УДК 005.96:005.336
DOI: 10.32342/2074-5354-2024-1-60-14

L. HARMIDER,
Doctor of Science (Economics), Professor, Head of the Department of Entrepreneurship, Theoretical and Applied Economics,
SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine)
orcid.org/0000-0001-7837-2734

L. KOROTKA,
PhD (Eng.), Associate Professor of the Department of Information Systems,
SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine),
orcid.org/0000 -0003-0780-7571

S. BAZHAN,
PhD (Ped.), Associate Professor of the Department of Philosophy and Ukrainian Studies,
SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine)
orcid.org/0000-0002-5739-4616

D. ANISKEVICH,
Director of the company, «Platinum Electric» LLC, Dnipro (Ukraine)
orcid.org/0009-0005-8168-5965

THE APPLICATION OF FUZZY SETS THEORY IN THE METHODOLOGICAL APPROACH TO ASSESSING PERSONNEL RISKS OF AN ENTERPRISE

The main idea of this paper is the substantiation of the methodological approach to the assessment of personnel risks of enterprises based on the application of the fuzzy logic apparatus in order to identify the problems of personnel risk management and provide appropriate recommendations for their solution. The methodological basis of the study is the classic provisions and fundamental works of foreign and domestic scientists, statistical data, the results of our research into the problems of assessing personnel risks of enterprises. The methods of fuzzy set theory, comparative analysis, scientific abstraction, generalization of scientific experience of modern theoretical research, system-complex approach were used.

The study proposed a methodological approach to assessing the level of personnel risks of an enterprise; numerical experiments were conducted on the basis of a group of construction equipment manufacturers. Analysis of the results of assessing the level of personnel risks of enterprises made it possible to identify the problems of managing personnel risks at enterprises. The proposed methodological approach to assessing the level of personnel risks of enterprises based on the apparatus of fuzzy logic allows, in contrast to existing ones, to integrate the consideration of both qualitative and quantitative indicators when assessing the level of personnel risks and personnel movement indicators and to significantly increase the efficiency of decision-making under conditions of uncertainty and reduce costs in the event of adverse situations. Using in practice a methodological approach to assessing the level of personnel risks of enterprises based on the apparatus of fuzzy logic allows us to analyze the level of personnel risk as a multi-element object that is closely related to the structured functioning of the enterprise and its capabilities; and expands the original basis for conclusions, which provides a more accurate assessment of the level of personnel risk and making a reasoned decision to reduce its level.

Keywords personnel risk, enterprise, theory of fuzzy sets, assessment, methodological approach
JEL classification: ***C69, C89, M12, M14***

Основною ідеєю статті є обґрунтування методологічного підходу до оцінювання кадрових ризиків підприємств на основі застосування апарату нечіткої логіки з метою виявлення проблем управління кадровими ризиками та надання відповідних рекомендацій щодо їх вирішення. Методологічною основною дослідження є класичні положення та фундаментальні праці зарубіжних і вітчизняних учених, статистичні дані, результати авторських досліджень проблем оцінки кадрових ризиків підприємств. Використані методи теорії нечітких множин, порівняльного аналізу, наукової абстракції, узагальнення наукового досвіду сучасних теоретичних досліджень, системно-комплексний підхід. В дослідженні запропоновано методологічний підхід до оцінювання рівня кадрових ризиків підприємства, проведені чисельні експерименти на базі груп підприємств-виробників будівельного обладнання. Аналіз результатів оцінки рівня кадрових ризиків підприємств дозволив визначити проблеми управління кадровими ризиками на підприємствах. Запропонований методологічний підхід до оцінювання рівня кадрових ризиків підприємств на базі апарату нечіткої логіки дозволяє, на відміну від існуючих, інтегрувати облік як якісних і кількісних показників при оцінці рівня кадрових ризиків, так і показників руху, а також істотно підвищити ефективність ухвалення рішень в умовах невизначеності і понизити витрати при виникненні несприятливих ситуацій. Використання в практичній діяльності методологічного підходу до оцінювання рівня кадрових ризиків підприємств на базі апарату нечіткої логіки дає можливість аналізувати рівень кадрового ризику як багатоелементний об’єкт, який тісно пов’язаний зі структурованістю функціонування підприємства та його можливостями; та розширює вихідну базу висновків, що забезпечує більш точне оцінювання рівня кадрового ризику та прийняття обґрунтованого рішення щодо зменшення його рівня.

Ключові слова: кадровий ризик, підприємство, теорія нечітких множин, оцінка, методологічний підхід
JEL classification: ***C69, C89, M12, M14***

Introduction. The task of assessing the personnel risks of an enterprise is quite complex due to the large amount of fragmented numerical data, in some cases incomplete, which complicates the analysis done by generally accepted quantitative methods. In addition, linguistic interpretation uses qualitative characteristics that are difficult to interpret quantitatively. Attention should also be paid to such an issue as the construction of a universal, intelligent system for assessing personnel risks of an enterprise. All existing changes and additions to the company’s personnel risk assessment model are aimed only at changes and additions, related to the modernization of the already existing principle of assessment procedures. But solving complex, integrated problems requires the application of greater knowledge than was used in their formation. At the same time, the emergence of suprasystemic contradictions is observed – such as, for example, the contradiction of the efficiency of macro- and microeconomies. Their solution is characterized by the use of methods from other sciences, not related to the science in which the current problems arose. To build a model of adequate reality, which uses a large amount of disconnected numerical data, fuzzy logic provides an effective means for reflecting the uncertainties and inaccuracies of the real world. The availability of mathematical tools for displaying the vagueness of the initial information makes it possible to build a model that is adequate to reality. Fuzzy set theory (FST) is a generalization and reinterpretation of the most important areas of classical mathematics, which, since the time of Plato and Aristotle considered logically sound deductive methods of drawing conclusions to be exclusively scientific. The origins of FST date back to the ideas and achievements of multi-valued logic, which pointed the possibility of transition from two to an arbitrary number of truth values and set the task of solving the problem of operating with concepts with changing content, characteristic of systems that are difficult to submit to strict deduction.

