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S. P. Bazhan[1],
orcid.org/0000-0002-5739-4616,
L. D. Harmider[*1],
orcid.org/0000-0001-7837-2734,
L. I. Korotka[1],
orcid.org/0000-0003-0780-7571,
A. I. Kryvoruchko[2],
orcid.org/0009-0004-2833-3496

1 – Ukrainian State University of Science and Technologies SHEI "Ukrainian State University of Chemical Technology", Dnipro, Ukraine
2 – FG "Tetyana", Dnipro, Ukraine
* Corresponding author e-mail: garm@ukr.net

METHODOLOGY OF COMPREHENSIVE DIAGNOSTICS OF TECHNICAL EDUCATIONAL AND SCIENTIFIC CLUSTER MANAGEMENT RISKS

Purpose. Substantiation of the methodological approach to assessing the indispensable dangers of managing a technical educational and scientific cluster based on utilizing a fuzzy rationale instrument in order to distinguish issues within the educational cluster and give suitable suggestions for their solution.

Methodology. The methodological premise of the research is the classical provisions and fundamental works by foreign and domestic scientists, statistical data, and the results of unique investigation on the issues of surveying the dangers of cluster improvement. The research utilized the method of fuzzy set theory, comparative analysis, method of abstractions, generalization of the results of advanced theoretical research, a systematic and comprehensive approach.

Findings. A methodological approach to surveying the dangers of managing a technical educational and scientific cluster was proposed, various tests were carried out based on the official statistics. The analysis of the results of evaluating the main components that impact the performance of the technical educational and scientific cluster made it possible to distinguish issues within the functioning of the cluster and to identify ways to solve them.

Originality. The methodological approach to the evaluation of integral dangers based on the device of fuzzy rationale has been progressed, which, unlike the existing ones, permits you to coordinate strategies of the theory of fuzzy sets and fuzzy rationale and permits you to achieve more exact and important outcomes compared to the conventional strategies. The proposed approach can be utilized in different areas where processing of expansive volumes of fuzzy data is required.

Practical value. The practical significance of the study arises from the possibility of applying the developed fuzzy model for making managerial decisions in a technical educational and scientific cluster under conditions of uncertainty.

Keywords: *educational and scientific cluster, risks, fuzzy sets, uncertainty factors, Mamdani method*

Introduction. Modern trends in the development of education require the improvement of methods for regulating the market of educational services in Ukraine. It is necessary to assess the current state of the educational domain, taking into account the requirements of employers and international standards. Therefore, the relevance of this study is the identification of key areas of regulation of changes in this domain based on the cluster approach under conditions of the economic crisis and limited possibilities of state funding.

Risk management is one of the effective innovative management technologies, which is already actively used in the private sector of the economy. The implementation of such technologies in the activities of educational institutions is associated with a number of advantages: coordination of strategic planning with current goals, achievement of synergy in combining resources and efforts of employees and units to fulfill the mission of the institution, increasing the flexibility of the management system, predicting and minimizing negative internal and external influences. For the educational system, one of the elements of internal financial control, along with environmental control, information exchange and monitoring, is risk assessment, which is a complex and multifaceted category.

Given the above, the tasks of this paper are to investigate the essence and forms of risk manifestation in the field of education, to analyze risk management system in educational clusters, as well as to reveal the essence and features of technical educational-scientific clusters (TESCs) in the context of risk management in education.

Literature review. The tasks related to identifying and assessing risks, determining their types and kinds, the basics of risk management at an enterprise have been studied in the scientific works by many scientists. These include the works by Danchenko [1], Zanora, Ishchenko [2], Kaleniuk [3], Kuklin, Lagunova [4], L. Tkachuk, M. Tkachuk [5], and others.

However, the issue of implementing risk-oriented concepts of management is not considered in detail in available studies. The growth of risks under the conditions of market transformations reduces the competitiveness of educational services of technical and educational-scientific clusters and inhibits the development of management system in accordance with international standards.

Risk assessment includes the process of identifying and analyzing relevant risks on the way to achieving the cluster's goals, as well as devising measures for their management. Therefore, risk assessment should be carried out on an ongoing basis.

