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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF THE DECISION-MAKING INFORMATION SUPPORT SYSTEM FOR LENDING TO INDIVIDUALS UNDER UNCERTAINTY

Specialty:	3338.01 – "System Analysis, Management and Information Processing"
Field of science:	Technical sciences

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Baku - 2021

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GENERAL DESCRIPTION OF THE DISSERTATION

Actuality of the topic and the degree of its elaboration. Currently, there is a significant tendency to increase the living standards of the population in Azerbaijan, which has unambiguously led to an increase in the lending market for private parsons (individuals), including consumer lending, mortgage lending, car lending, educational lending, lending using plastic cards, etc. At the same time, in the banking sector and within the micro-financial organizations of Azerbaijan, the share of borrowed funds reaches 80% of the total capital. It is owing to these assets that the function of lending to all borrowers is performed: both individuals and legal entities. Under dynamic development of the consumer market, the return of borrowed funds is of paramount, if not the main, importance for the effective functioning of a commercial bank (CB), especially when lending is carried out under risk and/or uncertainty. In order to form a loan portfolio – optimal from the point of view of minimizing risks and maximizing profits, to ensure maximum repayment of borrowed funds, CBs conduct a preliminary assessment of the applicant's creditworthiness, and in our case, a natural parson (NP). For example, the risk of non-repayment of the principal and interest can be significantly reduced by assessing the likelihood of the borrower repaying the loan. Currently, a loan is a popular means of attracting funds, the volume of loans issued has a tendency to grow annually, while the share of loans to individuals in the loan portfolio of Azerbaijani CBs is almost a sixth part.

The creditworthiness of the NP is its ability to fully and on time repay its debts under its contractual obligations. Therefore, it is obvious that the entire lending process depends on the degree of reliability of the assessment of the creditworthiness of the NP. The solvency of the NP is a multifactorial category that must be studied and assessed in each specific case for its correlation with each of the factors of the solvency of the NP. At the same time, the determination of changes in all solvency factors, reasons and circumstances affecting the solvency of the NP at the current moment and in the future, remains an essential and very difficult task

for the analyst. In this regard, the assessment of the creditworthiness of the NP is one of the most important tasks of the CB, on the solution of which the formation of a reliable loan portfolio and the minimization of risk directly depend.

Currently, to ensure the efficiency of activities the CBs develop their own methods for assessing the creditworthiness of potential borrowers, using international experience, periodic statistical studies, requirements of fiscal authorities and the macroeconomic situation in the country. Modern technologies for assessing the creditworthiness of the NP, including the methods and means of Soft Computing technologies, allow not only to reduce credit risks, but also minimize errors in the assessment, accelerating the overall process of assessing the creditworthiness of the NP. Every year, assessment technologies are being improved and implemented by an increasing number of design bureaus. Actually, this is the starting motive for the topic of this dissertation work, which determines its relevance at the current stage of development of the banking sector of the economy of Azerbaijan Republic.

The main goal and objectives of the study. A significant increase in the living standards of the population in Azerbaijan has become one of the main reasons for the development of the retail lending market. Nevertheless, crises arising alternately in the economy lead to an increase in the percentage of default on loans, which forces the CB to revise, and in some cases, to tighten its credit policy. There is a correlation between related events: the less risk a CB is at lending, the lower the interest rate it offers, and, consequently, the larger the CB will have a customer base, which, in turn, will provide it with the acquisition of more profit. This is the main purpose of the bank's commercial activities. This predetermined the main goal and objectives of the study, which is focused on developing a methodology to support the process of forming an optimal loan portfolio by the bank under uncertainty. More specifically, it is the development of methods for assessing the creditworthiness of the NP as potential borrowers, which are characterized by quantitative and qualitative indicators of solvency (SI), including their credit history. The ultimate goal of the study is

to develop an analytical core for the credit decision support information system that would be equally understandable to analysts and users. The methods and models proposed within this core for assessing the creditworthiness of the NP are distinguished by their flexibility and transparency, which makes it possible to relatively quickly adapt the system to new changed conditions.

Thus, the purpose of the thesis is to develop methods and models for assessing the creditworthiness of individuals for the formation of the information system for supporting the adoption of credit decisions under risk and/or uncertainty. Based on this goal, the following main tasks have been solved in the work:

- analysis of causal-effect relations between solvency factors of dissimilar nature that affect the levels of creditworthiness of NP;
- formation of a system of solvency indicator (SI) for assessing the creditworthiness of NPs;
- development and testing of methods of fuzzy inference and fuzzy maximin convolution for assessing the creditworthiness of NPs;
- development of an expert system for identifying the specific weights of assessment criteria and obtaining a weighted assessment of the creditworthiness of NPs;
- development of hybrid methods for assessing the creditworthiness of NPs.

Object and subject of research. The object of the research is the loan portfolio of NPs of the CB, and the subject of the research is the mathematical apparatus of fuzzy and neuro-fuzzy modeling and analysis of the creditworthiness of private consumers of borrowed funds.

The applied research methodology. The research methodology is based on the methods of management technologies using elements of artificial intelligence, including methods of fuzzy logic and neural network modeling, which have proven themselves in the management of weakly structured systems of a humanistic type. In particular, the use of fuzzy methods of multi-criteria assessment of alternatives makes it relatively easy to take into account many different parameters for making informed decisions and does not require complex mathematical calculations. Moreover, the

mathematical apparatus of the theory of fuzzy sets makes it equally easy to operate with both quantitative and qualitative (weakly structured) categories, which provides a systematic approach that consolidates processes of different nature. Within the framework of this approach, expert modeling is used as one of the most common tools for describing and researching weakly structured systems. At the same time, the main advantage of the mathematical apparatus of expert analysis is the knowledge provided by it, which can be compiled both by methods of fuzzy inference and fuzzy maxmin convolution, and using neural network modeling or, even better, by the hybrid (neuro-fuzzy) modeling system.

The solvent features for the defense. The main results submitted for defense are:

- formation of the system of SIs for assessing the creditworthiness of NPs, as potential customers of borrowed funds of the CB;
- description of the expert approach to the issue of identifying specific weights of the relative influence of the SIs of NPs;
- development of approaches that allow compiling expert knowledge regarding the creditworthiness of NPs using a fuzzy inference system and fuzzy methods of simple and weighted maxmin convolution;
- formation of the analytical core for the development of an information support system for credit decision-making.

Scientific novelty in research. The scientific novelty of the dissertation work is as follows:

1. Methods of fuzzy inference and fuzzy maxmin convolution for assessing the creditworthiness of NPs have been developed and tested, providing for complex processing of available information, including weakly structured (qualitative) characteristics of their financial stability;
2. The expert system has been developed for identifying the weights of the evaluation criteria and obtaining the weighted assessment of the creditworthiness of NPs and their ranking relative to the levels of solvency;
3. The method has been developed for assessing the creditworthiness of NPs by integration of the expert system in the logical basis of

the neural network;

4. Approaches and algorithms have been developed and tested to compile expert knowledge regarding the creditworthiness of NPs using the hybrid (neuro-fuzzy) modeling system;
5. It has been developed the analytical core of the information support system for credit decision-making under risk and/or uncertainty.

Scientific and practical significance of the research. The numerical assessments of the creditworthiness of NPs for granting loans obtained on specific examples by different methods made it possible to formulate a methodology that significantly increases the degree of objectivity of the results regarding the responsibility and financial reliability of potential borrowers, characterized by their quantitative and qualitative data. The approaches proposed in the work are, in a certain sense, flexible with respect to possible additions and/or clarifications that can be presented by the specialists of CB. Compiling the Expert Knowledge, the fuzzy models, without giving out the absolute values of assessments of the creditworthiness of NPs, are able to respond to possible changes in the list of SIs and ensure the integrity, consistency and synergistic effect of actions aimed at optimizing the loan portfolio of CB. The neuro-fuzzy models developed in the dissertation were tested both with hypothetical examples and with specific examples, which received a positive opinion from the expert community of CBs.