Analysis of recent publications. Theoretical and methodological aspects of risk management within an organization are considered in the works of V. Kovalenko [1], O. Losheniuk [2], S. Semenova [3], S. Spivak [4]. The issue of the essence and classification of personnel risk and the peculiarities of its occurrence were investigated by T. Bilorus [5], S. Mishina, O. Mishyn [6], etc. Methodical approaches to the assessment of personnel risks are given in the studies by V. Proskura, R. Bilak [7], I. Iepifanova, L. Tkachuk [8], V. Kurepin [9]. Despite a significant body of research on risk management, the issue of personnel risk management has not received wide coverage in the specialized literature. This is due, first of all, to the high level of informational and behavioral uncertainty inherent in humans as the most complex object of management.

Currently, there are various methods and approaches to the assessment of economic risks: statistical, expert, calculation-analytical, analogy, cost feasibility analysis, and combined [10].

To eliminate this or that problem, scientists propose various systems of indicators and methods for assessing a company's personnel risks, taking into account various factors. Our review of the above scientific works led to the conclusion that the existing evaluation methods do not take into account the fact that a modern enterprise is a complex socio-economic system; this substantiates the feasibility and necessity of using a systematic approach in the evaluation process, based on a systematic analysis, which requires phased implementation. Existing models and approaches are characterized by an insufficient range of analyzed factors that are selected to describe the impact on the level of personnel risk; subjectivity in the selection, ranking and evaluation of the studied personnel risk parameters, which can lead to a significant decrease in the accuracy of the result; the lack of formalized approaches to obtaining their cardinal estimates; the weakness of the dynamic component of labor potential analysis and support for making specific managerial decisions.

According to all the above criteria, the application of the theory of fuzzy sets for devising a procedure for assessing the labor potential appears to be extremely promising.

Therefore, **the purpose of the study** is to justify the methodological approach to assessing the level of personnel risks of enterprises based on the application of the fuzzy logic apparatus, which makes it possible to increase the validity of relevant management decisions regarding increasing the level of use of labor potential.

In the scientific literature, there are papers on the application of the theory of fuzzy sets in various fields of human activity (political, social, and economic processes, medicine, etc.) [11]. In this regard, in our opinion, it is expedient to use linguistic variables [11], i.e., variables whose values are not numbers but words in a natural or formal language, when assessing personnel risk. This paper proposes a model for assessing the level of personnel risk of an enterprise using the apparatus of fuzzy sets.

In various subject areas, when modeling processes with multifactorial dependencies with linguistic uncertainties and the need to operate with both qualitative and quantitative estimates of input data, fuzzy knowledge bases (FDB) are widely used. The quality of operation of such systems depends on the methods of formalizing incomplete information, a complete or numerically complete base of rules and, in fact, on the choice of fuzzy logic derivation algorithm.

The design of fuzzy systems involves the use of various models of fuzzy knowledge bases [12–15]. In this work, special attention will be paid to the construction of a rule base, which is the basis of any knowledge base. As is known, the basis for constructing production models of knowledge representation are products. Traditional approaches to building, setting up and working with a rule base include approaches [16] that rely on the experience of experts or a direct automated method. Of course, using only expert experience when constructing rules is associated with some difficulties in formalizing such information. It is necessary to carry out a qualitative separation of input information in the workspace and formalize it.

When designing fuzzy systems, it is necessary to determine both the storage of the data to be formalized and the base of rules based on the processed data. Obviously, the division of input information should be performed in an optimal way, the quality of the constructed fuzzy model will depend on this. As noted in works [14], there are requirements for models (including vague ones): interpretability of behavior and its adequacy. This is what the Zadeh's principle of incompatibility is based on: high accuracy is incompatible with high complexity of the system, that is, the complexity of the system and the accuracy with which it can be analyzed are inversely proportional to the first approximation [11]. This principle implies that as the size and complexity of the system increases, its modeling with the help of known mathematical expressions becomes significantly more difficult.

There is no doubt that the successful development and design of fuzzy knowledge bases, as the basis of fuzzy systems, is the quality of the knowledge base, to which the requirements are imposed: the degree of deviation of the results of fuzzy inference from experimental data [13]. At the same time, there is an issue of balance between the optimal number of rules and the accuracy of the designed system. This issue is fundamental in determining the compactness of the knowledge base and the accuracy of the system. In economic science, it is difficult to overestimate the use of fuzzy mathematics and fuzzy derivation technologies [17, 18].

Statement of a mathematical problem.

The work considers hierarchical fuzzy data, namely: four groups of indicators for assessing the level of personnel risks (quantitative composition – F_1, state of qualifications and intellectual potential – F_2, staff turnover – F_3, motivational system – F_4), each of the indicators has a different number of fuzzy coefficients (there are twelve of them in the current work – v_i, $i=1\div12$). Indicators are functions of fuzzy coefficients: $F_1 = r(v_1, v_2, v_3)$; $F_2 = g(v_4, v_5, v_6, v_7)$; $F_3 = h(v_8, v_9, v_{10})$; $F_4 = q(v_{11}, v_{12})$. As an output variable, there is a functional – an integrated indicator $Int = f(F_1, F_2, F_3, F_4)$ of the personnel risk level, which, in turn, is also a fuzzy value. Here, the functions r, g, h, q, f are unknown functions of the given variables.

