HİGH: $\mu_{TH}(j)=\begin{cases}1, & j=1,\\ 0, & j<1\end{cases}$. Thus, Fig. The causal relations shown in Fig. 2 can be described using a sufficient set of typical logical non-contradictory rules of the form (1). As a result, exemplary fuzzy inference systems (FIS – Fuzzy Inference System) were applied for each local concept of FCM. FCM's "Country risk" concept was chosen as the main localization point to describe the bank risk assessment algorithm using FIS.

The well-known auditing firm Pricewaterhouse Coopers uses the following variables to evaluate countries: x1 – presence of corruption; x2 – compliance with legislation; x3 – level of economic growth; x4 – state policy on accounting and control; x5 – state regulation. In terms of the "country risk" concept, the gradation of investment attractiveness of countries was carried out on the basis of relevant implicative rules:

d_1: If x1 is absent and x3 is observed, then y is acceptable;

d_2: If x1 is absent and x3 is observed and x4 is carried out, then y is more than acceptable;

d_3: If x1 is absent and x2 is exist and x3 is observed and x4 is carried out and x5 is implemented, then y is low:

d_4: If x1 is absent and x2 is present and x3 is observed and x4 is carried out, then y is very acceptable;

d_5: If x1 appears and x2 exists and x3 is observed and x4 is carried out, then y is acceptable;

d_6: If x1 appears and x3 is not visible and x5 is not implemented, then y is unacceptable.

As a result, it was possible to establish a basic gradation scale on a scale of [0, 100] to assess ER levels.The expert community was invited to test 10 alternative countries ak (k = 1÷10) on a five-point system: to assess the degree of influence of financial-economic, socio-political and state-legal factors on their levels of EC in these countries. Expertise was conducted on the factor listed above and as a result consolidated (averaged) expert assessments were obtained and summarized in Table 5.

Table 4. Grading of ER-levels using FIS

Interval	CR-level	Interval	CR-level
(84.90, 100]	PRETTY LOW	(34.94, 41.66]	UP
[60.34, 84.90]	VERY LOW	(30.09, 34.94]	FURTHER UP
(49.29, 60.34]	FURTHER DOWN	[27.11, 30.09]	VERY HİGH
(41.66, 49.29]	DOWN	[0, 27.11]	QUİTE HİGH

Table 5. Average expert estimates of impact rates

Country	Influence factors				
	x_1	x_2	x_3	x_4	x_5
a_1	4.5	4.75	4.5	4.75	4.25
a_2	4.85	4.50	4.55	2.75	3.75
a_3	3.75	4.00	3.25	3.85	3.25
a_4	4.25	3.45	2.85	2.75	1.85
a_5	4.00	2.55	3.00	2.25	1.85
a_6	3.55	2.85	2.00	1.25	0.85
a_7	2.25	1.75	1.25	1.85	1.50
a_8	2.25	1.85	1.25	0.75	0.25
a_9	5.00	4.75	4.85	4.85	4.75
a_{10}	3.25	2.85	3.75	4.25	3.50

One of the possible properties of the factors xi (i = 1÷5) reflecting the risk situation, choosing the term "not available" as the basis, the input properties in the universe U={a1, a2, a3, ..., a10} are expressed by the following fuzzy sets:

- A_1={0.9394/a1, 0.9944/a2, 0.6766/a3, 0.8688/a4, 0.7788/a5, 0.5912/a6, 0.1510/a7, 0.1510/a8, 1/a9, 0.4650/a10};
- A_2={0.9845/a1, 0.9394/a2, 0.7788/a3, 0.5485/a4, 0.2230/a5, 0.3149/a6, 0.0713/a7, 0.0837/a8, 0.9845/a9, 0.3149/a10};
- A_3={0.9394/a1, 0.9506/a2, 0.4650/a3, 0.3149/a4, 0.3679/a5, 0.1054/a6, 0.0297/a7, 0.0297/a8, 0.9944/a9, 0.6766/a10};

- A_4={0.9845/a1, 0.2821/a2, 0.7185/a3, 0.2821/a4, 0.1510/a5, 0.0297/a6, 0.0837/a7, 0.0109/a8, 0.9944/a9, 0.8688/a10};
- A_5={0.8688/a1, 0.6766/a2, 0.4650/a3, 0.0837/a4, 0.0837/a5, 0.0135/a6, 0.0468/a7, 0.0036/a8, 0.9845/a9, 0.5698/a10}.