Approbation and implementation of work. The main results of the dissertation were expounded:

- at the 10th International Scientific and Practical Conference Internet-Education-Science: ION-2016 (2016, Vinnitsa, Ukraine);
- at the 21st scientific-practical conference of doctoral students and young researchers (2017, Baku, Azerbaijan);
- at the XXIV International Open Science Conference «Modern Informatization Problems in Economics and Safety» (2019, Yelm, WA, USA);
- at the International Workshop "Advanced Technologies in Material Science, Mechanical and Automation Engineering-MIP: Engineering – 2019" (2019, Krasnoyarsk, Russian Federation);

- at the 3rd International Scientific and Practical Conference "Applied Systems and Technologies in the Information Society" (2019, Kiev, Ukraine),

as well as at seminars of the Department of Information Technologies and Programming of the Faculty of Applied Mathematics and Cybernetics of Baku State University and at seminars of the Institute of Control Systems of the National Academy of Sciences of Azerbaijan.

The solutions obtained in the dissertation were tested on specific examples of SIs of potential borrowers of consumer loans in the commercial bank "Ziraat Bank Azerbaijan". Based on the results of testing and comparative analysis with the scoring assessment systems used in the Bank, the management of "Ziraat Bank Azerbaijan" gave a positive assessment to the research, which is confirmed by the corresponding certified Implementation Act (it is attached).

The name of the organization, where the dissertation was carried out. The dissertation was carried out at the Department of Information Technologies and Programming of the Faculty of Applied Mathematics and Cybernetics of Baku State University.

The number of published scientific articles. According to the results of the research, 12 works were published in total: 8 scientific articles, including 6 – abroad, of which 3 articles with international scientific citation indices from the Web-Science and SCOPUS archives, and 4 theses of reports at conferences.

The structure and volume of the dissertation. The dissertation consists of the introduction, 4 chapters, the conclusion, and the list of used literature. The volume of the general and structural sections of the dissertation is distributed approximately as follows:

- Total – 172,000 characters,
- Table of contents – 4,000 characters,
- Introduction – 17,000 characters,
- Chapter One – 33,000 characters,
- Chapter Two – 34,000 characters,
- Chapter Three – 59,000 characters,
- Chapter Four – 23,000 characters,
- Result – 2,000 characters.

THE CONTENT OF THE DISSERTATION

The introduction outlines the actuality of the dissertation, where it is provided a list of tasks and approaches necessary to achieve the goal of the dissertation, described the structure and content of the work, as well as the desired results submitted for defense.

In the first chapter, which is devoted to the study of the content, forms and types of consumer loans, as well as the basic principles of bank lending and the analysis of the problem of forming a loan portfolio in the CB, new expert and analytical methods for modeling the assessment of the creditworthiness of NPs are considered. Today, CBs use three main approaches to assess the creditworthiness of an individual entrepreneur: 1) scoring, 2) study of credit history, 3) assessment by financial indicators of solvency. At the same time, the classical approach to an objective assessment of NP implies the presence of a list of key quantitative and qualitative indicators that characterize the economic and personal factors of creditworthiness.

Quantitative indicators include: 1) current and prospective total net income; 2) the volume of deposits; 3) loan security and its liquidity; 4) financial ratios, which characterize the current financial stability of the NP and its financial capabilities to fulfill its obligations in accordance with the loan agreement. In particular, the analysis of the current solvency of NP is carried out by assessing financial ratios: F_1 – *PTI* (Payment-to-Income Ratio), 2) F_2 – *OTI* (Obligations-to-Income Ratio), 3) F_3 – solvency ratio.

The qualitative characteristics of the financial stability of NP include: 1) its financial position; 2) social stability; 3) age; 4) credit history. Nevertheless, most of the methods used to assess the creditworthiness of NP are mainly based on quantitative characteristics. In the chapter it is noted that fuzzy sets, as a way to formalize the linguistic knowledge, make it possible to avoid this limitation. It is substantiated that the use of the apparatus of fuzzy logic allows banks, when choosing the estimated indicators, to be guided only by the degree of their significance for making a credit decision, and the task of assessing the creditworthiness of NPs will not be reduced to only calculating the quantitative values of the

financial indicators of NP. The chapter provides a methodology for expert multi-criteria assessment of alternatives and some fuzzy decision-making methods under risk and/or uncertainty.

In the second chapter, an alternative approach to assessing the creditworthiness of NPs is proposed. This approach based on the use of fuzzy decision-making methods under uncertainty. On the example of five alternative NPs, ten criteria were selected as a basis. The quantitative values of these criteria (*C*) for NPs are presented in Table 1.

Table 1**. Numerical criteria for assessing the solvency of NP**

C	Criteria	Alternative NPs					Standard
		a_1	a_2	a_3	a_4	a_5	
K_1	Current and prospective total net income ($)	280	340	370	310	280	The bigger, the better
K_2	The volume of deposits	6	8	5	4	9	[0, 10]
K_3	Loan security and its liquidity	2	5	7	9	8	[0, 10]
K_4	*PTI*	0.3000	0.3467	0.3827	0.3134	0.4286	[0, 0.45]
K_5	*OTI*	0.5333	0.5467	0.5432	0.5373	0.5000	[0, 0.55]
K_6	Solvency	1.2000	1.1194	1.0800	1.1754	1.0769	The larger the one, the better
K_7	Total financial position	7	6	9	8	7	[0, 10]
K_8	Social stability	10	8	6	8	7	[0, 10]
K_9	Age (years)	28	39	55	64	47	[0, 100]
K_{10}	Credit history	5	4	8	9	6	[0, 10]

Assuming the intervals of the normative values of NPs as universal sets U_i, their fuzzy subsets are constructed, which describe the qualitative criteria for assessing K_i (i=1÷10). For example, HIGH (current and prospective total net income), SUFFICIENT (the volume of deposits), etc. The discrete set $\{a_1, a_2, a_3, a_4, a_5\}$ was chosen as the universe. To restore the indicated fuzzy sets in the form $K_i=\{\mu_{Ki}(a_1)/a_1, \mu_{Ki}(a_2)/a_2, \ldots, \mu_{Ki}(a_5)/a_5\}$ the following Gaussian membership function (MF) is used:

$$\mu_{K_i}(u_i) = \exp\left[-\frac{(u_i-u_0)^2}{\sigma_i^2}\right], u_i \in U_i\,, i = 1 \div 10, \qquad (1)$$

where $u_{i0} \in U_i$ is the function vertex abscissa, and σ_i^2 – density (variance) of the distribution of elements according to the *i*-th criterion. To assess the solvency of NP using the fuzzy inference method, the following consistent and logically grounded rules were selected as a basis, which reflect the causal-effect relations between the solvency criteria K_i (i=1÷10), on the one hand, and the degree of creditworthiness of NP, on the other:

e_1: «If K_5=LOW and K_6=HIGH and K_7=HIGH and K_8=HIGH, then the degree of solvency of the NP is SATISFACTORY»;

e_2: «If K_2=SUFFICIENT and K_4=LOW and K_5=LOW and K_6=HIGH and K_7=HIGH and K_8=HIGH, then the degree of solvency of the NP is MORE THAN SATISFACTORY»;

e_3: «If K_1=HIGH and K_2=SUFFICIENT and K_3=ACCEPTABLE and K_5=LOW and K_6=HIGH and K_7=HIGH and K_8=HIGH and K_{10}=FAVORABLE, then the degree of solvency of the NP is VERY SATISFACTORY»;

e_4: «If K_1=HIGH and K_2=SUFFICIENT and K_3=ACCEPTABLE and K_4=LOW and K_5=LOW and K_6=HIGH and K_7=HIGH and K_8=HIGH and K_9=ACCEPTABLE and K_{10}=FAVORABLE, then the degree of solvency of the NP is PERFECT»;

e_5: «If K_2=SUFFICIENT and K_3=UNACCEPTABLE and K_4=LOW and K_5=LOW and K_6=HIGH and K_7=HIGH and K_8=HIGH and K_9=UNSUITABLE, then the degree of solvency of the NP is SATISFACTORY»;

e_6: «If K_3=UNACCEPTABLE and K_6=NOT HIGH and K_7=NOT HIGH and K_{10}=UNFAVORABLE, then the degree of solvency of the NP is UNSATISFACTORY».