The structural diagram of input and output data can be represented as follows (Fig. 1).

The structural diagram of personnel risk assessment can be represented as follows (Fig. 2):

We have expert evaluations of the change in all input data; as a rule, they vary within three terms: Low (I), Medium (G), High (E). Formalized information on each variable can be written as $\{(v_i, \mu(v_i)), i = 1 \div 12\}$, then for a group of indicators we have: $\{(F_j, \mu(F_j)), j = 1 \div 4\}$. Of course, for an integrated indicator, with a built-in knowledge base and applying a fuzzy logical derivation of a hierarchical fuzzy system, we can obtain a defuzzified clear value with an expert's degree of confidence.

Utilizing a fuzzy system and performing calculations with its help requires the system to have the following structural elements: membership functions of input and output variables, a rule base, and an output mechanism. These structural elements are the components that will be built when designing a fuzzy system.

In order to build a knowledge base, it is necessary to construct its basis, that is, a base of rules that specify cause-and-effect relationships between the fuzzy values of its input data and the output integrated indicator. Various types of activation functions were used as membership functions to describe the terms of fuzzy sets, in particular, direct methods of constructing membership functions were applied based on expert evaluations.

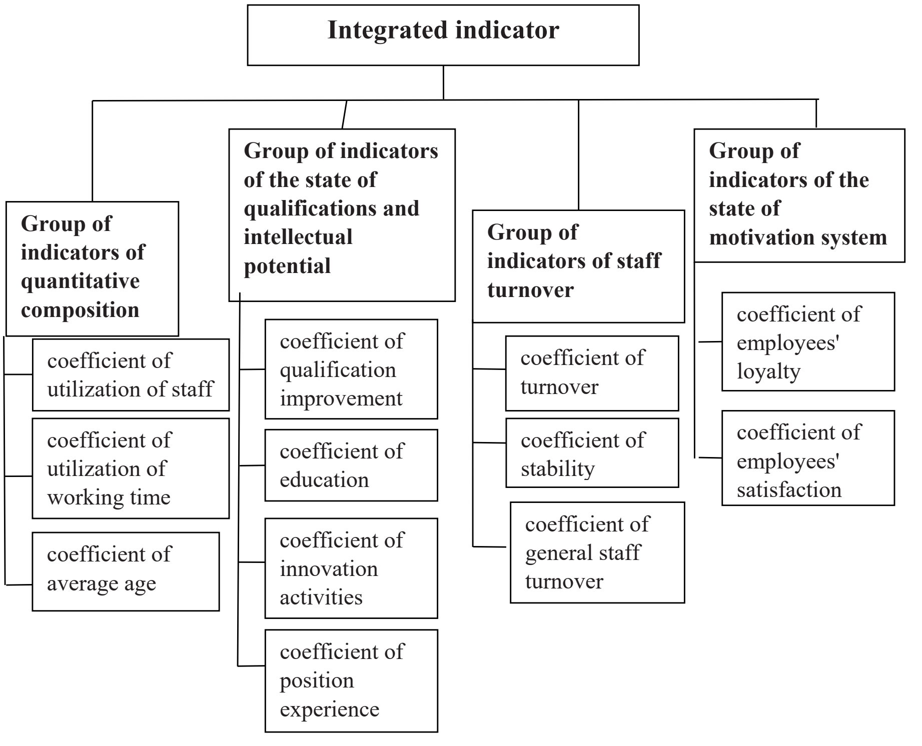

Fig. 1. Block diagram of relationships between fuzzy data
(*developed by the authors*)

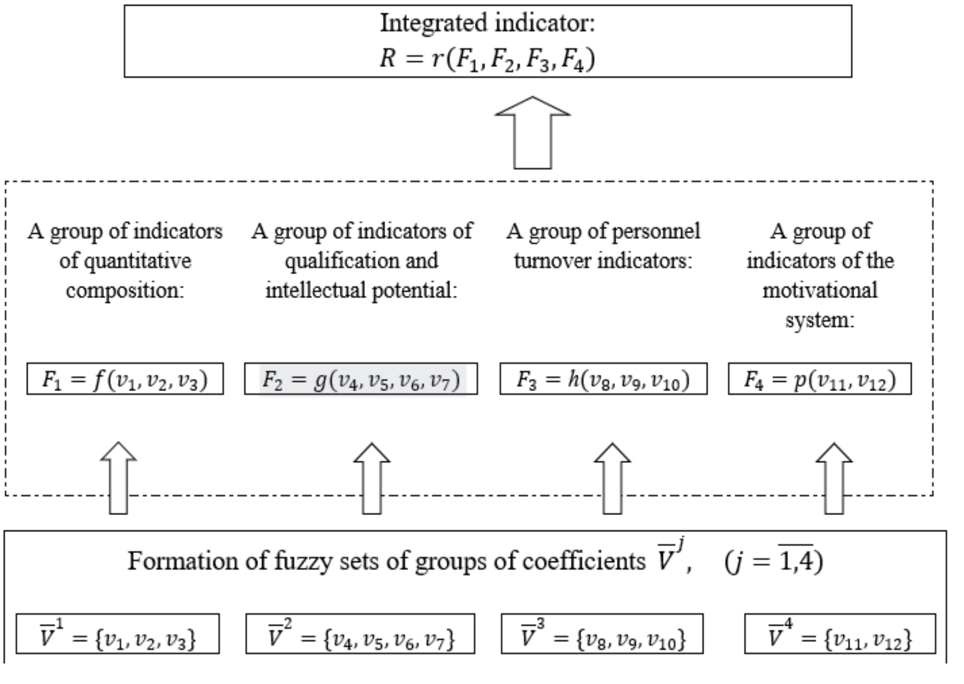

Fig. 2. Structural presentation of the HR risk assessment model
(*developed by the authors*)

It is known that the rule base must contain basic information about the system being modeled. It is possible to correctly and completely describe the system with the help of rules, but this process requires retraining and adjusting the rules. Therefore, special requirements are imposed on the rule base. We believe that these points should be considered separately. The rule base can have the following properties, which were taken into account when building the products: the local nature of the rules; dependence of the number of rules on the number of fuzzy sets in the model; completeness of the model; non-contradiction of rules; connectivity and redundancy of the rule base [19].