Taking into account these formalisms and the above formal descriptions of the terms on the right-hand side of the rules d1 ÷ d6, the FIS was constructed as follows:

d_1: (x1 = A1) & (x3 = A3)⇒ (y= Q);
d_2: (x1 = A1) & (x3 = A3) & (x4 = A4)⇒(y= MS);
d_3: (x1 = A1) & (x2 = A2) & (x3 = A3) & (x4 = A4) & (x5 = A5)⇒ (y= L);
d_4: (x1 = A1) & (x2 = A2) & (x3 = A3) & (x4 = A4)⇒ (y= VS);
d_5: (x1 =$\neg A_1$) &(x2 = A2) & (x3 = A3) & (x4 = A4)⇒ (y= Q);
d_6: (x1 =$\neg A_1$) & (x_3=$\neg A_3$) & (x_5=$\neg A_5$)⇒ (y=US).

Alternative as a result of the processing of these rules*ac*(k = 1÷10) integrated evaluations of ER-levels for countries are shown in Table 6. Fuzzy MixMin convolution and weighted in Table 6 for comparative analysisevaluationthe results obtained by the methods are also reflected.

Table 6. Comparison of the results obtained by three methods

Country	With weighting factors		MaxMin		FIS	
	Indicator	Color	Indicator	Color	Indicator	Color
a_1	91.27	2	0.8688	2	93.88	2
a_2	84.62	3	0.2821	5	76.87	3
a_3	73.30	4	0.4650	3	60.47	4
a_4	64.47	6	0.0837	6	53.70	5
a_5	57.64	7	0.0837	7	52.06	6
a_6	47.13	8	0.0135	9	45.52	8
a_7	35.54	9	0.0297	8	30.55	9
a_8	29.06	10	0.0036	10	30.01	10
a_9	97.04	1	0.9845	1	99.27	1
a_{10}	68.55	5	0.3149	4	51.40	7

At the next stage, in the example of solving the BR evaluation problem (see Table 2), a comparison of the fuzzy inference method and decision-making methods under conditions of uncertainty was made.of BR$x_i$after accepting subcategories as linguistic variables, their respective terms were considered as quality evaluation criteria. The term "high risk" was chosen as one of the criteria, and each of its*xi*in terms of the effect of the factorfor description$E$={A1, A2, …, A15}The following fuzzy subsets of the discrete universe are chosen:

- $X_1 = \frac{0.2604}{A_1} + \frac{0.5105}{A_2} + \frac{0.2257}{A_3} + ... + \frac{0.2726}{A_{13}} + \frac{0.3391}{A_{14}} + \frac{0.1943}{A_{15}}$;
- $X_2 = \frac{0.1751}{A_1} + \frac{0.2485}{A_2} + \frac{0.3827}{A_3} + ... + \frac{0.3115}{A_{13}} + \frac{0.2604}{A_{14}} + \frac{0.3679}{A_{15}}$;
- $X_3 = \frac{0.1054}{A_1} + \frac{0.1660}{A_2} + \frac{0.3251}{A_3} + ... + \frac{0.2604}{A_{13}} + \frac{0.1751}{A_{14}} + \frac{0.0992}{A_{15}}$;
- $X_4 = \frac{0.1489}{A_1} + \frac{0.0877}{A_2} + \frac{0.2257}{A_3} + ... + \frac{0.2485}{A_{13}} + \frac{0.2149}{A_{14}} + \frac{0.1186}{A_{15}}$.

The following rules were chosen to evaluate the BR-level:

d_1: If the interest rate risk and commodity risk are high, then the BR level is high;

d_2: If interest rate risk is high, equity risk is high and commodity risk is high, then BR level is higher;

d_3: If interest rate risk is high, currency risk is high, equity risk is high and commodity risk is high, then the BR level is too high;

d_4: If interest rate risk is high, currency risk is high and equity risk is high, then the BR level is too high;

d_5: If interest rate risk is high, currency risk is high, equity risk is low and commodity risk is high, then the BR level is high;

d_6: If interest rate risk is low and equity risk is low, then BR level is lower.

After processing these rules in the traditional way, the final functional solution was obtained in the form of the following R matrix. This matrix reflects the internal cause-and-effect relationships between xi (i=1÷4) factors affecting the BR level and the BR levels. The jth row of the matrix Aj (j=1÷15) represents the fuzzy result of the aggregated BR level for the alternative banking decision. A defuzzification procedure is applied to numerically interpret each of these fuzzy results.