For the output linguistic variable (LV) “the degree of creditworthiness”, the corresponding terms are described on the discrete set J={0, 0.1, 0.2, …., 1} by following fuzzy sets: S=SATISFACTORY: $\mu_S(u)=u$; MS=MORE THAN SATISFACTORY: $\mu_{MS}(u)=u^{(1/2)}$; VS=VERY SATISFACTORY: $\mu_{VS}(u)=u^2$; P=PERFECT: $\mu_P(u)$=1, if u=1 и $\mu_P(u)$=0, if u<1; US=UNSATISFACTORY: $\mu_{US}(u)$=1-u.

As a result of the implementation of the fuzzy inference system, the estimates of the solvency of the NPs were calculated as follows: a_1=0.4073, a_2=0.3332, a_3=0.4957; a_4=0.4961; a_5=0.4686. The owner of the highest grade has the highest degree of solvency and, accordingly, is the best applicant for a loan. In this case, it is a_4 with the estimate of 0.4961. Further – in descending order.

Assuming K_i (i=1÷10) as qualitative criteria for assessing the ability to pay with the same importance, the key rule for choosing the best NP using the maxmin convolution method will be: K = K=$K_1 \cap K_2 \cap \ldots \cap K_{10}$. In this case, the NP with the maximum value of the MF to the fuzzy set (FS) K is considered as optimal. The operation of intersecting the FS K_i (i=1÷10) is carried out based on the choice of the minimum value for the k-th NP, i.e. by finding the minimum by the formula $\mu_K(a_k)=\min\{\mu_{Ki}(a_k)\}$. As a result, the most solvent NP is determined from the equality: $\max\{\mu_K(a_k)\}=\max\{0.00280, 0.00479, 0.00149, 0.00986, 0.00028\}$. The maximum value of 0.00986 of the fourth vector component corresponds to the choice of a_4, which repeats the previous result with respect to the most solvent NP.

Using the criteria K_i (i=1÷10), a new method was formulated, described and tested for the individual assessment of the creditworthiness of NP. As a preliminary procedure, the classification of the levels of financial stability was carried out, for which five evaluative concepts were selected to characterize the level of financial solvency: u_1 – "TOO UNACCEPTABLE", u_2 – "UNACCEPTABLE", u_3 – "LESS THAN ACCEPTABLE", u_4 – "ACCEPTABLE" and u_5 – "MORE THAN ACCEPTABLE". For this purpose, the following fuzzy model was chosen as a basis:

e_1: «If K_5=ACCEPTABLE and K_6=ACCEPTABLE and K_7=ACCEPTABLE and K_8=ACCEPTABLE, then Y=SATISFACTORY »;

e_2: «If K_2=ACCEPTABLE and K_4=ACCEPTABLE and K_5=ACCEPTABLE and K_6=ACCEPTABLE and K_7=ACCEPTABLE and K_8=ACCEPTABLE, then Y=MORE THAN SATISFACTORY»;

e_3: «If K_1=ACCEPTABLE and K_2=ACCEPTABLE and K_3=ACCEPTABLE and K_4=ACCEPTABLE and K_5=ACCEPTABLE and K_6=ACCEPTABLE and

K_7=ACCEPTABLE and K_8=ACCEPTABLE and K_9=ACCEPTABLE and K_{10}=ACCEPTABLE, then Y=PERFECT»;

e_4: «If K_1=ACCEPTABLE and K_2=ACCEPTABLE and K_3=ACCEPTABLE and K_5=ACCEPTABLE and K_6=ACCEPTABLE and K_7=ACCEPTABLE and K_8=ACCEPTABLE and K_{10}=ACCEPTABLE, then Y=VERY SATISFACTORY»;

e_5: «If K_2=HEACCEPTABLE and K_3=HEACCEPTABLE and K_4=ACCEPTABLE and K_5=ACCEPTABLE and K_6=ACCEPTABLE and K_7=ACCEPTABLE and K_8=ACCEPTABLE and K_9=HEACCEPTABLE, then Y=SATISFACTORY»;

e_6: «If K_3=NOT ACCEPTABLE and K_6=NOT ACCEPTABLE and K_7=NOT ACCEPTABLE and K_{10}=NOT ACCEPTABLE, then Y=UNSATISFACTORY».

The output linguistic variable Y is given on the set J={0; 0.1; 0.2; …; 1}, and its terms, as in the previous case, are described by FS: $\mu_S(u)=u$; $\mu_{MS}(u)=u^{(1/2)}$; $\mu_{VS}(u)=u^2$; $\mu_P(u)$=1, если u=1 и $\mu_P(u)$=0, если u<1; $\mu_{US}(u)=1-u$. Fuzzification of terms from the left-hand sides of the rules was carried out using membership functions (1) restoring the fuzzy subsets of the discrete universe $\{u_1, u_2, u_3, u_4, u_5\}$, where $u_i=0.2\cdot i$ (i=1÷5), σ_k are selected based on the importance of the evaluation criteria. After implementation of the rules $e_1 \div e_6$ by sequential application of the operations of intersection of FS from the left-hand sides and the Lukasiewicz's implication, the corresponding fuzzy relations are obtained in the form of matrices R_1, R_2, …, R_6. As a result of the intersection of these matrices, a common functional solution was obtained that reflects the causal-effect relations between SI and the creditworthiness level of the NP:

$$R = \left[\begin{array}{c|cccccccccc} & 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ u_1 & 0{,}9972 & 0{,}9028 & 0{,}8028 & 0{,}7028 & 0{,}6028 & 0{,}5028 & 0{,}4028 & 0{,}3028 & 0{,}2028 & 0{,}1028 & 0{,}0028 \\ u_2 & 0{,}9633 & 0{,}9367 & 0{,}8367 & 0{,}7367 & 0{,}6367 & 0{,}5367 & 0{,}4367 & 0{,}3367 & 0{,}2367 & 0{,}1367 & 0{,}0367 \\ u_3 & 0{,}7699 & 0{,}7699 & 0{,}7699 & 0{,}7699 & 0{,}7699 & 0{,}7301 & 0{,}6301 & 0{,}5301 & 0{,}4301 & 0{,}3301 & 0{,}2301 \\ u_4 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}9633 & 0{,}8926 & 0{,}7926 & 0{,}6926 \\ u_5 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 0{,}9972 & 1 \end{array}\right].$$

To classify the levels of creditworthiness, the procedure of defuzzification of fuzzy outputs of the used model was applied. As a

result, point estimates of fuzzy conclusions relative to levels of creditworthiness were established: for the evaluative concept u_1 (TOO UNACCEPTABLE) – 0.2270; for u_2 (UNACCEPTABLE) – 0.2526; for u_3 (LESS THAN ACCEPTABLE) – 0.3871; for u_4 (ACCEPTABLE) – 0.4734; for u_5 (MORE THAN ACCEPTABLE) – 0.5014. The final scale for assessing the level of creditworthiness of NP looks like it is shown in Fig. 1.

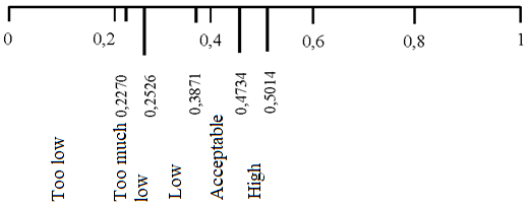

Fig. 1. The gradation of the of creditworthiness level of the NP

To assess the NP a_k (k=1÷5), which are characterized by the indicators presented in Table 1, on the base of the rules e_1÷e_6 the fuzzy inference system is applied in the notation of the MATLAB package (see Fig. 2).