In view of the above, the purpose of this paper is to develop approaches to identifying and assessing risks in the field of educational services by technical and educational-scientific clusters. According to all the above criteria, the application of the theory of fuzzy sets to devise the methodology for assessing the risks of educational clusters is extremely attractive and promising. Therefore, *the purpose of the study* is to justify the methodological approach to the assessment of integrated risks of management of technical and educational-scientific clusters based on the application of the fuzzy logic apparatus, which contributes to improving the validity of relevant management decisions to increase the level of efficiency of cluster activities.

Methods. The method of fuzzy set theory, comparative analysis of abstractions, generalization of scientific experience of modern theoretical studies, systematic and complex approach were used in the study.

Results. In the theory and practice of management, the main approaches to managing educational institutions on the basis of risk management are the situational approach (choos-

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ing the most appropriate management approach for the current situation), the process approach (risk management is considered as a continuous series of interdependent management functions), and the comprehensive approach (complex, systematic, continuous process covering all domains of activity of the educational institution), a complex, systematic and continuous process covering all domains of activity of the educational institution) [5]. We believe that risk assessment should be an integral part of the risk management process, covering both qualitative and quantitative analysis, as well as reconciling the objective risk assessment with the subjective perception of the risk by the decision maker. An evaluation of risk assessment methods shows that none of them is universally applicable, has both disadvantages and advantages, and requires a significant amount of data.

Thus, according to William Ho, the method of expert evaluations can be used as a tool for solving complex problems in various fields, using different mathematical approaches in risk management, etc. [6]. In his works, Klaus-Peter Klas proved that expert evaluations have a heuristic or qualitative nature in contrast to quantitative evaluations, the purpose of which is to obtain statistically significant results. Expert evaluations differ from other types of heuristic evaluations in that they do not have predetermined heuristics. Experts are free to provide any comments, assuming that their views will be well-founded [7]. The results of Huwei Li's research show that fuzzy clustering algorithms, such as FCM, can be successfully applied for early detection of signs of financial instability and development of effective risk management strategies [8]. Manuel Salas-Velasco, using a hierarchical cluster analysis, revealed clear differences between European countries in terms of the level of development of the dual education system, that is, the combination of work and education. Based on the results, he formulated the concept of cluster systems for professional and technical education, which allow better adaptation of personnel training to the needs of the labor market [9].

In his research, Peide Liu used the method of failure and effect analysis (FMEA) for comprehensive risk assessment in various fields of activity. Based on the obtained data, a decision support model was built, which took into account the clustering of experts by level of experience and specialization. The attitude of experts to risks was assessed on a five-point scale. Data processing on expert assessments was carried out in a cloud environment using machine learning algorithms. The behavior of experts in the cluster process was modeled on the basis of a trust network, which took into account the similarity of their opinions and attitude to risk. According to the results of the study, it was established that the use of cluster analysis makes it possible to increase the accuracy of risk assessment and the efficiency of management decision-making [10].

Mohammad Siami has developed an innovative system (AFDSS) that allows businesses to effectively assess a wide range of risks, including financial, operational, and reputational ones. Thanks to the use of fuzzy logic and machine learning algorithms, AFDSS is able to process large volumes of data, detect hidden dependences, and provide accurate forecasts. The system can be applied in various industries, helping enterprises to increase their resistance to external shocks and make more informed strategic decisions [11].

The selection of an evaluation method that is feasible and effective for application depends on the characteristics of the risk, the availability of relevant data for the study, and the importance of obtaining an accurate estimate of the probability of a risk event. As a result, in order to obtain an unbiased assessment of risks, we have proposed a mathematical model for assessing the integrated risks in managing technical and educational-scientific clusters based on the application of the fuzzy logic apparatus.

We substantiate in more detail the conditions for effective management of TESC, which influenced the choice of factors for the model.

1. Strategic planning and risk management. This includes the development and implementation of a clear strategy for the development of TESC, which takes into account key factors of uncertainty and risks, the construction of a system to monitor and early detect risks, as well as the implementation of a risk response plan. Therefore, strategic management is an ongoing process aimed at stimulating innovation and introducing new areas of activity of TESC, which ensures the successful development of TESC in the long term. Here, strategic management is extremely important for TESC because it makes it possible to increase the competitiveness and quality of education and ensure the effective use of resources. A clear strategy helps TESC stand out in the market of educational services and attract more applicants and focus on innovation and development of new areas of activity.