$$
R = \left[\begin{array}{c|ccccccccccc}
 & 0 & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & 0.7 & 0.8 & 0.9 & 1 \\
\hline
A_1 & 0.8511 & 0.8946 & 0.8946 & 0.8946 & 0.8604 & 0.7604 & 0.6604 & 0.5604 & 0.4604 & 0.3604 & 0.2604 \\
A_2 & 0.8340 & 0.8440 & 0.8740 & 0.9123 & 0.9123 & 0.9123 & 0.9105 & 0.8105 & 0.7105 & 0.6105 & 0.5105 \\
A_3 & 0.7743 & 0.7743 & 0.7743 & 0.7743 & 0.7743 & 0.7743 & 0.7251 & 0.6251 & 0.5251 & 0.4251 & 0.3251 \\
A_4 & 0.7396 & 0.7496 & 0.7631 & 0.7631 & 0.7631 & 0.7631 & 0.7251 & 0.6251 & 0.5251 & 0.4251 & 0.3251 \\
A_5 & 0.8057 & 0.8155 & 0.8155 & 0.8155 & 0.8155 & 0.8155 & 0.7827 & 0.6827 & 0.5827 & 0.4827 & 0.3827 \\
A_6 & 0.8249 & 0.8743 & 0.8743 & 0.8743 & 0.7751 & 0.6751 & 0.5751 & 0.4751 & 0.3751 & 0.2751 & 0.1751 \\
A_7 & 0.8511 & 0.8511 & 0.8511 & 0.8511 & 0.8511 & 0.8115 & 0.7115 & 0.6115 & 0.5115 & 0.4115 & 0.3115 \\
A_8 & 0.8057 & 0.8157 & 0.8340 & 0.8340 & 0.8340 & 0.7604 & 0.6604 & 0.5604 & 0.4604 & 0.3604 & 0.2604 \\
A_9 & 0.7396 & 0.7496 & 0.7796 & 0.8296 & 0.8743 & 0.8743 & 0.8610 & 0.7610 & 0.6610 & 0.5610 & 0.4610 \\
A_{10} & 0.8340 & 0.8814 & 0.8814 & 0.8660 & 0.7660 & 0.6660 & 0.5660 & 0.4660 & 0.3660 & 0.2660 & 0.1660 \\
A_{11} & 0.7396 & 0.7496 & 0.7796 & 0.8296 & 0.8340 & 0.8340 & 0.7391 & 0.6391 & 0.5391 & 0.4391 & 0.3391 \\
A_{12} & 0.7956 & 0.8056 & 0.8356 & 0.8856 & 0.9227 & 0.8827 & 0.7827 & 0.6827 & 0.5827 & 0.4827 & 0.3827 \\
A_{13} & 0.7396 & 0.7496 & 0.7515 & 0.7515 & 0.7515 & 0.7515 & 0.6726 & 0.5726 & 0.4726 & 0.3726 & 0.2726 \\
A_{14} & 0.7851 & 0.8249 & 0.8249 & 0.8249 & 0.8249 & 0.8249 & 0.7391 & 0.6391 & 0.5391 & 0.4391 & 0.3391 \\
A_{15} & 0.8814 & 0.9008 & 0.9008 & 0.8943 & 0.7943 & 0.6943 & 0.5943 & 0.4943 & 0.3943 & 0.2943 & 0.1943
\end{array}\right]
$$

Numerical evaluations of alternative decisions according to the BR-level are found after the defuzzification process and are presented in Table 7, which shows the results of solving the problem with other traditional methods.

Table 7. Ranking alternative decisions in different ways

n alternativ	MaxMin		MaxMax		Criterion of regret		Hurwicz criterion ($\alpha = 0.35$)		Pareto	Bord method		FIS	
	Ind.	Rank	Ind.	Rank	Ind.	Rank	Ind.	Rank		Ind.	Rank	Ind.	Rank
A_1	0.25	12	0.42	15	0.42	1	0.3605	15	15	17	15	0.3717	12
A_2	0.22	14	0.59	1	0.59	15	0.4605	3	12	26	12	0.4548	2
A_3	0.39	3	0.51	3	0.51	10	0.4680	1	1	45	1	0.4195	7
A_4	0.40	2	0.47	13	0.47	3	0.4455	5	2	40	3	0.4245	6
A_5	0.35	4	0.51	4	0.51	11	0.4540	4	10	32	10	0.4292	3
A_6	0.28	9	0.49	9	0.49	7	0.4165	12	5	39	4	0.3430	13
A_7	0.31	8	0.48	10	0.48	4	0.4205	11	7	34	7	0.3979	10
A_8	0.33	6	0.50	7	0.50	8	0.4405	7	8	33	8	0.3864	11
A_9	0.28	10	0.56	2	0.56	14	0.4620	2	4	39	5	0.4618	1
A_{10}	0.27	11	0.51	5	0.51	12	0.4260	10	9	33	9	0.3369	15
A_{11}	0.33	7	0.48	11	0.48	5	0.4275	9	6	37	6	0.4258	4
A_{12}	0.20	15	0.51	6	0.51	13	0.4015	14	13	24	13	0.4257	5
A_{13}	0.41	1	0.46	14	0.46	2	0.4425	6	3	41	2	0.4081	9
A_{14}	0.34	5	0.48	12	0.48	6	0.4310	8	11	32	11	0.4158	8
A_{15}	0.24	13	0.50	8	0.50	9	0.4090	13	14	21	14	0.3428	14

In the fourth chapter In commercial banks, appropriate algorithms are developed based on the application of neural-fuzzy methods for the identification and assessment of market risks, that is, the effective management of market risks. Assessments obtained based on expert analysis of the data given in Table 8, bank operations exposed to market risks, assets and liabilities of "X" bank by currency types, as well as general data on its open currency positions are used as initial information.