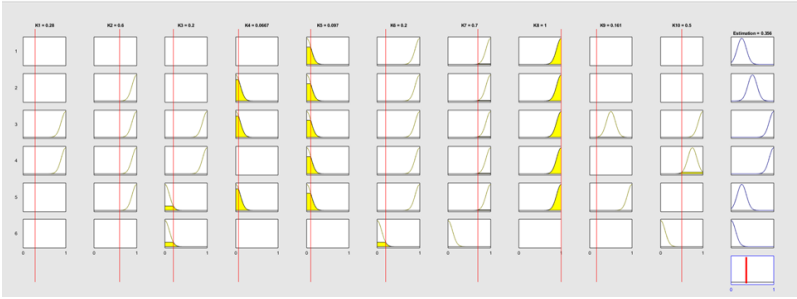

Fig. 2. Interactive window for the implementation of the fuzzy inference system regarding the assessment of the creditworthiness of NP (case of alternative a_1)

As a result, the following assessments of the FL creditworthiness were obtained: for a_1 – 0.356; a_2 – 0.307; a_3 – 0.463; a_4 – 0.5; a_5 – 0.405. According to the established classification (see Fig. 1), NP a_4 is assigned a HIGH level of solvency. Estimates for the others NPs are given in descending order: a_3 (0.462) and a_5 (0.405) – the ACCEPTABLE level of solvency; a_1 (0.356) и a_2 (0.307) – LOW level of solvency. Within the framework of the proposed approach, based on the integrated processing of the available quantitative and qualitative information on the financial stability of potential borrowers, the use of various assessment methods gave similar results for the example of five NPs.

The third chapter proposes a balanced approach to assessing the solvency of NPs, based on the use of three methods for assessing the current solvency, including the method of weighted summation of expert assessments of solvency, as well as fuzzy inference methods and weighted maxmin convolution.

In particular, the CB considers a set of n quantitative and qualitative indicators $X=\{x_1, x_2, \ldots, x_n\}$ to assess the creditworthiness of alternative NP: a_1, a_2, ..., a_{10}. At an early stage, the indicators x_i are estimated by m experts: each expert is asked to form a rank estimate r_{ij} for each i-th SI and the normalized value of this estimate – α_{ij} if condition of $\sum_{i=1}^{n} \alpha_{ij} = 1$ (j=1÷m) is fulfilled.

As a result, SIs are evaluated on the basis of two methods: by comparative qualitative assessment of SIs – by the method of simple ranking of experts, and by quantitative assessment of SI parameters – by setting the normalized values of their weights.

By independent questioning of 15 experts, appropriate assessments were determined for the above SIs x_i (i=1÷10). Each expert was asked to arrange the SI s according to the principle: designate the most important factor with the number "1", the next less important factor with the number “2”, and then in descending order of preference. All estimates are summarized in Table 2.

To establish the degree of consistency of experts' opinions for the rank correlation of Sİ priorities, the Kendall concordance coefficient is used. In the case when n=10 and m=15, the value of the Kendall concordance coefficient at S=14836.5 calculated as

$$S = \sum_{i=1}^{n} \sum_{j=1}^{m} (r_{ij} - m(n+1)/2)^2 ,$$

where $r_{ij} \in \{1, 2, \ldots, n\}$ is the rank of the i-th criterion, established by the j-th expert, based on data from Table 2, will be: $W=(12\cdot S)/[m^2(n^3-n)]=12\cdot 14836.5/[15^2(10^3-10)]=$ 0.799273. This value significantly exceeds the key consistency threshold of 0.6, which indicates a fairly strong consistency of expert assessments using a 10-point scoring system with respect to the priority of SI x_i (i=1÷10). Based on these results, calculations are carried out to determine and then identify the weights x_i.

Table 2. Ranking of PPs in orders of preference of experts

Expert	Estimated SIs and these rang estimates (r_{ij})									
	Current and prospective total net income	The volume of deposits	Loan security and its liquidity	*PTI*	*OTI*	Solvency ratio	Total financial position	Social stability	B Age (years)	Credit history
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
01	8	6	4	7	5	1	2	3	10	9
02	7	9	4	8	5	1	3	2	10	6
03	8	5	6	7	4	1	2	3	10	9
04	8	6	4	10	5	2	1	3	9	7
05	8	6	5	7	4	1	3	2	10	9
06	10	6	4	8	3	1	2	5	7	9
07	8	6	4	7	1	5	2	3	9	10
08	6	8	4	9	5	1	2	3	10	7
09	8	10	4	5	2	1	3	7	6	9
10	8	6	4	7	2	3	5	1	10	9
11	7	8	4	6	5	1	2	3	10	9
12	8	6	4	7	1	2	3	5	10	9
13	10	6	4	7	3	1	2	5	8	9
14	8	4	6	7	5	2	1	3	10	9
15	8	9	4	3	5	1	2	7	10	6
$\sum r_{ij}$	120	101	65	105	55	24	35	55	139	126

At each step of the iteration, group estimates of SIs are determined by the formula $\alpha_i(t+1) = \sum_{j=1}^{m} w_j(t)\alpha_{ij}$ and numerical indicators characterizing the competence of experts, based on the equalities:

$$w_j(t)=[1/\eta(t)]\sum_{i=1}^{n}\alpha_i(t)\cdot\alpha_{ij}\ (j=\overline{1,m-1}),\ w_m(t)=1-\sum_{j=1}^{m-1}w_j(t),\ \sum_{j=1}^{m}w_j(t)=1,$$

where $\eta(t)=\sum_{i=1}^{n}\sum_{j=1}^{m}\alpha_i(t)\alpha_{ij}$ is the normalizing factor. In this case, the process finishes when executed $\max\{|\ \alpha_i(t+1)-\alpha_i(t)\ |\}\le\varepsilon$, where ε is the calculation error. As a result, in the 3rd approximation, the values of the weights of x_i are obtained as follows: $\alpha_1(3)=0.0350$; $\alpha_2(3)=0.0486$; $\alpha_3(3)=\ =0.1032$; $\alpha_4(3)=0.0723$; $\alpha_5(3)=0.1185$; $\alpha_6(3)=0.2447$; $\alpha_7(3)=0.1973$; $\alpha_8(3)=0.1183$; $\alpha_9(3)=0.0239$; $\alpha_{10}(3)=0.0384$.

To establish a weighted assessment of the creditworthiness of NP, the criterion $C=100\times[\sum_{i=1}^{10}\alpha_i e_i]\cdot[\max\{\sum_{i=1}^{10}\alpha_i e_i\}]^{-1}$ is used, where $\alpha_i=\alpha_i(3)$ is the weight of significance x_i; e_i is the consolidated expert assessment of x_i according to the 10-point scale. Another group of m experts was asked to evaluate ten NP a_k (k=1÷10) by the 10-point scale for their current solvency for each SI x_i (i=1÷10).

According to the test results, for NPs a_k (k=1÷10) the average estimates of SIs were obtained in accordance with the expression $avr_{ki}=(1/m)\sum_{j=1}^{m}e_{ij}^{k}$, where e_{ij}^{k} is the j-th expert's assessment given to him by the k-th NP relative to x_i. On the basis of these assessments and criterion C, weighted assessments of the creditworthiness of the NPs were determined and summarized in Table 3.