2. Financial support. In our case, the effective use of budget funds is carried out by implementing a system of budgetary control over expenses and achieving results, which contributes to public accountability and improving the transparency of its activities. For proper financial support of TESC, we have a number of tools in our toolset – budgeting, as a process of developing, approving, and executing the budget of TESC; financial control, introduction of a system of internal control over revenues and expenses of TESC; audit, as measures of independent verification of financial activities of TESC; accountability, providing information about the financial activities of TESC to interested parties. Therefore, effective financial support creates the necessary conditions for increasing the robustness and competitiveness of TESC, effective use of resources, which contributes to the growth of TESC's investment attractiveness and increasing trust in TESC on the part of interested parties.

3. Educational activity. For effective work in the field of education, the educational activities of TESC should be aimed at updating educational programs taking into account the needs of the labor market and changes in production technologies. An important condition for TESC's success is comprehensive cooperation with employers involving them in the development of educational programs, conducting joint research projects, organizing internships and practices for students at operating factories, creating career centers, etc. Therefore, effective educational activity is critically important for the success of TESC. By updating training programs, applying modern training methods, and cooperating with employers, TESC can produce highly qualified specialists who meet the needs of the labor market.

4. The scientific activity of TESC is carried out by conducting fundamental and applied scientific research, creating conditions for the commercialization of scientific developments and integrating scientific activity with the educational process in order to expand the knowledge and skills of students and create a basis for new technologies, development of new products and solutions for solving current production tasks. Commercialization of scientific advancements (transfer of technologies, creation of startups under the conditions of TESC) is an important factor in the development of TESC, the economy of the region, and the stimulation of innovations in the country. The implementation of commercialization of scientific developments makes it possible to effectively use the scientific potential of TESC, to generate new knowledge and technologies, as well as to transform them into competitive products and services.

5. International cooperation. International cooperation plays a key role at TESC, serving as a catalyst for innovation, knowledge sharing, and expanding horizons. This aspect is embodied in the development of TESC's partnership relations with foreign educational and scientific organizations, as well as in active participation in international projects and programs. Effective international cooperation is an important factor for the success of TESC. By developing partnerships with foreign organizations and participating in international projects and programs, TESC under such conditions integrates into the global scientific and educational space and becomes a leader in its field.

6. Information support to TESC involves the creation and development of its modern information infrastructure in order to ensure the availability of information for all participants of the educational process, promotion of TESC on the domestic and international markets of educational services. One of the key priorities of TESC is ensuring the availability of information for all participants in the educational process. This means that all information about TESC is public and available on the university's website, and students and lecturers have access to all necessary information resources, including electronic libraries, scientific databases, and online courses. It should be noted that the development and improvement of TESC is possible under the condition of using information resources to promote it in the domestic and international markets of educational services. This becomes possible with the help of advertising campaigns on the Internet and traditional mass media, participation in educational exhibitions and conferences, cooperation with other universities and educational organizations.

7. Quality management involves the implementation of a quality management system in TESC with the aim of continuous improvement of educational and scientific processes. Ensuring the high quality of education and scientific research is a key task of TESC. The implementation and effective functioning of the quality management system (hereinafter, QMS) may become a powerful tool for the continuous improvement of educational and scientific processes, provided that the international standards ISO 9001:2015 are implemented.

Meeting these conditions could ensure effective management of TESC, increase its competitiveness on the domestic and international markets of educational services, as well as contribute to the development of science and innovation.

Therefore, in order to build a mathematical model of integrated risk assessment, the main factors affecting the results of the activity of the technical educational and scientific cluster, on which it depends and which, in turn, are fuzzy quantities, are taken into account: financial, political and economic, personnel, educational, competitive ones.

The specified factors are dependent variables of the corresponding fuzzy quantities (Table 1).

To build a mathematical model, we introduce some notations for variables and represent the integrated indicator in the form of a functional.

Since each of the above integrated factors is a fuzzy variable (in turn, a function of several variables), while fuzzy data is supplied to the input, then, obviously, we also have fuzzy variables at the output, which, in turn, are transferred to the functional of the general of the integrated risk indicator I_{rys}.

It is necessary to formalize all information about input and output data. To this end, the paper proposes to apply the mathematical apparatus of the theory of fuzzy sets. We represent the fuzzy mathematical statement of the problem as follows.