Table 8. Details of market risk in hypothetical bank 'X' example

Factor	Share of the indicator in the total capital of the bank (%)	Pointer in BR-share (%) of
Market risk, total:	32.3	100
interest rate risk (x1)	19.6	60.68
currency risk (x2)	4.9	15.17
capital risk (x3)	3.6	11.15
commodity risk (x4)	4.2	13

"X" bank invited 15 experts to conduct a measured expertise related to the evaluation of BR. At the initial stage, each expert was asked to rank the xi variables according to the following principle: assigning the most important with the number "1", the next less important - with the number "2", and then in descending order of importance. As a result of independent questioning of experts, expert rankings of xi factors were established and summarized in Table 9.

Table 9. Ranks and weights of xi variables based on experts' opinions

Expert	Ranks and weights of BR variables							
	x_1		x_2		x_3		x_4	
01	1	0.350	2	0.250	3	0.245	4	0.155
02	1	0.400	3	0.200	2	0.300	4	0.100
03	1	0.360	2	0.240	3	0.225	4	0.175
04	1	0.450	3	0.200	2	0.250	4	0.100
05	1	0.500	3	0.150	4	0.100	2	0.250
06	1	0.400	4	0.150	3	0.200	2	0.250
07	1	0.500	3	0.100	2	0.350	4	0.050
08	1	0.350	3	0.250	2	0.300	4	0.100
09	1	0.450	2	0.300	3	0.200	4	0.050
10	2	0.300	1	0.350	4	0.100	3	0.250
11	1	0.350	3	0.200	2	0.300	4	0.150
12	2	0.300	1	0.400	4	0.050	3	0.250
13	1	0.400	2	0.300	4	0.100	3	0.200

14	1	0.450	3	0.150	2	0.300	4	0.100
15	1	0.350	2	0.250	3	0.225	4	0.175
Σ	17	5,910	37	3,490	43	3.245	53	2.355

Before identifying the weights of the BR factors, it is necessary to determine the existence of unanimity of expert opinions in the form of a rank that demonstrates an acceptable multiple rank correlation of expert opinions. For this, the Kendall correlation coefficient is usually used, which is calculated by the following formula:

$$W = 12 \cdot S / [m^2 (n^3 - n)] \;. \quad (2)$$

where m is the number of experts; n is the number of BR variables; S is the deviation from the average degree of the BR variable of expert opinions calculated by the following formula [4]:

$$S = \sum\nolimits_{i=1}^{n} [\sum\nolimits_{j=1}^{m} r_{ij} - m(n+1)/2]^2 \;. \quad (3)$$

Rij here $\in \{1, 2, 3, 4\}$ is the rank given by the jth expert to the ith factor (variable). In this case, i.e. taking into account the S=691 value calculated by formula (3) and the data in Table 9, according to formula (2) Kendall's correlation coefficient will be W = 0.6142 > 0.6, and this indicates sufficient unanimity of expert opinions.

*xi*the following iterative equation is used to calculate the weights of the variables:

$$\alpha_i (t+1) = \sum\nolimits_{j=1}^{15} w_j (t) \alpha_{ij} \;. \quad (4)$$

Here, wj(t) is an indicator that characterizes the level of competence of the jth expert (j = 1÷15) for the time point t. At each iteration step, these metrics are updated using the following formulas:

$$\begin{cases} w_j(1) = \dfrac{1}{\eta(1)} \sum\nolimits_{i=1}^{4} \alpha_i(1) \cdot \alpha_{ij} \, (j = \overline{1,\ 14}), \\ w_{15}(1) = 1 - \sum\nolimits_{j=1}^{14} w_j(1), \sum\nolimits_{j=1}^{15} w_j(1) = 1. \end{cases} \quad (5)$$

Here η(t) is the calculated normalizing factor that ensures the transition to the next iteration step $\eta(t) = \sum\nolimits_{i=1}^{4} \sum\nolimits_{j=1}^{15} \alpha_i(t) \alpha_{ij}$.

*xi*The process of finding the normalized values of the generalized weights of the variables (i=1÷4) is completed under the following condition

$$\max\{|\alpha_i(t+1)-\alpha_i(t)|\}\le\varepsilon . \quad (6)$$

hereε- is the possible accuracy of calculations. It is defined by the user.