Table 3. Final weighted assessments of the NP creditworthiness

NP	Estimated SI										Final estimation
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	
	Corresponding weights of SIs										
	0.0350	0.0486	0.1032	0.0723	0.1185	0.2447	0.1973	0.1183	0.0239	0.0384	
a_1	8.46	4.88	3.68	4.99	5.09	4.24	9.95	7.04	4.74	2.88	59.33
a_2	3.56	2.40	5.54	9.06	5.55	7.12	9.82	8.67	3.45	3.86	70.60
a_3	4.95	7.52	6.33	2.19	3.49	5.92	9.86	5.45	4.63	2.56	60.11
a_4	5.25	4.50	3.00	3.07	2.44	5.56	6.12	3.78	3.17	5.86	45.38
a_5	4.27	0.45	3.02	6.84	9.39	7.18	2.98	6.02	6.03	8.30	56.09
a_6	9.83	8.23	8.22	7.81	9.08	1.56	4.78	4.96	5.03	7.88	55.66
a_7	2.82	8.26	4.12	6.55	8.55	6.54	7.97	2.26	5.55	3.66	61.24
a_8	2.00	9.73	3.59	5.25	9.02	6.55	4.37	2.86	6.11	6.56	55.62
a_9	5.90	3.56	3.00	3.78	5.14	5.07	6.39	8.16	7.54	2.45	53.12
a_{10}	3.30	9.58	7.07	4.25	7.65	5.97	6.57	9.15	4.23	7.24	67.42

Assuming the segment U = [0, 10] as a continuous universe, its fuzzy subsets are constructed that describe the criteria for assessing K_i (i=1÷10) relative to SIs x_i (i=1÷10), for example, such as HIGH (current and prospective cumulative net income), SUFFICIENT (volume of deposits), etc. In general, each criterion is interpreted in the form of FS:

$$K_i=\{\mu_{K1}(u_1)/u_1;\ \mu_{K2}(u_2)/u_2;\ \ldots;\ \mu_{K10}(u_{10})/u_{10}\}\ (i=1\div10),$$

where $\mu_{Ki}(u_j)$ (j=1÷10) is the MF value of the average estimate u_j of the FS K_i. The function $\mu_{Ki}(u_j)=\exp[-(u_j-10)^2/\sigma_i^2]$, $u_j\in U$ (i ,j=1÷10), where $\sigma_i^2=16$, is chosen as the MF. On the basis of expert assessments, the qualitative criteria for assessing K_i (i=1÷10) are described by following FS:

- HIGH (*current and prospective cumulative net income*) – K_1={0.8622/a_1; 0.0749/a_2; 0.2031/a_3; 0.2441/a_4; 0.1285/a_5; 0.9982/a_6; 0.0399/a_7; 0.0183/a_8; 0.3497/a_9; 0.0605/a_{10}};
- SUFFICIENT (*volume of deposits*) – K_2={0.1943/a_1; 0.0271/a_2; 0.6809/a_3; 0.1510/a_4; 0.0033/a_5; 0.8222/a_6; 0.8276/a_7; 0.9955/a_8; 0.0749/a_9; 0.9890/a_{10}};
- ACCEPTABLE (*loan security and its liquidity*) – K_3={0.0824/a_1; 0.2885/a_2; 0.4309/a_3; 0.0468/a_4; 0.0476/a_5; 0.8203/a_6; 0.1152/a_7; 0.0767/a_8; 0.0468/a_9; 0.5848/a_{10}};
- LOW (*indicator PTI*) – K_4={0.2083/a_1; 0.9463/a_2; 0.0221/a_3; 0.0497/a_4; 0.5357/a_5; 0.7410/a_6; 0.4753/a_7; 0.2441/a_8; 0.0891/a_9; 0.1266/a_{10}};
- LOW (*indicator OTI*) – K_5={0.2216/a_1; 0.2901/a_2; 0.0707/a_3; 0.0281/a_4; 0.9770/a_5; 0.9485/a_6; 0.8769/a_7; 0.9417/a_8; 0.2285/a_9; 0.7081/a_{10}};
- HIGH (*solvency indicator*) – K_6={0.1257/a_1; 0.5955/a_2; 0.3533/a_3; 0.2917/a_4; 0.6083/a_5; 0.0117/a_6; 0.4732/a_7; 0.4753/a_8; 0.2189/a_9; 0.3624/a_{10}};
- HIGH (*total financial position*) – K_7={0.9998/a_1; 0.9980/a_2; 0.9988/a_3; 0.3903/a_4; 0.0460/a_5; 0.1821/a_6; 0.7729/a_7; 0.1379/a_8; 0.4429/a_9; 0.4794/a_{10}};
- HIGH (*social stability*) – K_8={0.5783/a_1; 0.8953/a_2; 0.2742/a_3; 0.0891/a_4; 0.3716/a_5; 0.2044/a_6; 0.0237/a_7; 0.0413/a_8; 0.8093/a_9; 0.9558/a_{10}};
- SUITABLE (*age*) – K_9={0.1774/a_1; 0.0685/a_2; 0.1649/a_3; 0.0542/a_4; 0.3734/a_5; 0.2136/a_6; 0.2901/a_7; 0.3884/a_8; 0.6851/a_9; 0.1248/a_{10}};

- FAVORABLE (*credit history*) – K_{10}={0.0421/a_1; 0.0948/a_2; 0.0314/a_3; 0.3426/a_4; 0.8347/a_5; 0.7551/a_6; 0.0811/a_7; 0.4773/a_8; 0.0284/a_9; 0.6212/a_{10}}.

Assuming *y*="*The degree of solvency*" as the linguistic variable, the following implicative rules were chosen as a basis for assessing the current solvency of NP:

d_1: «If K_5=LOW и K_6=HIGH и K_7=HIGH и K_8=HIGH, then *y*=SATISFACTORY»;

d_2: «If K_2=SUFFICIENT и K_4=LOW и K_5=LOW и K_6=HIGH и K_7=HIGH и K_8=HIGH, then *y*=MORE THAN SATISFACTORY »;

d_3: «If K_1=HIGH и K_2=SUFFICIENT и K_3=ACCEPTABLE и K_5=LOW и K_6=HIGH и K_7=HIGH и K_8=HIGH и K_{10}=FAVORABLE, then *y*=VERY SATISFACTORY »;

d_4: «If K_1=HIGH и K_2=SUFFICIENT и K_3=ACCEPTABLE и K_4=LOW и K_5=LOW и K_6=HIGH и K_7=ВЫСОКОЕ и K_8=HIGH и K_9=SUITABLE и K_{10}=FAVORABLE, then *y*=PERFECT»;

d_5: «If K_2=SUFFICIENT и K_3=NOT ACCEPTABLE и K_4=LOW и K_5=LOW и K_6=HIGH и K_7=HIGH и K_8=HIGH и K_9=UNSUITABLE, then *y*=SATISFACTORY»;

d_6: «If K_3=UNACCEPTABLE и K_6=NOT HIGH и K_7=NOT HIGH и K_{10}=UNFAVORABLE, then *y*=UNSATISFACTORY».

Taking into account the formalisms adopted for the right-hand of the rules, the fuzzy inference system in symbolic form looks as:

d_1: $(x_5=K_5)$ & $(x_6=K_6)$ & $(x_7=K_7)$ & $(x_8=K_8)$ $\Rightarrow (y=S)$;

d_2: $(x_2=K_2)\&(x_4=K_4)\&(x_5=K_5)\&(x_6=K_6)\&(x_7=K_7)\&(x_8=K_8)\Rightarrow(y=MS)$;

d_3: $(x_1=K_1)\&(x_2=K_2)\&(x_3=K_3)\&(x_5=K_5)\&\ldots\&(x_8=K_8)\&(x_{10}=K_{10}) \Rightarrow (y=VS)$;

d_4: $(x_1=K_1)$ & $(x_2=K_2)$ & … & $(x_9=K_9)$ & $(x_{10}=K_{10}) \Rightarrow (y=P)$;

d_5: $(x_2=K_2)\&(x_3=\neg K_3)\&(x_4=K_4)\&(x_5=K_5)\&\ldots\&(x_8=K_8)\&(x_9=\neg K_9) \Rightarrow(y=S)$;

d_6: $(x_3=\neg K_3)$ & $(x_6=\neg K_6)$ & $(x_7=\neg K_7)$ & $(x_{10}=\neg K_{10}) \Rightarrow (y=US)$.