It is required to obtain an estimate of the level of the total integrated risk: $I_{rys} = F(X_1, X_2, X_3, X_4, X_5)$, where I_{rys} is the risk functional, which depends on five independent functions, which in the present work are called integrated indicators of factors. In particular: $X_i = f_i(\bar{x})$ are the unknown convolution functions of the factors affecting the integrated I_{rys} risk indicator $(i = \overline{1,5})$. Let us describe each of these functions:

$X_1 = f_1(x_{11}, x_{12}, x_{13})$ – financial factors;
$X_2 = f_2(x_{21}, x_{22}, x_{23})$ – political and economic factors;
$X_3 = f_3(x_{31}, x_{32}, x_{33})$ – personnel factors;
$X_4 = f_4(x_{41}, x_{42}, x_{43})$– educational factors;
$X_5 = f_5(x_{51}, x_{52}, x_{53})$ – competitive factors.

Here, X_i are aggregated influential factors $(i = \overline{1,5})$; $f_i(\bar{x})$ – convolutions of factors; $\bar{x}$ are vectors of particular factors. In particular:

x_{11} – change in budget funding;
x_{12} – efficiency of use of budget funds;
x_{13} – diversification of funding sources;
x_{21} – change in the political situation;
x_{22} – economic stability;
x_{23} – change of state policy priorities;
x_{31} – salary level;

Table 1

Fuzzy sets for uncertainty factors affecting the management of a technical educational and scientific cluster

Uncertainty factor	Low	Average	High
1. Financial factors, X_1			
Change in budget funding, x_{11}	[0.02, 0.1, 0.2]	[0.1, 0.2, 0.4]	[0.2, 0.4, 0.8]
Efficiency of the use of budget funds, x_{12}	[0.02, 0.14, 0.25]	[0.14, 0.25, 0.55]	[0.25, 0.55, 0.85]
Diversification of funding sources, x_{13}	[0.02, 0.16, 0.28]	[0.16, 0.28, 0.53]	[0.28, 0.53, 0.9]
2. Political and economic factors, X_2			
Change in the political situation, x_{21}	[0.2, 0.4, 0.6]	[0.4, 0.6, 0.8]	[0.6, 0.8, 1.0]
Economic stability, x_{22}	[0.1, 0.5, 0.7]	[0.5, 0.7, 0.9]	[0.7, 0.9, 1]
Changing public policy priorities, x_{23}	[0.33, 0.53, 0.73]	[0.53, 0.73, 0.93]	[0.73, 0.93, 1.0]
3. Personnel factors, X_3			
Salary level, x_{31}	[0.08, 0.17, 0.35]	[0.17, 0.35, 0.65]	[0.35, 0.65, 1.0]
Working conditions, x_{32}	[0.08, 0.15, 0.3]	[0.15, 0.3, 0.6]	[0.3, 0.6, 1]
Opportunities for professional development, x_{33}	[0.08, 0.19, 0.33]	[0.19, 0.33, 0.65]	[0.33, 0.65, 1.0]
4. Educational factors, X_4			
Quality of training programs, x_{41}	[0.05, 0.2, 0.5]	[0.2, 0.5, 0.8]	[0.5, 0.8, 1.0]
Use of modern teaching methods, x_{42}	[0.05, 0.27, 0.48]	[0.27, 0.48, 0.76]	[0.48, 0.76, 1]
Level of scientific work, x_{43}	[0.1, 0.15, 0.3]	[0.1, 0.3, 0.5]	[0.3, 0.6, 1]
5. Competitive factors, X_5			
Clarity of TESC positioning in the market, x_{51}	[0.07, 0.15, 0.25]	[0.15, 0.25, 0.55]	[0.25, 0.55, 0.95]
Competitiveness of products and services by TESC, x_{52}	[0.07, 0.1, 0.2]	[0.1, 0.2, 0.4]	[0.2, 0.4, 0.6]
Effectiveness of marketing activities, x_{53}	[0.07, 0.16, 0.29]	[0.16, 0.29, 0.68]	[0.29, 0.68, 0.98]

x_{32} – working conditions;
x_{33} – opportunities for professional development;
x_{41} – quality of educational programs;
x_{42} – use of modern teaching methods;
x_{43} – level of scientific work;
x_{51} – clarity of positioning of the technical educational-scientific cluster (TESC) in the market;
x_{52} – competitiveness of TESC products and services;
x_{53} – effectiveness of marketing activities.