In the 3rd approximation $\{\alpha_1(3),\alpha_2(3),\alpha_3(3),\alpha_4(3)\}$ numbers are identified weights of variables xi (i = 1÷4) that affect the overall level of BR. The method of expert evaluations involves the discussion of the influence of factors xi (i=1÷4) on the overall level of BR for bank "X". Each expert is invited to individually evaluate the impact on the BR level based on the following five-point rating system for xi factors:

5 – there is no risk;
4 - the possibility of a risk situation is unlikely;
3 - nothing can be said about the possibility of risk;
2 – is the probability of the possibility of a risk situation;
1 – a risk situation will definitely occur.

Theoretically, the weighted BR index ranging from 0 to 100 is determined using the following formula:

$$R=\frac{\sum_{i=1}^{4}\alpha_i e_i}{\max\limits_{e_i}\{\sum_{i=1}^{4}\alpha_i e_i\}}\times 100 . \quad (7)$$

Hereα_i– is the specific weight of variable xi (i=1÷4) as a component of BR; ei is a consolidated expert assessment of the probability of a risk situation occurring according to factor i of BR on a five-point system. Here, minimum index means maximum risk and conversely, maximum index means minimum risk. Expert opinions are summarized in Table 10, which shows the integral BR index obtained by formula (8).

Table 10. Expertise of BR according to the five-point rating system

Expert	Weights of BR variables				BR index
	α_1	α_2	α_3	α_4	
	0.39676	0.23023	0.21826	0.15475	
	Expert evaluations on a five-point system				
e_1	4	3	2	3	68.69

e_2	5	4	3	2	83.62
e_3	3	5	4	3	79.51
e_4	4	4	4	4	86.45
e_5	5	3	3	3	81.99
e_6	3	4	2	3	65.10
e_7	3	4	4	4	77.87
e_8	4	5	3	3	83.36
e_9	5	4	4	2	88.34
e_{10}	3	5	2	4	73.42
Average score	3.5	4.1	3.1	3.1	78.83

*xi*variables are represented as fuzzy subsets of a finite set of alternative expert decisions {e1, e2, …, e10} as quality evaluation criteria, i.e. Here (j=1÷10) Xi is the membership function of the fuzzy set: ej is the degree of relevance of the expert opinion on the possibility of the risk situation on the component xi. A Gaussian-type function was chosen as the appropriate membership function$X_i = \frac{\mu_{X_i}(e_1)}{e_1} + \frac{\mu_{X_i}(e_2)}{e_2} + \cdots + \frac{\mu_{X_i}(e_{10})}{e_{10}} \mu_{X_i}(e_j)$

$$\mu_{X_i}(e_j) = e^{-\frac{(e_{ji}-5)^2}{\sigma_i^2}}. \quad (8)$$

Here, eji is the jth expert's five-point assessment of the risk situation on the i-th component of BR as "not available";σ_i=2 was chosen the same for all cases of fuzzification.

Using the fuzzy MaxMin convolution method to determine the most rational solution according to the MR level involves constructing a set of optimal alternatives. This procedure is performed by finding the intersection Xi of fuzzy sets containing alternative expert solutions according to the non-existent risk criterion: $X = X_1 \cap X_2 \cap X_3 \cap X_4$. According to the MaxMin convolution method, the most rational solution is the alternative with the largest value of the membership function e*:

$$\mu_X(e^*) = \max_i \{\mu_X(e_j)\}. \quad (9)$$

The optimal set of alternatives under consideration is as follows:

A={min{0.7788, 0.3679, 0.1054, 0.3679}; min{1.0000, 0.7788, 0.3679, 0.1054}; min{0.3679, 1.0000, 0.7788, 0.3679}; min{0.7788, 0.7788, 0.7788, 0.7788}; min{1.0000, 0.3679, 0.3679, 0.3679}; min{0.3679, 0.7788, 0.1054, 0.3679}; min{0.3679, 0.7788, 0.7788, 0.7788}; min{0.7788, 1.0000, 0.3679, 0.3679}; min{1.0000, 0.7788, 0.7788, 0.1054}; min{0.3679, 1.0000, 0.1054, 0.7788}}.

Then, according to (10), the result vector of alternative expert decisions corresponding to risky situations has the following form:

max{μX(ej)} = max {0.1054, 0.1054, 0.3679, 0.7888, 0.3679, 0.1054, 0.3679, 0.3679, 0.1054, 0.1054}.

Regarding the evaluation of the BR level, the best alternative solution is the evaluation of the 4th expert (e4), which corresponds to the maximum value of 0.7788. The evaluations of the remaining expert decisions are divided into two groups: 0.3679– compatible with e3, e5, e7 and e8 expert solutions; 0.1054 – corresponds to solutions e1, e2, e6, e9 and e10.