Realization of these rules in the usual manner gave fuzzy relations in the form of matrices R_1, R_2, …, R_6. As a result of their intersection, a common functional solution $R=R_1\cap R_2\cap \ldots \cap R_6$ was obtained, reflecting the

causal-effect relations between x_i and the aggregate assessment of the creditworthiness of the NP.

$$R = \begin{array}{c|cccccccccccc} & 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ \hline a_1 & 0{,}8743 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9579 & 0{,}9998 \\ a_2 & 0{,}7099 & 0{,}8099 & 0{,}9099 & 0{,}9729 & 0{,}9729 & 0{,}9729 & 0{,}9729 & 0{,}9729 & 0{,}9729 & 0{,}9729 & 0{,}9980 \\ a_3 & 0{,}9293 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9779 & 0{,}9988 \\ a_4 & 0{,}9719 & 0{,}9719 & 0{,}9719 & 0{,}9719 & 0{,}9719 & 0{,}8903 & 0{,}7903 & 0{,}6903 & 0{,}5903 & 0{,}4903 & 0{,}3903 \\ a_5 & 0{,}9540 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9967 & 0{,}9347 & 0{,}8347 \\ a_6 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9883 & 0{,}9203 & 0{,}8203 \\ a_7 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9763 & 0{,}9729 & 0{,}8729 & 0{,}7729 \\ a_8 & 0{,}9587 & 0{,}9817 & 0{,}9817 & 0{,}9817 & 0{,}9817 & 0{,}9773 & 0{,}8773 & 0{,}7773 & 0{,}6773 & 0{,}5773 & 0{,}4773 \\ a_9 & 0{,}7811 & 0{,}8811 & 0{,}9716 & 0{,}9716 & 0{,}9716 & 0{,}9429 & 0{,}8429 & 0{,}7429 & 0{,}6429 & 0{,}5429 & 0{,}4429 \\ a_{10} & 0{,}6376 & 0{,}7376 & 0{,}8376 & 0{,}9376 & 0{,}9395 & 0{,}9395 & 0{,}9395 & 0{,}9212 & 0{,}8212 & 0{,}7212 & 0{,}6212 \end{array}.$$

The generalized assessment of the solvency of the k-th NP a_k (k=1÷10) is interpreted by fuzzy subset of the universe {0, 0.1, 0.2, ..., 1} with the MF values from the k-th row of the matrix R. As a result of defuzzification of fuzzy conclusions, numerical estimates of the solvency levels of the declared NPs are obtained as follows: for a_1 – 0.5251; a_2 – 0.5370; a_3 – 0.5129; a_4 – 0.3976; a_5 – 0.4909; a_6 – 0.4881; a_7 – 0.4841; a_8 – 0.4234; a_9 – 0.4284; a_{10} – 0.4965. The holder of the highest grade has the highest degree of creditworthiness and, therefore, it is the most preferred borrower. In this case, it is NP a_2 with the estimate of 0.5370. Further, in descending order.

Assuming that the criteria K_i (i=1÷10) have equal degrees of importance, the rule for choosing the best borrower using the maxmin convolution method is: $K=K_1 \cap K_2 \cap ... \cap K_{10}$. The optimal alternative is found from the equality: $\max\{\mu_K(a_j)\}$={0.0421; 0.0271; 0.0221; 0.0281; 0.0033; 0.0117; 0.0237; 0.0183; 0.0284; 0.0605}. The maximum value 0.0605 of the 10-th component of the vector $\mu_K(a_k)$ tends to choose a_{10}. Further, in descending order: $a_1 \rightarrow 0.0421$; $a_9 \rightarrow 0.0284$; $a_4 \rightarrow 0.0281$; $a_2 \rightarrow 0.0271$; $a_7 \rightarrow 0.0237$; $a_3 \rightarrow 0.0221$; $a_8 \rightarrow 0.0183$; $a_6 \rightarrow 0.0117$; $a_5 \rightarrow 0.0033$.

The final results of assessing the creditworthiness of the declared NPs a_k (k=1÷10) by all methods are presented in Table 4, from which it can be seen that the results obtained using the method of weighted SI estimates and the method of fuzzy inference regarding the best and worst NP from the point of view of their current paying capacity coincide, and in all other cases the orders of the final estimates do

not coincide, but are relatively close. The results obtained by the maxmin convolution method are in complete contrast to the rest of the results, since this method does not take into account the priority of the indicators of the paying capacity of the NPs.

Table 4. Results of assessments of the creditworthiness of NPs

NP	Weighted Scoring		Fuzzy inference		Maxmin convolution	
	Estimate	Order	Estimate	Order	Estimate	Order
a_1	59.33	5	0.5251	2	0.0421	2
a_2	70.60	1	0.5370	1	0.0271	5
a_3	60.11	4	0.5129	3	0.0221	7
a_4	45.38	10	0.3976	10	0.0281	4
a_5	56.09	6	0.4909	5	0.0033	10
a_6	55.66	7	0.4881	6	0.0117	9
a_7	61.24	3	0.4841	7	0.0237	6
a_8	55.62	8	0.4234	9	0.0183	8
a_9	53.12	9	0.4284	8	0.0284	3
a_{10}	67.42	2	0.4965	4	0.0605	1

In addition to these studies, the expert community is discussing the influences of SIs x_i (i=1÷10) on the level of NP creditworthiness. In contrast to the previous case, experts are invited to assess the degree of influence of SI x_i on the values of the total creditworthiness indices of the NP by the 5-point scale: 5 – TOO STRONG; 4 - SIGNIFICANTLY STRONG; 3 – STRONG; 2 – WEAKLY; 1 – NOT SIGNIFICANT; 0 – TOO WEAKLY. Taking into account expert assessments of the influences x_i, 40 scenarios for the formation of weighted creditworthiness indices by the criterion

$$C = 100 \times [\sum_{i=1}^{5} \alpha_i e_i] \cdot [\max\{\sum_{i=1}^{5} \alpha_i e_i\}]^{-1}$$

where α_i is the previously established weight of the SI x_i; e_i is the consolidated expert assessment of the NP's creditworthiness from the point of view of the influence of x_i. (see Table 5).

In the case when quantitative estimates of the relative influence of the values x_i on the level of NP's creditworthiness do not raise doubts, the multivariate function F can be approximated by a three-layer feedforward neural network (see Fig. 3), which induces output signals of the form:

$$z_j = \sum_{k=1}^{r} c_k \varphi[w_{ki} x_{ij}) - \theta_k], \; i=1\div10, \; j=1\div40,$$

where r is the number of neurons in the hidden layer, selected by the user during the simulation; w_{ki} and c_k are the weights of the input and output relationships, respectively; θ_i is the threshold of the k-th nonlinear neuron from the hidden layer; $\varphi(\cdot)$ is the activation function of the nonlinear neuron, for example, sigmoidal type $\varphi(t)=1/[1+e^{-(t-\theta)}]$.