Here, the variables $x_{ij} = [x_{ij}^-; x_{ij}^+], (i = \overline{1,5}, j = \overline{1,n};$ n – the number of independent variables of each factor) are fuzzy values and each of them changes in its corresponding range $[x_{ij}^-; x_{ij}^+]$ (Table 1).

It is obvious that the influencing factors X_i will be fuzzy sets, the definition ranges of which depend on the independent variables. The analytical form of functions $f_i(\overline{x})$ is unknown $(i = \overline{1,5})$, but it is possible to use expert estimates for their construction. The structural diagram of the overall integrated risk assessment of the technical educational-scientific cluster can be represented as follows (Fig. 1).

The data are fuzzy quantities, so there is a need to formalize them to build a model of the system being designed [11, 12]. Fuzzification operations are usually performed with fuzzy information using membership functions [13]. As is known, there are both direct and indirect methods of theironstruction. The choice of the membership function (MF) construction method depends on the designer of the fuzzy system.

Formally, a fuzzy mathematical model of integrated risk assessment can be represented as

$$\left.\begin{array}{l} X_1 = \{[x_{11}^-; x_{11}^+]; [x_{12}^-; x_{12}^+]; [x_{13}^-; x_{13}^+]\} \xrightarrow{f_1} R(\tilde{X}_1) \\ X_2 = \{[x_{21}^-; x_{21}^+]; [x_{22}^-; x_{22}^+]; [x_{23}^-; x_{23}^+]\} \xrightarrow{f_2} R(\tilde{X}_2) \\ X_3 = \{[x_{31}^-; x_{31}^+]; [x_{32}^-; x_{32}^+]; [x_{33}^-; x_{33}^+]\} \xrightarrow{f_3} R(\tilde{X}_3) \\ X_4 = \{[x_{41}^-; x_{41}^+]; [x_{42}^-; x_{42}^+]; [x_{43}^-; x_{43}^+]\} \xrightarrow{f_4} R(\tilde{X}_4) \\ X_5 = \{[x_{51}^-; x_{51}^+]; [x_{52}^-; x_{52}^+]; [x_{53}^-; x_{53}^+]\} \xrightarrow{f_5} R(\tilde{X}_5) \end{array}\right\} \xrightarrow{F} \tilde{I}_{rys}, \quad (1)$$

where $X_j, (j = \overline{1,5})$ are input fuzzy vectors of groups; f_i are unknown laws (functions) that translate fuzzy sets of input vectors into sets of groups of fuzzy integrated risks (IR) of factors, respectively $(\tilde{X}_j)$; F is an unknown law that translates, in turn, sets of groups of fuzzy factors into a fuzzy set of the general integrated risk $\tilde{I}_{rys}$.

Since all the fuzzy variables are defined and the functions that translate their groups of fuzzy IRs, the process of building a fuzzy mathematical model can be considered complete. The next stage of working with the built model is the direct process of formalizing fuzzy information, building a fuzzy knowledge base, and applying fuzzy logical inference.

Using the mathematical apparatus of the theory of fuzzy sets, to formalize fuzzy information about independent input variables, we shall use expert evaluations [12] to construct membership functions, and we shall apply Gaussian functions to this end [14]

$$\mu(x) = be^{-\frac{(x-a)^2}{2\sigma^2}}, \quad (2)$$

where $b = 1$, $a > 0$, $\sigma > 0$.

All linguistic variables [5, 14] have three terms: low (Low – L), middle (Middle – M), and high (High – H) values. Any abstract variable (Fig. 2), for example, financial factors, can be represented without limiting judgment.

In fuzzy modeling, special attention should be paid to the construction of the knowledge base, which consists of fuzzy rules. The quality of the fuzzy rule base (RB) determines how fully and adequately the modeling process will be described; in the work, it is obtaining an integrated risk assessment. As is known, the following requirements can be stated to the rule base: local or global nature of the rules; the total volume of the rule base; completeness of the model; coherence, logic, and consistency of RB; redundancy of the rule base [15, 16].