Checking for the locality of the rules should take place at the stage of designing and configuring the fuzzy system, namely: it is necessary to monitor situations when changing the conclusion of the rule leads to local changes in the model, i.e., to changes adjacent to the reference point specified by the rule in the state space of the system, while other segments are not affected by this conclusion.

As the complexity of a system increases, the number of rules and fuzzy sets can increase, resulting in an improved ability to describe the real system. In the case of fuzzy modeling, it is advisable to use reasonable boundaries for the level of complexity of the model and highlight the points that lead to its complexity.

Obviously, with a non-hierarchical approach, the total number of rules will be as follows:

$$rules = k^{var},$$

where k is the number of terms of each fuzzy set; in the current work, their maximum number was three; *var* is the number of system input variables, which is a total of twelve.

Of course, such an approach is irrational, so in this work we are planning a hierarchical approach that involves building rules for each indicator, and then for the entire system as a whole. This approach makes it possible to reduce the number of rules to one hundred.

The completeness of the model, consistency, coherence, and redundancy of the rule base are checked in the work in the process of tuning and training the knowledge base.

The formal notation of the hierarchical rule base can be represented as:

IF $T(F_1)\& T(F_2)\& T(F_3)\& T(F_4)$, THEN $T(Int)$,

where T is the value of the corresponding term, which can take the following values: Low (I), Medium (G), High (E). The values of the terms $T(F_i)$ ($i=1 \div 4$) are obtained at the previous level, for example, for the second indicator:

IF $t(v_1)\& t(v_2)\& t(v_3)\& t(v_4)$, THEN $t(F_2)$,

where t is the value of the corresponding term, which can take the following values: (I), (G), (E).

We can assume that the knowledge base has been built. Next, the designer of the fuzzy system faces other questions regarding the elements of the fuzzy model, such as the derivation mechanism, aggregation of conditions, and defuzzification operations (that is, the choice of the method of reduction to a clear number).

Without limiting judgment, this paper used the max-min derivation mechanism and the min-max principle of aggregation. Regarding defuzzification methods, several methods were considered: centroid, bisector, and method of moments, which are well-known and well-described [11, 18] (1) to (3).

$$x_{def} = \frac{\int_{\underline{x}}^{\bar{x}} x\mu(x)dx}{\int_{\underline{x}}^{\bar{x}} \mu(x)dx} \tag{1}$$

$$\int_{\underline{x}}^{x_{def}} \mu_X(x)dx = \int_{x_{def}}^{\bar{x}} \mu_X(x)dx \tag{2}$$

$$x_{def} = \frac{\int_G x dx}{\int_G dx} \tag{3}$$

The personnel potential of a group of construction equipment manufacturers (Dnipro, Ukraine) was chosen as an object of simulation:

– “Platinum Electric” LLC;
– SK DP Bud LLC;
– Budivelnyk V LLC;
– Golden Line Ukraine LLC.

Table 1 provides data for constructing a model for assessing threats to personnel security of the enterprises under study.

Results of numerical experiments.

Table 2 shows the limits of change in input data to the fuzzy system.

The results of numerical experiments given in Table 3, were obtained as a result of simulation modeling with a fuzzy model. Mamdani’s algorithm was used as a fuzzy logic derivation algorithm. The experimental results are given for different values of the terms of the initial variable – the integrated indicator. In Table 3, only the input and output values of the variables are given, the intermediate results of the hierarchical system are not given due to their bulkiness, but the values of the terms of these variables are given.

The results of numerical experiments allow us to build matrices for assessing threats to personnel security of the enterprises under study.

One of the options for representing input information in the form of an input data evaluation matrix is given in Table 4.

Table 1

Initial data for building a model for evaluating personnel risks of the enterprises under study

Index		Golden Line Ukraine LLC			SK DP Bud LLC			Budivelnyk V LLC			«Platinum Electric» LLC		
		2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
v_1	Payroll utilization rate	0,93	0,86	0,96	0,90	0,84	0,86	0,92	0,87	0,93	0,90	0,90	0,89
v_2	Working time utilization rate	0,97	0,83	0,98	0,91	0,76	0,91	0,80	0,79	0,95	0,92	0,95	0,98
v_3	Average age coefficient	45,2	45,1	45,9	39,5	36,9	41,9	39,2	42,3	45,5	31,8	36,9	37,7
v_4	Coefficient of advanced training	0,46	0,68	0,63	0,15	0,58	1,07	0,97	0,64	0,48	2,04	1,11	1,66
v_5	Education coefficient	2,2	2,4	2,4	1,6	1,8	2,0	3,6	3,8	3,6	0,6	0,6	0,8
v_6	Coefficient of inventive activity	4,6	3,6	3,3	6,3	4,4	3,7	3,3	2,5	1,8	16,7	16	10
v_7	Job experience ratio	2,2	2,4	2,4	1,6	1,8	2,0	3,6	3,8	3,6	2,04	1,11	1,66
v_8	Turnover rate	0,19	0,26	0,17	0,16	0,28	0,20	0,28	0,26	0,13	0,21	0,20	0,23
v_9	Stability factor	0,87	0,74	0,83	0,81	0,67	0,89	0,71	0,63	0,83	0,80	0,88	0,85
v_{10}	The coefficient of total personnel turnover,	0,19	0,26	0,17	0,16	0,28	0,2	0,28	0,26	0,13	0,21	0,20	0,23
v_{11}	Employee loyalty ratio	0,74	0,70	0,75	0,81	0,77	0,80	0,70	0,73	0,76	0,82	0,85	0,85
v_{12}	Employee satisfaction ratio	0,71	0,77	0,72	0,88	0,74	0,85	0,67	0,70	0,73	0,79	0,82	0,82