Table 5. Scenarios of the forming of NP creditworthiness indexes

Scenario	Estimated SIs										Index
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	
	Weights of SI										
	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	
	0.0350	0.0486	0.1032	0.0723	0.1185	0.2447	0.1973	0.1183	0.0239	0.0384	
1	0	0	0	0	0	0	0	0	0	0	0
2	0.45	0.34	0.29	0.12	0.09	0.09	0.13	0.40	0.11	0.41	3.88
…. …. …. …. …. ….											
39	4.86	4.80	4.88	4.93	4.94	4.95	4.76	4.81	4.76	4.99	97.47
40	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	100

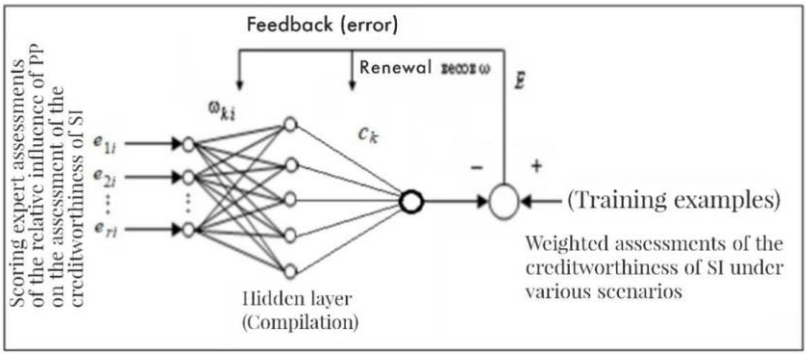

Fig. 3. Three-layer feedforward neural network

The problem under consideration and its solution look much more complicated, since in the general case, the very nature of SI x_i (i=1÷10) and the determination of their relative weights when summing the final indices of the NP's creditworthiness, remains the main problem of the quantitative method of assessment. For multifactorial assessment and ranking of NPs by the levels of their solvency, the fuzzy maxmin convolution method is implemented by weighted intersection of fuzzy sets in terms of K_i (i=1÷10) looks like $D = K_1^{\alpha_1} \cap K_2^{\alpha_2} \cap ... \cap K_{10}^{\alpha_{10}}$, where α_i are the generalized weights of SI x_i (i=1÷10) established above. As a result, the decision relative to the creditworthiness of the evaluated NPs is interpreted from the following expression: $\max\{\mu_D(e_j)\}$=max{0.2933; 0.6793; 0.4939; 0.1195; 0.5178; 0.6793; 0.2256; 0.2132; 0.3674; 0.4002}, meaning that the most solvent is NP a_6 with the estimate of 0.6793, followed by NP a_2 with the same estimate of 0.6793 and further in descending order: a_5 (0.5178), a_3 (0.4939), a_{10} (0.4002), a_9 (0.3674), a_1 (0.2933), a_7 (0.2256), a_8 (0.2132) и a_4 (0.1195).

The final results of assessing the creditworthiness of the NPs a_k (k=1÷10) by all methods are presented in Table 6. Ordinal estimates obtained using all three methods completely coincide relative to the solvency of the sixth and second NPs. In other cases, insignificant and/or significant differences are not fundamental, since the solution to the problem is to find the most solvent NP.

Table 6. Results of assessments of the NP creditworthiness

NP	Weighted Scoring		Neural network		Weighted Maxmin convolution	
	Estimate	Order	Estimate	Order	Estimate	Order
a_1	42.11	10	41.43	10	0.2933	7
a_2	67.31	2	68.06	2	0.6793	2
a_3	56.42	6	59.82	6	0.4939	4
a_4	47.79	7	60.43	5	0.1195	10
a_5	66.64	4	66.38	3	0.5178	3
a_6	72.77	1	82.91	1	0.6793	1
a_7	46.07	8	53.72	8	0.2256	8
a_8	44.89	9	54.45	7	0.2132	9
a_9	66.68	3	65.72	4	0.3674	6
a_{10}	59.10	5	52.33	9	0.4002	5

In the fourth chapter, a method of implementing a fuzzy inerence system for assessing the creditworthiness of NP based on a generalized neural network model is considered. The proposed hybrid model supports the ideology of fuzzy inference in the neural-network logical basis and is a key link in the formation of an information system for supporting the process of lending to NP.

The calculation of a personal assessment of the creditworthiness of NPs requires structural and parametric optimization of the fuzzy inference system, formalized in the form of the above logical rules. For this, the MATLAB\ANFIS editor was used.

For this purpose, a training set was loaded, composed of scenarios for assessing the creditworthiness of forty hypothetical NPs, which ensured the generation of a neural network structure (Fig. 4).

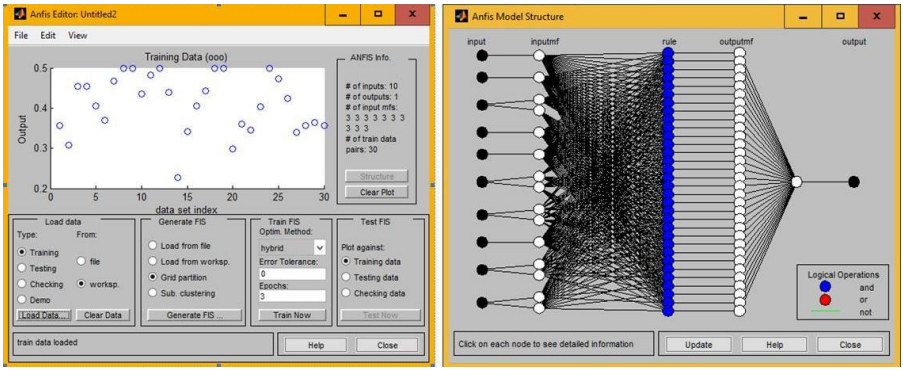

Fig. 4. Fuzzy inference generation in the neural network basis

After applying the supervisory hybrid training method, which is a combination of the least squares method and the method of decreasing the inverse gradient, structural and parametric optimization of the fuzzy inference system, specified at the initial stage in the form of implicative rules $e_1 \div e_6$ was carried out.

As a result of training, the system generated 1024 implicative rules, the graphical interface for viewing the functioning of which is shown in Fig. 5.

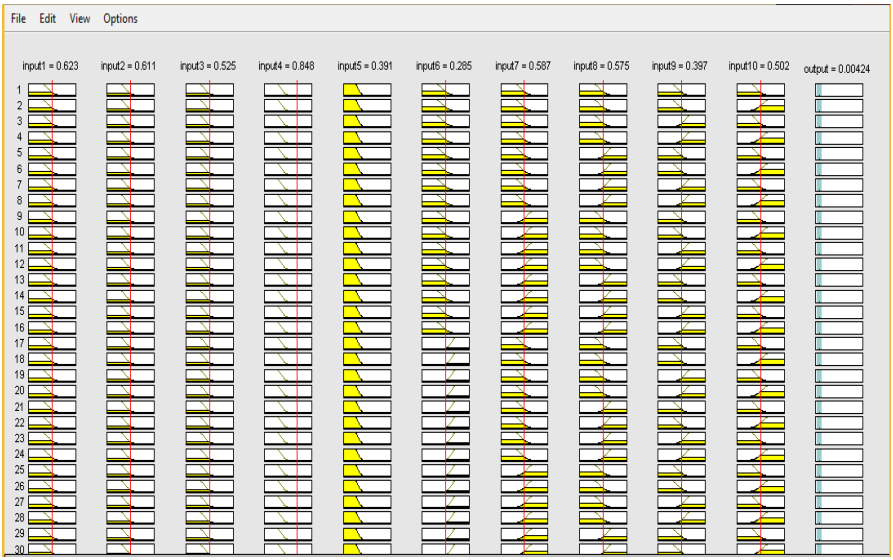

Fig. 5. Graphical interface of fuzzy inference system

Starting from the fuzzy paradigm, an information support system for credit decision-making process is proposed for the integral assessment of the creditworthiness of NPs, which combines both expert assessments and some fuzzy models of multi-criteria assessment of alternatives. In continuation of this, the structure of the analytical core is proposed for the information system for supporting the credit decision-making. The structure of the analytical core of the information system, which includes all the developments described above regarding the assessment of the creditworthiness of NPs is shown in Fig. 6.