BR components have different importance, so their contribution to the total solution should be represented as a weighted cross section:

$$X = X_1^{\alpha_1} \cap X_2^{\alpha_2} \cap X_3^{\alpha_3} \cap X_4^{\alpha_4}\ .$$

Here α_1=0.39676, α_2=0.23023, α_3=0.21826, α_4=0.15475 are the weights of the relevant criteria for evaluating the BR-level. As a result, the following exists:

A={min{0.77880.39676, 0.36790.23023, 0.10540.21826, 0.36790.15475}; min{1.00000.39676, 0.77880.23023, 0.36790.21826, 0.10540.15475}; min{0.36790.39676, 1.00000.23023, 0.77880.21826, 0.36790.15475}; min{0.77880.39676, 0.77880.23023, 0.77880.21826, 0.77880.15475}; min{1.00000.39676, 0.36790.23023, 0.36790.21826, 0.36790.15475}; min{0.36790.39676, 0.77880.23023, 0.10540.21826, 0.36790.15475}; min{0.36790.39676, 0.77880.23023, 0.77880.21826, 0.77880.15475}; min{0.77880.39676, 1.00000.23023, 0.36790.21826, 0.36790.15475}; min{1.00000.39676, 0.77880.23023, 0.77880.21826, 0.10540.15475}; min{0.36790.39676, 1.00000.23023, 0.10540.21826, 0.77880.15475}.

The resulting vector of alternative expert decisions relative to risk situations is as follows:

$$\max\{\mu X(ej)\} = \max \{0.6120, 0.7060, 0.6725, 0.9056, 0.7944, 0.6120, 0.6725, 0.8039, 0.7060, 0.6120\}.$$

Here, the best decision according to (10) relative to the BR level is expert opinion e4, which corresponds to a value of 0.9056. Furthermore, the expert values are ranked in descending order of the corresponding values of the membership functions: e8→0.8039, e5→0.7944, e2, e9→0.7060, e3, e7→0.6725, e1, e6, e10→0.6120.

The following considerations are used to evaluate expert judgments regarding the BR level:

d_1: If there is no interest rate risk and no commodity risk, then the level of BR is low;

d_2: In addition to the above, if there is no capital risk, then the level of MR is even lower;

d_3: If, in addition to the requirements given in e2, there is no currency risk, then the level of BR is quite low;

d_4: If there is no interest rate risk, no currency risk and no capital risk, then the level of BR is very low;

d_5: If interest rate risk is absent, currency risk is absent, and commodity risk is absent, but equity risk is present, then the level of BR is still low;

d_6: If there is interest rate risk and commodity risk, then the level of BR is high.

As a result of the analysis of these fragments, a complete set of input and output characteristics of the fuzzy extraction system was determined and summarized in Table 11.

Table 11. Inputs and outputs of fuzzy inference system

Login/ output	Name	Term-plurality	Univers
x_1	Interest rate risk	X_1=NOT AVAILABLE,$\neg X_1$= AVAILABLE	{1, 2, 3, 4, 5}
x_2	Currency risk	F_2=NOT AVAILABLE	{1, 2, 3, 4, 5}
x_3	Capital risk	X_3=NOT AVAILABLE,$\neg X_3$= AVAILABLE	{1, 2, 3, 4, 5}

x_4	Commodity risk	X_4= NOT AVAILABLE,$\neg X_4$= AVAILABLE	{1, 2, 3, 4, 5}
y	The level of BR	H=high, L=low, ML=even lower, VL=very low, TL=very low	{0, 0.1, ..., 1}

The fuzzy inference system is described as follows:

d_1: $(x_1=X_1)$ & $(x_4=X_4) \Rightarrow (y = L)$;

d_2: $(x_1=X_1)$ & $(x_3=X_3)$ & $(x_4=X_4) \Rightarrow (y = ML)$;

d_3: $(x_1=X_1)$ & $(x_2=X_2)$ & $(x_3=X_3)$ & $(x_4=X_4) \Rightarrow (y = TL)$;

d_4: $(x_1=X_1)$ & $(x_2=X_2)$ & $(x_3=X_3) \Rightarrow (y = VL)$;

d_5: $(x_1=X_1)$ & $(x_2=X_2)$ & $(x_3=\neg X_3)$ & $(x_4=X_4) \Rightarrow (y = L)$;

d_6: $(x_1= \neg X_1)$ & $(x_3=\neg X_4) \Rightarrow (y = H)$.