Source: authors’ calculations *based on the* enterprises data

Table 2

Fuzzy system input

Input	Values of terms and limits of change of variables		
	Low (I)	Medium (G)	High (E)
Group of indicators of quantitative composition, F_1			
Payroll utilization rate, v_1	less 0,7	0,71-0,77	larger 0,77
Working time utilization rate, v_2	less 0,89	0,90-0,94	larger 0,94
Average age coefficient, v_3	18-24	25-45	>45
Group of indicators of the state of qualification and intellectual potential, F_2			
Coefficient of advanced training, v_4	less 0,2	0,3-0,7	larger 0,7
Education coefficient, v_5	less 0,5	0,5-0,7	larger 0,7
Coefficient of inventive activity, v_6	less 15	15-30	larger 30
Job experience ratio, v_7	less 3	3-5	larger 5
Group of employee turnover indicators, F_3			
Turnover rate, v_8	less 0,10	0,10-0,15	larger 0,15
Stability factor, v_9	less 0,89	0,90-0,95	larger 0,95
The coefficient of total personnel turnover, v_{10}	less 0,12	0,13-0,19	larger 0,19
Group of indicators of the state of the motivational system, F_4			
Employee loyalty ratio, v_{11}	less 0,70	0,70-0,90	larger 0,90
Employee satisfaction ratio, v_{12}	less 0,60	0,70-0,80	larger 0,90

Source: authors' calculations

Table 3

Results of numerical experiments

Input variables (term):											
v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}
0,095 (I)	0,331 (I)	21,34 (G)	0,263 (G)	0,371 (I)	13,98 (I)	1,991 (I)	0,144 (G)	0,371 (I)	0,144 (G)	0,233 (I)	0,280 (I)
F_1 *(I)*			F_2 *(I)*				F_3 *(I)*			F_4 *(I)*	
The value of the original variable (term) – the method of defuzzification:											
Int_{def} *= 0,214 (I)* – centroid method; Int_{def} *= 0,210 (I)* – bisector method; Int_{def} *= 0,175 (I)* – method of moments.											
Input variables (term):											
v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}
0,5 (I)	0,836 (I)	34,01 (G)	0,353 (G)	0,647 (G)	27,16 (G)	4,405 (G)	0,140 (G)	0,728 (I)	0,167 (G)	0,785 (G)	0,868 (E)
F_1 *(G)*			F_2 *(G)*				F_3 *(G)*			F_4 *(G)*	
The value of the original variable (term) – the method of defuzzification:											
Int_{def} *= 0,519(G)* – centroid method; Int_{def} *= 0,52(G)* – bisector method; Int_{def} *= 0,05 (G)* – method of moments.											
v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}
0.733 (G)	0.974 (E)	37.03 (G)	0.509 (G)	0.922 (E)	43.53 (E)	3.5 (G)	0.026 (I)	0.816 (I)	0.143 (G)	0.802 (G)	0.974 (E)
F_1 (G)			F_2 *(E)*				F_3 *(G)*			F_4 *(E)*	
The value of the original variable (term) – the method of defuzzification:											
Int_{def} *= 0,843 (E)* – centroid method; Int_{def} *= 0,86 (E)* – bisector method; Int_{def} *= 0,975 (E)* – method of moments.											

Source: authors' calculations

According to Table 4, for example, two high (E) values (v_1 - payroll utilization rate, v_2- working time utilization rate) and one (v_3 - average age coefficient) medium (G) make it possible to obtain a high (E) level of the general indicator (F_1- group of indicators of quantitative composition) or two medium (G) values (v_8 - turnover rate, v_9 - stability factor) and one (v_{10} - the coefficient of total personnel turnover) low (I) make it possible to obtain a medium (G) level of the general indicator (F_3 - group of employee turnover indicators).

The evaluation matrix of the integral indicator (R) is built on the same principle as the input data evaluation matrix. For example, two high (E) values (F_1- group of indicators of quantitative composition, F_2 - group of indicators of the state of qualification and intellectual potential) and two (F_3 - group of employee turnover indicators, F_4- group of indicators of the state of the motivational system) medium (G) make it possible to obtain a high level of the integral indicator (R), that is, the level of threats to personnel security is low.

Thus, we obtain a fuzzy base of logical inference rules (Table 5).

The assessment of personnel security risks is carried out on the basis of the obtained fuzzy base of rules for logical inference (Table 5).