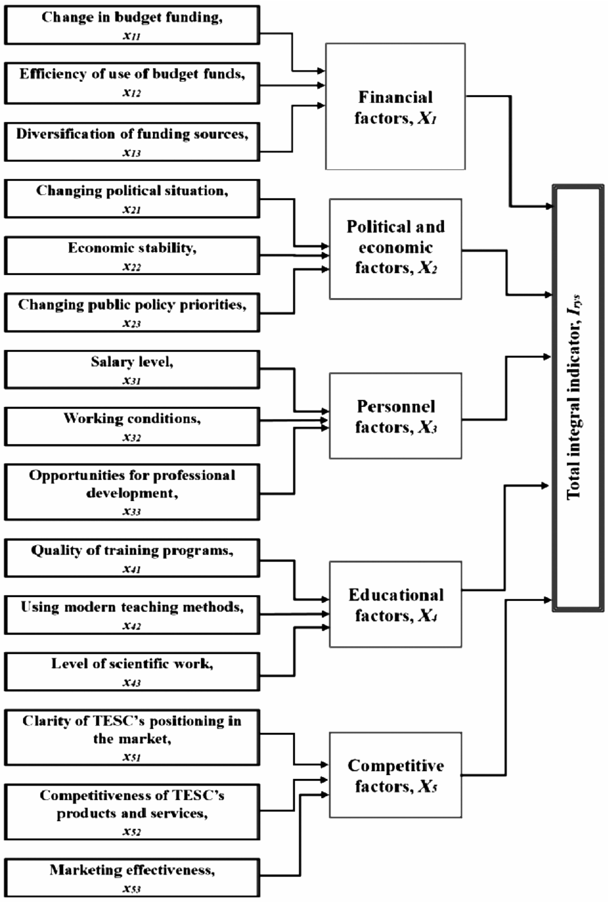


Fig. 1. Structural diagram of connections between input and output variables

In [13, 14], it is noted that in the case of fuzzy modeling, there is a need for reasonable limits of the level of complexity of the model. A grouping of factors is proposed, which, on the one hand, makes it possible to use the hierarchy of rules and, on the other hand, to reduce the number of rules that are necessary for the completeness of the model.

The quality of the rule base is hard to overestimate. The current work considered the approaches of absolute, linguistic, and numerical completeness [13]. It is proposed to work with a numerically complete, not linguistically complete rule base, namely: let the activation of at least one rule R^* from RB correspond to each clear input state of variables $(X_1^*, X_2^*, X_3^*, X_4^*, X_5^*)$, which, in turn, makes it possible to reduce the volume of the rule base and adequately describe the simulated process [17, 18].

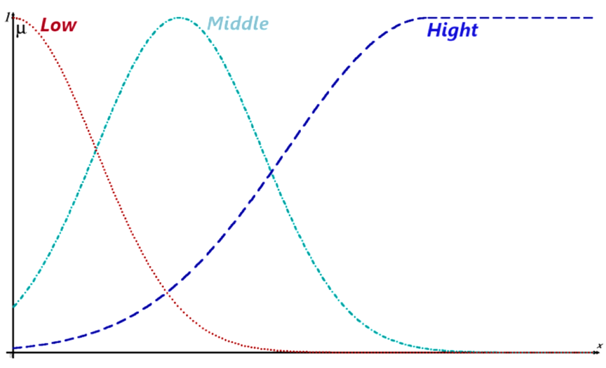


Fig. 2. Terms of linguistic variable X_1

After building the knowledge base, any fuzzy system needs tuning and training [19, 20]. Points of incompatibility of the rule base were considered; a check was carried out regarding the measurement of input and output data of the system for ambiguity, in particular: the states $(X_1^*, X_2^*, X_3^*, X_4^*, X_5^*)$ were checked for compliance with different initial values of the overall integrated risk indicator; checking for incompatibility and inconsistency of rules was carried out and similar points were excluded.

The authors' computer software [21] was used to build the model. Mamdani-type algorithm is used as a fuzzy logical inference algorithm, which is reasonably known and does not require additional description and unnecessary explanations [22, 23].