As a result of processing the rules, the general functional solution of the problem is obtained in the form of the following matrix

$$R = \begin{array}{c|ccccccccccc} & 0 & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & 0.7 & 0.8 & 0.9 & 1 \\ \hline e_1 & 0.6321 & 0.7321 & 0.8321 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8788 & 0.7788 \\ e_2 & 0.6321 & 0.6421 & 0.6721 & 0..7221 & 0.7921 & 0.8821 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 1.0000 \\ e_3 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.5679 & 0.4679 & 0.3679 \\ e_4 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.2212 & 0.7788 \\ e_5 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 1.0000 \\ e_6 & 0.6321 & 0.7321 & 0.8321 & 0.8946 & 0.8946 & 0.8679 & 0.7679 & 0.6679 & 0.5679 & 0.4679 & 0.3679 \\ e_7 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.7788 \\ e_8 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.6321 & 0.7788 \\ e_9 & 0.2212 & 0.2312 & 0.2812 & 0.3112 & 0.3812 & 0.4712 & 0.5812 & 0.7112 & 0.8612 & 0.8946 & 1.0000 \\ e_{10} & 0.6321 & 0.7321 & 0.8321 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8946 & 0.8788 & 0.7788 \end{array}$$

Numerical evaluations of expert opinions on BR level after defuzzification were obtained as follows: F(E2)=0.6039,F(E1)=0.5199,F(E3)=0.4610,F(E4)=0.8580, F(E5)=0.6839, F(E6)=0.4344,F(E7)=0.5942,F(E8)=0.5942,F(E9)=0.7537,F(E10)=0.5199.

Expert systems cannot reflect internal cause-and-effect relationshipsrightly criticized for what they do.At the same time, the analytical approach to multi-criteria assessment allows comparing alternatives using an integral index that reflects the relative influence of a finite number of factors in the form of a multifactorial function of the form F=F(x1, x2, …, xn). However, F-type econometric (regression) models are difficult to provide current sources of information about the influence of factors xi (i=1÷n), especially when some factors are poorly structured or fuzzy. Therefore, the goal is to present the working model as a "black box".appropriate, here*xi*with expert evaluation on the influence of factorsentrances and exits are determined based on the application of

30 possible scenarios for evaluating BR levels in the considered problem are presented in the form of an "external knowledge" information model: $\{(x_{1j}, x_{2j}, x_{3j}, x_{4j}) \rightarrow y_j\}_{j=1}^{30}$, where yj is an integral index calculated by formula (8) reflecting BR levels.

Fig. 3 Numerical evaluations of experts with a 5-point system about the existence of risk situations on the xi signs of BR show loading to the MATLAB\ANFIS editor.

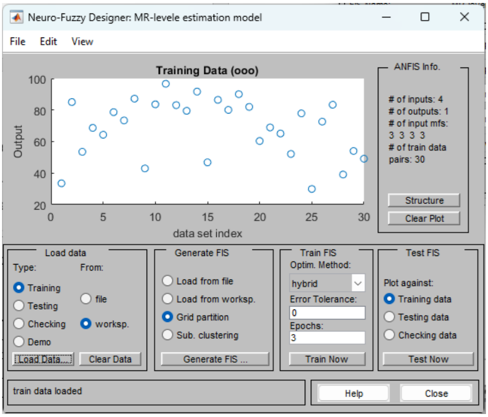

Fig. 3. Downloading expert assessments

As a result of structural and parametric optimization, ANFIS generated 81 implicative rules for FIS based on neural network logic. Specifically, for scenario 2:(x1=5; x2=2; x3=4; x4=4)→y=85.07, corresponding graphical functional interface Fig. 4 is shown.

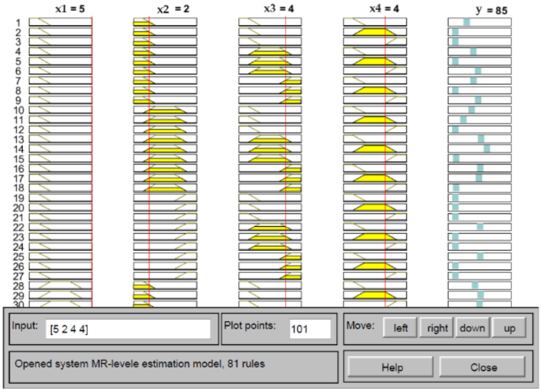

Fig. 4. Graphical interface of FIS for estimation of BR in the logic base of neural network

Table 12 shows the classification of ak (k = 1÷10) expert opinions from the test sample obtained using the hybrid system implemented in MATLAB\ANFIS notation.