Table 4

Input data evaluation matrix

v_1	v_2	v_3	F_1	v_4	v_5	v_6	v_7	F_2	v_8	v_9	v_{10}	F_3	v_{11}	v_{12}	F_4
E	E	G	E	E	E	E	E	E	I	E	I	E	E	G	E
E	G	G		G	G	G	G		G	E	G		E	E	
G	E	G		G	E	E	G		I	G	I		G	E	
E	E	E	G	G	E	G	G	G	G	I	G	G	G	E	G
G	G	G		G	G	G	G		G	G	I		G	G	
E	E	E		G	G	G	B		I	I	G		E	G	
I	I	I	I	I	I	I	G	I	G	I	G	I	I	I	I
I	I	E		G	G	I	I		E	I	G		G	I	
G	I	I		I	G	I	G		E	I	G		I	G	

Source: developed by the authors (Low (I), Medium (G), High (E))

Table 5

A fuzzy base of rules for logical inference

Rule number	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	F1	F2	F3	F4	R
1	E	E	G	G	E	E	G	G	I	I	I	E	E	E	E	E	E
2	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
3	I	I	I	I	G	I	I	E	E	G	G	I	I	I	I	I	I
4	E	E	G	I	G	I	I	E	E	G	G	E	G	I	I	G	I
5	E	E	G	G	E	E	G	G	G	G	G	E	E	E	G	E	E
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Source: developed by the authors (Low (I), Medium (G), High (E))

Defuzzified clear values obtained by three methods are given for the output variable. It is quite expected that the values would be close but not equal. The choice of one or another value is left to the expert in the given subject area, it is possible to obtain the value of the membership function in order to make a more informed decision.

The constructed mathematical model and the method of its formalization based on the FTS make it possible to assess the level of personnel risk at the enterprise, which enables to further justify a set of measures to improve the efficiency of its use. The constructed fuzzy logical inference system can be considered intelligent, since it uses elements of computational intelligence, in particular, the theory of fuzzy sets.

The use of such an automated system for assessing the level of personnel risk suggests that it can provide a number of positive effects that help reduce the level of personnel risk. It is clear from the model that the parameters of the proposed model are easy to interpret in terms of content, and this, as a rule, provides higher accuracy.

Thus, to model the assessment of the level of personnel risk, it is convenient and effective to use methods of fuzzy set theory. They make it possible to describe qualitative characteristics that are difficult or impossible to quantify. Analysis of the indicators allows us to conclude that the most critical situation is with staff turnover rates, which increases the level of personnel risk. The next stage of the research is the development of tools for managing personnel risks of an enterprise, taking into account the key factors of its movement.

Conclusions. This paper proposes the formalization of fuzzy information using the mathematical apparatus of fuzzy set theory. In particular, the input data are formalized using membership functions, both linear and non-linear. A fuzzy hierarchical mathematical model of the system is built, which is based on the knowledge base. The rule base is numerically complete, consistent, and not excessive.

The results of numerical experiments allow us to assert that the system model is interpretable and adequate, which is confirmed by the results of numerical experiments and expert assessments. Fuzzy modeling technologies enable managers to make managerial decisions regarding the level of personnel risk under conditions of uncertainty and at the stage of conceptual planning.

Bibliography

1. Коваленко В.В. Ризики в системі економічної безпеки підприємства та засоби їх нейтралізації. *Вчені записки Університету «КРОК»*. 2018. №3 (51). С. 175-180.
2. Співак С.М. Оцінка та управління ризиками як інструмент підвищення конкурентоспроможності підприємства. *Вісник Хмельницького національного університету.* 2020. № 4. Том 3. С. 159-162.
3. Семенова С.М. Класифікація ризиків: систематизований підхід з метою управління. *Вісник Хмельницького національного університету.* 2020. № 4. Том 2. С. 42-51.
4. Лошенюк О.В., Мурована Т. О. Ризики ведення бізнесу в умовах воєнного стану та шляхи їх подолання. *Ефективна економіка*. 2023. № 2. URL: https://www.nayka.com.ua/index.php/ee/article/view/1166
5. Білорус Т. В., Бурмістрова О. О. Ризики при прийнятті кадрових управлінських рішень: теоретико-методичний підхід. *Ефективна економіка*. 2021. № 1. URL: http://www.economy.nayka.com.ua/?op=1&z=8499
6. Мішина С.В., Мішин О.Ю. Класифікація кадрових ризиків підприємства. *Вісник економіки транспорту і промисловості*. 2016. Вип. 53. С. 87–92.
7. Проскура В. Ф., Білак Р. Г. Методологічні підходи до управління ризиками. *Економіка і суспільство*. 2017. Вип. 9. С. 599–607.
8. Єпіфанова І.Ю., Ткачук Л.М. Стратегічне управління ризиками і системі управління персоналом. *Вісник Хмельницького національного університету.* 2021. № 6. Том 1. С. 12-15.

9. Курепін В. М. Систематизація ризиків та загроз кадрової безпеки підприємств. *Український журнал прикладної економіки*. 2020. Том 5. № 4. С. 170-176.

10. Вдовин М. Л., Данилюк Л. Г., Лелик Л. І., Березяк І. М., Мельник О. М. *Моделі і методи оцінювання економічних ризиків у різних функціональних сферах бізнесу*: *монографія*. Львів: Вид-во ННВК «АТБ». 2015. 248 с

11. Зеленцов Д.Г., Короткая Л.И. Технологии вычислительного интеллекта в задачах моделирования динамических систем: монография. Днепр: Баланс-Клуб, 2018. 178 с. URL: http://dx.doi.org/10.32434/mono-1-ZDG-KLI

12. Per Hilletofth, Movin Sequeira, Anders Adlemo. Three novel fuzzy logic concepts applied to reshoring decision-making. *Expert Systems with Applications*. 2019. Volume 126. P. 133-143

13. Parpiyeva Almaxon, Nurmuxamad Duisenov. Ensuring the Accuracy and Transparency of the Mamdani Fuzzy Model when Training Experimental Data. *International Journal of Innovative Research in Science Engineering and Technology*. 2022, 11(2). P. 1664-1675. URL: http://doi: 10.15680/IJIRSET.2022.1102120)

14. Терновой М. Ю., Штогрина Е. С. Формальная спецификация свойств баз нечетких знаний Мамдани на основе мета графа. *Вісник Харківського національного університету імені В.Н. Каразіна.* 2015. С. 157-171.