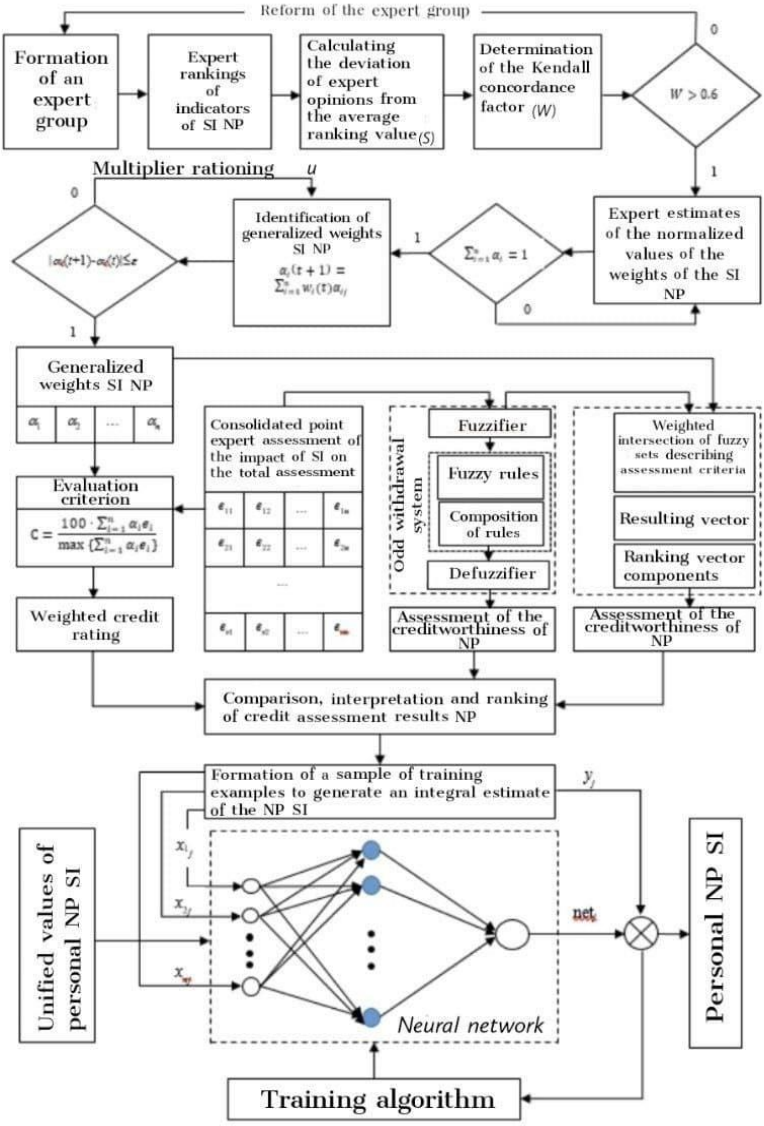

Fig. 6. The structure of the analytical core of support system

THE MAIN RESULTS

The main scientific results presented for the defense are formulated in the form of the following statements:

- taking into account the world experience in the field of bank lending, a system of solvency indicators was formed for a multi-criteria assessment of the creditworthiness of individuals, as potential customers of borrowed funds of a commercial bank;
- methods of fuzzy inference and fuzzy maximin convolution have been developed and tested for assessing the creditworthiness of individuals, providing for complex processing of available information, including weakly structured factors of financial stability of potential borrowers; разработаны и апробированы методы нечёткого вывода и
- formulated and tested an expert approach to the issue of identifying the specific weights of the relative influence of the indicators of the solvency of individuals;
- the expert system has been developed for a balanced assessment of the creditworthiness of individuals and their ranking in relation to the levels of solvency;
- the compilation of expert knowledge regarding the creditworthiness of individuals was carried out using a fuzzy inference system and a fuzzy method of weighted maxmin convolution;
- the method has been developed for assessing the creditworthiness of individuals through the integration of expert knowledge in the logical basis of a neural network;
- it has been developed the method for compiling expert knowledge on the creditworthiness of individuals using a hybrid (neuro-fuzzy) modeling system;
- it has been formed the structure of the analytical core for the build the information support system for credit decision-making.

The main results of the dissertation are published in the following scientific articles:

1. Алиев, А.А. Анализ платёжеспособности физического лица на основе оценки его информационного профиля из доступных источников интернета // - Баку: Вестник Бакинского Университета, - 2016. №3, - С. 96-104.
2. Рзаев, Р.Р., Алиев, А.А. Оценка кредитоспособности физических и юридических лиц в условиях неопределенности // Материалы X международной научно-практической конференции «Интернет–Образование-Наука» (ИОН-2016), - Винница: - 11-14 октября, - 2016, - С. 2-4.
3. Rzayev, R.R., Aliyev, A.A. Estimation of credit borrowers solvency using fuzzy logic // Journal of Automation and Information Sciences. Begell House, - 2017. Vol. 49, №2, - P. 70-84.
4. Рзаев, Р.Р., Алиев, А.А. Оценка кредитоспособности физического лица на основе нечеткого анализа его платежеспособности // - Москва: Системы и средства информатики, - 2017. Том 27, №3, - С. 202-218.
5. Алиев, А.А. Комплексная оценка кредитоспособности физических лиц на основе нечеткого анализа их показателей платёжеспособности // Doktorantların və gənc tədqiqatçıların XXI Respublika elmi konfransının materialları, - Bakı: - 24-25 oktyabr, - 2017, - S. 16-18.
6. Кравец, О.Я., Алиев, А.А. Информационная поддержка процесса кредитования физических лиц на основе нейро-нечёткой системы моделирования // - Воронеж: Экономика и менеджмент систем управления, - 2017. №4.3(26), - С. 364-372.
7. Алиев, А.А. Оценка текущей кредитоспособности физических лиц на основе экспертных оценок их показателей платежеспособности // - Киев: Математические машины и системы, - 2018. №2, - С. 119-132.
8. Aliyev, A.A. Credit surveillance of an individual in the logical basis of the neural network // Proceedings of the XXIV-th International Open Science Conference “Modern Informatization Problems in Economics and Safety”, - Yelm, WA, USA: - January, - 2019, - P. 9-16.

9. Алиев, А.А. Комбинированный подход к оценке кредитоспособности физических лиц с применением многослойных нейронных сетей // - Баку: Вестник Бакинского Университета, - 2019. №1, - С. 112-122.
10. Rzayev, R.R., Aliyev, A.A. and Kravets O.Ja. Credit rating of natural person by expert knowledge compilation in logic basis of neural networks // IOP Conference Series: Materials Science and Engineering, - 2019. Vol. 537, 042028.
11. Aliyev, A.A. Credit rating of natural person using MATLAB\ANFIS // Материалы III международной научно-практической конференции «Прикладные системы и технологии в информационном обществе», - Киев: - 30 Сентября, - 2019, - С. 197-201.
12. Aliyev, A.A. Multi-factor evaluation of natural person solvency by expert knowledge integration //Journal of Automation and Information Sciences. Begell House, - 2020. Vol.52, №3, P. 65-76.

Personal contribution of the applicant to the works published in co-authorship:

[2] Analysis of financial stability indicators, the formation on their basis of criteria for assessing the creditworthiness of legal entities and individuals and the development of standard fuzzy models for assessing the current creditworthiness of potential borrowers.

[3] Development of a methodology for the formation of the scale of gradation of creditworthiness levels of individuals and fuzzy assessment methods with the use of the fuzzy inference system and maxmin convolution of equivalent assessment criteria.

[4] Development of fuzzy models for ranking NPs according to the levels of their current creditworthiness.

[6] Development of the neural network model for assessing the current creditworthiness of individuals, characterized by quantitative and qualitative indicators of their solvency.

[10] Development of the expert system for the formation of expert knowledge relative to influence of solvency indicators on the creditworthiness levels of individuals and the compilation of this knowledge by neural network models.

The defense will be held on 17 december 2021 at 16^{00} at the meeting of the Dissertation council ED 1.20 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Institute of Control Systems of ANAS.

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Dissertation is accessible at the Institute of Control Systems of ANAS Library.

Electronic version of dissertation and its abstract are available on the official website (http://www.isi.az) of the Institute of Control Systems of ANAS.

Abstract was sent to the required addresses on 15 november 2021.

Signed for print: 12.11.2021

Paper format: A5

Volume: 38468 characters

Number of hard copies: 20