Table 12. Expert evaluations of BR using ANFIS

Expert opinions	Weights of factors affecting BR				The final ratio	
	α_1	α_2	α_3	α_4	(8) by formula	Using ANFIS
	0.39676	0.23023	0.21826	0.15475		
e_1	4	3	2	3	68.69	68.70
e_2	5	4	3	2	83.62	83.60
e_3	3	5	4	3	79.51	79.40
e_4	4	4	4	4	86.45	86.30
e_5	5	3	3	3	81.99	82.00
e_6	3	4	2	3	65.10	65.10
e_7	3	4	4	4	77.87	77.70
e_8	4	5	3	3	83.36	83.30
e_9	5	4	4	2	88.34	87.70
e_{10}	3	5	2	4	73.42	73.40

MAIN RESULTS OF THE DISSERTATION WORK

Based on the research conducted on the subject of the dissertation, the main scientific results submitted to the defense were compiled in the form of the following provisions:

1. The concept of "Risk management" system for commercial banks was developed based on fuzzy cognitive model [1].
2. A balanced approach based on the combined use of traditional and fuzzy methods for bank decision-making in the field of risk assessment is proposed [2, 3, 9].
3. An expert system that takes into account the influence of relevant subcomponents has been developed for market risk assessment [4, 5, 6].
4. A new approach is proposed for market risk assessment based on the application of the fuzzy Minimax convolution method (taking into account equal and different importance levels of the influencing subcomponents) [7].
5. An algorithm based on the application of the Fuzzy Extraction System was designed for the numerical assessment of market risks [8].
6. An algorithm was designed based on the application of the neuro-fuzzy hybrid modeling system, which ensures the compilation of expert knowledge for the numerical assessment of bank risks [5,6].

The main results of the dissertation work were published in the following scientific works:

1. Aghajanov JH Fuzzy cognitive map-based Risk management system in a commercial bank // Proceedings of the 8th International Conference on Control and Optimization with Industrial Applications (COIA – 2022) Baku, Azerbaijan, 24-26 August 2022, Vol. 1, pp. 39-41.
2. Aghajanov JH Organization of risk management in a commercial bank based on a fuzzy cognitive map. Mathematical Machines and Systems, Institute of Mathematical Machines and Systems Problems of the National Academy of Ukraine, Kyiv, 2022, №3, pp. 77-90.
3. Rzayev RR, Aghajanov JH Risk management in banking: fuzzy inference-based process model // Springer Series: Recent

Developments and the New Directions of Research, Foundations, and Applications, 2023, Vol. 1, pp. 351-358.
4. Aghajanov JH Market risk assessment by compilation of expert knowledge // News of Baku University, 2023, No. 1, p. 68-78.
5. Aliyev ER, Rzayeva IR, Aghajanov JH Market risk assessment by expert knowledge compilation using a fuzzy maximin convolution // The Springer Series "Lecture Notes in Networks and Systems", 758, 2023, Vol. 1, pp. 767-775.
6. Aliyev ER, Rzayeva IR, Aghajanov JH Market risk assessment by expert knowledge compilation using fuzzy analysis methods // Proceeding of 5th International Conference on Problems of Cybernetics and Informatics (PCI 2023), Baku, Azerbaijan, August 28-30, 2023, Vol. 1, pp. 1-5.
7. Aghajanov JH A combined approach to decision making under uncertainty // Baku State University Journal of Mathematics & Computer Sciences 2024, Vol. 1(1), pp. 12-24.
8. Aghajanov JH, Rzayev RR Комбинированный проход к очень принконого риска // Економика и менеджмент систем управления, 2024, №2(52), стр. 77-88
9. Rzayev RR, Aghajanov JH, Rzayeva IR A Combined Fuzzy Approach to Market Risk Assessment // Proceeding of International Conference on Intelligent and Fuzzy Systems (INFUS – 2024) Çanakkale Onsekiz Mart University, Çanakkale, Turkish, July 16-18, 2024, Vol. 2, pp. 620-629

Personal role of claimant in co-published cases:

[3] Development of a complex of relevant fuzzy inference systems that formalize the relationships between concepts in the fuzzy cognitive map of the Risk-management system in banks

[5] Development of an expert system for market risk assessment and adaptation of the fuzzy maximin convolutional method, which performs the compilation of heuristic knowledge obtained through it.

[6] Development of expert system and identification procedure of market risk weighting coefficients

[8] Development of fuzzy methods of decision-making under conditions of uncertainty that provide market risk assessment and their adaptation on a hypothetical bank scale

[9] Development of fuzzy methods for market risk assessment, including fuzzy inference system, fuzzy max-min convolution methods and adaptation in the example of a hypothetical bank

The defence will be held on 30 may 2025 at 13:00 at the meeting of the Dissertation council ED 1.20 of Supreme Attestation Comission under the President of the Republic of Azerbaijan operating at Institute of Control Systems of the Ministry of Science and Education of the Republic of Azerbaijan.

Address: AZ1141, Baku, St. B. Vahabzade, 68.

Dissertation is accessible at the Library of the Institute of Control Systems of the Ministry of Science and Education of the Republic of Azerbaijan.

Electronic versions of dissertation and its abstract are available on the official website (http://www.isi.az) of the Institute of Control Systems of the Ministry of Science and Education of the Republic of Azerbaijan.

Abstract was sent to the required addresses on 28 april 2025.

Signed for print: 25.04.2025.
Paper format: A5
Volume: 38925
Number of hard copies: 100