15. Korotka L. The use of fuzzy clustering in solving problem in predicting the durability of corrosive structures. *Mathematical modeling. 2020. №2(43)*, 44-54. URL: https://doi.org/10.31319/2519-8106.2(43)2020.219266

16. Korotka, L. The use of unclear conclusion in the tasks of forecasting of the durability of corrosive constructions. *International Journal of Computing Science and Mathematics*. 2021, Vol. 14, No. 3, 263-273. URL: https:// doi:10.1504/IJCSM.2021.119901

17. Harmider, L. Taranenko, I. Korotka, L. Begma P. (2019). Methodological approach to labor potential assessment based on the use of fuzzy sets theory. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *№ 6,* 144-149. URL: https://doi.org/10.29202/nvngu/2019-6/21

18. Ovcharenko, O., Korotka, L., Smiesova, V., Kuchkova, O., Karpenko, R. Economic security of regions: A methodological approach to assessment, management, and legal regulation. *Region: The journal of ERSA. 2022. Volume 9, Number 1,* 83–100.

References

1. Kovalenko V.V. (2018). *Ryzyky v systemi ekonomichnoi bezpeky pidpryiemstva ta zasoby yikh neitralizatsii* [Risks in the system of economic security of the enterprise and means of their neutralization]. *Vcheni zapysky Universytetu «KROK»* [Scientific Notes of «KROK» University], no. 3 (51), pp. 175-180 (in Ukrainian)

2. Losheniuk O.V., Murovana T. O. Risks of doing business under martial law and ways to overcome them. Efficient economy, 2023, no. 2. doi: 10.32702/2307-2105.2023.2.44

3. Semenova S.M. (2020). *Klasyfikatsiia ryzykiv: systematyzovanyi pidkhid z metoiu upravlinnia* [Risk classification: a systematicized management approach]. *Visnyk Khmelnytskoho natsionalnoho universytetu* [Bulletin of the Khmelnytskyi National University], tom. 2, no. 4, pp. 42-51 (in Ukrainian)

4. Spivak S.M. (2020). *Otsinka ta upravlinnia ryzykamy yak instrument pidvyshchennia konkurentospromozhnosti pidpryiemstva* [Risks assessment and management as a tool to increase the competitiveness of the enterprise]. *Visnyk Khmelnytskoho natsionalnoho universytetu* [Bulletin of the Khmelnytskyi National University], tom. 3, no. 4, pp. 159-162 (in Ukrainian)

5. Bilorus T. V., Burmistrova O. O. Risks in making personnel management decisions: a theoretical and methodological approach. Efficient economy, 2021, no. 1, doi: 10.32702/2307-2105-2021.1.74

6. Mishyna S.V., Mishyn O.Iu. (2016). *Klasyfikatsiya kadrovykh ryzykiv pidpryyemstva* [Classification of personnel risks of the enterprise]. *Visnyk ekonomiky transportu i promyslovosti* [The bulletin of transport and industry economics], Vyp. 53, pp. 87–92 (in Ukrainian)

7. Proskura V. F., Bilak R. H. (2017). *Metodolohichni pidkhody do upravlinnya ryzykamy* [Methodological approaches to risk management. Economy and society]. *Ekonomika i suspil'stvo* [Economy and society], Vyp. 9, pp. 599–607 (in Ukrainian)

8. Iepifanova I.Iu., Tkachuk L.M. (2021). *Stratehichne upravlinnia ryzykamy i systemi upravlinnia personalom* [Strategic risk management and personnel management system]. *Visnyk Khmelnytskoho natsionalnoho universytetu* [Bulletin of the Khmelnytskyi National University], no. 6, tom. 1, pp. 12-15 (in Ukrainian)

9. Kurepin V. M. Systematization of risks and threats to personnel security at enterprises. Ukrainian Journal of Applied Economics, 2020, tom 5, no. 4, pp. 170-176. doi: 10.36887/2415-8453-2020-4-19

10. Vdovyn M. L., Danyliuk L. H., Lelyk L. I., Bereziak I. M., Melnyk O. M. (2015). *Modeli i metody otsiniuvannia ekonomichnykh ryzykiv u riznykh funktsionalnykh sferakh biznesu: monohrafiya* [Models and methods of assessing economic risks in various functional areas of business: monograph], Lviv, Vyd-vo NNVK «ATB», 248 p. (in Ukrainian)

11. Zelentsov D.G., Korotkaya L.I. (2018). *Tehnologii vyichislitelnogo intellekta v zadachah modelirovaniya dinamicheskih sistem: monografiya* [Technologies of Computational Intelligence in Tasks of Dynamic Systems Modeling: Monograph], Balans-Klub, Dnepr, 178pp. URL: http://dx.doi.org/10.32434/mono-1-ZDG-KLI (in Ukrainian)

12. Per Hilletofth, Movin Sequeira, Anders Adlemo (2019) Three novel fuzzy logic concepts applied to reshoring decision-making. Expert Systems with Applications, Vol. 126, pp. 133-143 (in English).

13. Parpiyeva Almaxon, Nurmuxamad Duisenov Ensuring the Accuracy and Transparency of the Mamdani Fuzzy Model when Training Experimental Data. International Journal of Innovative Research in Science Engineering and Technology, 2022, 11(2), pp. 1664-1675 doi: 10.15680/IJIRSET.2022.1102120)

14. Ternovoy, M. Shtohryna E. S. (2015). *Formal'naya spetsyfykatsyya svoystv baz nechetkykh znanyy Mamdany na osnove meta hrafa* [Formal specification of properties of Mamdana's fuzzy knowledge bases based on a meta graph]. *Visnyk Kharkivs'koho natsional'noho universytetu imeni V.N. Karazina* [Bulletin of Kharkiv National University named after V.N. Karazin], Vyp. 27, pp. 157-171 (in Ukrainian)

15. Korotka L. The use of fuzzy clustering in solving problem in predicting the durability of corrosive structures. Mathematical modeling. 2020, no. 2(43), pp. 44-54. doi: 10.31319/2519-8106.2(43)2020.219266

16. Korotka L. The use of unclear conclusion in the tasks of forecasting of the durability of corrosive constructions. International Journal of Computing Science and Mathematics, 2021, vol. 14, no. 3, pp. 263-273. doi: 10.1504/IJCSM.2021.119901

17. Harmider, L. Taranenko, I. Korotka, L. Begma P. Methodological approach to labor potential assessment based on the use of fuzzy sets theory. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2019, № 6, pp. 144-149. doi: 10.29202/nvngu/2019-6/21

18. Ovcharenko, O., Korotka, L., Smiesova, V., Kuchkova, O., Karpenko, R. Economic security of regions: A methodological approach to assessment, management, and legal regulation. Region: The journal of ERSA, 2022, Volume 9, no 1, pp. 83–100. doi: 10.18335/region.v9i1.375

THE APPLICATION OF FUZZY SETS THEORY IN THE METHODOLOGICAL APPROACH TO ASSESSING PERSONNEL RISKS OF AN ENTERPRISE

Larysa D. Harmider, SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine).
E-mail: garm33@gmail.com
Larysa I. Korotka, SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine).
E-mail: larysakorotka@gmail.com
Serhii P. Bazhan, SHEI Ukrainian State Chemical Technology University, Dnipro (Ukraine).
E-mail: 2017bazhan.s@gmail.com
Dmytro M.. Aniskevich, «Platinum Electric» LLC, Dnipro (Ukraine).
E-mail: platinum.aniskevich@gmail.com
DOI: 10.32342/2074-5354-2024-1-60-14

Keywords: personnel risk, enterprise, theory of fuzzy sets, assessment, methodological approach
JEL classification: ***C69, C89, M12, M14***

The main idea of this paper is the substantiation of the methodological approach to the assessment of personnel risks of enterprises based on the application of the fuzzy logic apparatus in order to identify the problems of personnel risk management and provide appropriate recommendations for their solution. The methodological basis of the study is the classic provisions and fundamental works of foreign and domestic scientists, statistical data, the results of our research into the problems of assessing personnel risks of enterprises. The methods of fuzzy set theory, comparative analysis, scientific abstraction, generalization of scientific experience of modern theoretical research, system-complex approach were used. The study proposed a methodological approach to assessing the level of personnel risks of an enterprise; numerical experiments were conducted on the basis of a group of construction equipment manufacturers. Analysis of the results of assessing the level of personnel risks of enterprises made it possible to identify the problems of managing personnel risks at enterprises

Statement of a mathematical problem*:* the work considers hierarchical fuzzy data, namely: four groups of indicators for assessing the level of personnel risks (quantitative composition – F_1, state of qualifications and intellectual potential – F_2, staff turnover – F_3, motivational system – F_4), each of the indicators has a different number of fuzzy coefficients (there are twelve of them in the current work – v_i, i=1÷12). Indicators are functions of fuzzy coefficients: $F_1 = r(v_1, v_2, v_3)$; $F_2 = g(v_4, v_5, v_6, v_7)$; $F_3 = h(v_8, v_9, v_{10})$; $F_4 = q(v_{11}, v_{12})$. As an output variable, there is a functional – an integrated indicator $Int = f(F_1, F_2, F_3, F_4)$ of the personnel risk level, which, in turn, is also a fuzzy value. Here, the functions *r, g, h, q, f* are unknown functions of the given variables. We have expert evaluations of the change in all input data; as a rule, they vary within three terms: Low (I), Medium (G), High (E). Formalized information on each variable can be written as $\{(v_i, \mu(v_i)), i = 1 \div 12\}$, then for a group of indicators we have: $\{(F_j, \mu(F_j)), j = 1 \div 4\}$. Using a fuzzy system and performing calculations with its help requires the system to have the following structural elements: membership functions of input and output variables, a rule base, and an output mechanism. These structural elements are the components that will be built when designing a fuzzy system.

The built mathematical model and the method of its formalization on the basis of FST make it possible to estimate the level of personnel risk at the enterprise, which enables further substantiation of a set of measures to increase the efficiency of its use. The constructed system of fuzzy logical inference can be considered intelligent as it uses elements of computational intelligence, in particular, the theory of fuzzy sets.

The proposed methodological approach to assessing the level of personnel risks of enterprises based on the apparatus of fuzzy logic allows, in contrast to existing ones, to integrate the consideration of both qualitative and quantitative indicators when assessing the level of personnel risks and personnel movement indicators and to significantly increase the efficiency of decision-making under conditions of uncertainty and reduce costs in the event of adverse situations.

Using in practice a methodological approach to assessing the level of personnel risks of enterprises based on the apparatus of fuzzy logic allows us to analyze the level of personnel risk as a multi-element object that is closely related to the structured functioning of the enterprise and its capabilities; and expands the original basis for conclusions, which provides a more accurate assessment of the level of personnel risk and making a reasoned decision to reduce its level.

Одержано 16.09.2023.