To demonstrate the operation of the fuzzy logical inference system, let us give as an example a structured and composite rule that contains the values of the linguistic input variables with the corresponding terms, which were previously described

$$IF\,(x_{11} = H \,\&\, x_{12} = H \,\&\, x_{13} = H \vee M), \quad THEN\, X_1 = H;$$
$$IF\,(x_{21} = H \,\&\, x_{22} = H \,\&\, x_{23} = H \vee M), \quad THEN\, X_2 = H;$$
$$IF\,(x_{31} = H \vee M \,\&\, x_{32} = M \,\&\, x_{33} = M), \quad THEN\, X_3 = M; \quad (3)$$
$$IF\,(x_{41} = M \,\&\, x_{42} = M \,\&\, x_{43} = L \vee H), \quad THEN\, H_4 = M;$$
$$IF\,(x_{51} = L \,\&\, x_{52} = M \,\&\, x_{53} = L), \quad THEN\, X_5 = L;$$
$$R^{(k)}: \quad IF\, X_1 = H \,\&\, X_2 = H \,\&\, X_3 = M \,\&\, X_4 = M \,\&$$
$$X_5 = L \quad THEN\, I_{rys} = M.$$

It can be noted that it is possible to build a rule base without $X_j, (j = \overline{1,5})$, but then the task becomes much more complicated. In this case, it is very difficult to monitor the correctness of writing the rules and their quality for the knowledge base, in particular: consistency and non-repeatability. Therefore, it is suggested to use the hierarchical structure of the rule base, which is given in (3). The structural diagram of the knowledge base is shown in Fig. 3, which contains the components of each integrated risk factor affecting the process of managing the technical educational-scientific cluster.

It was noted above that for the modeling of complex fuzzy processes, it is proposed to apply the Mamdani-type fuzzy logical inference algorithm, which is flexible enough and widely used [24, 25]. As a result, the issue of implication and composition is resolved, i. e.: the logical minimum operation is taken as the implication, and the logical maximum operation is taken as the composition operation [26].

Defuzzification methods: obtaining a clear value from a fuzzy set are well known. Without limiting judgment, the centroid method was used for certainty.

It can be considered that the main stages of designing, training, and setting up the fuzzy system have been completed. Then proceed to numerical experiments.

Table 2 gives part of the results of experiments when using a knowledge base without structuring. Given the fact that such a database is difficult to build and checking its completeness is time-consuming, this paper proposes to apply a hierarchical approach (Fig. 3).

In this case, it is not only possible to obtain the value of the term of the linguistic variable of each integrated risk for the factor $X_j, (j = \overline{1,5})$, but it is also possible to obtain the value of each individual risk, and, if necessary, the value of the membership function (Table 2).

Based on the data in Table 2, we draw the following conclusions: since we have a functional as a general integrated indicator that depends on functions describing financial, economic, personnel, educational, and competitive indicators, that is, they in turn depend on independent variables $x_{ij} = [x_{ij}^-; x_{ij}^+], (i = \overline{1,5}, j = \overline{1,n})$, then we have hierarchical but

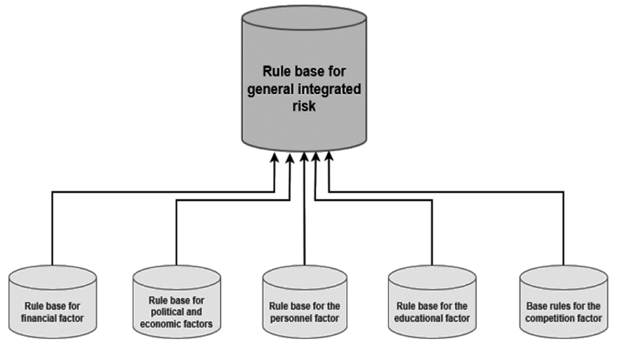


Fig. 3. Structural diagram of the knowledge base for general integrated risk

structured input data. For example, if we have low budget funding, poor efficiency in the use of budget funds, and average or low diversification of funding sources, then it is obvious that we shall have a low financial indicator, which is demonstrated in Table 2. The same is approximately the case with all other factors.

Analysis of our results, for example, for the total integrated risk with the value of the term "*medium*", makes it possible to state that this value is obtained if the IR of the financial factor and the political and economic factor have "*high*" values, the personnel factor and the education factor are "*medium*" and the competition factor – "*low*".

Based on Table 3, we can draw conclusions about the work of the fuzzy knowledge base: if we have the financial, economic, and educational factors with low or medium term values, and the personnel and competition factors are low, then it is expected that the overall integrated indicator will be low. If financial, economic, and personnel indicators are high and education and competition are high or, perhaps, medium, then in this case we shall have high values of the general integrated indicator. Similar approaches and judgments can be applied to the average value of the term for the general integrated indicator, namely: financial and economic factors are high; educational index and personnel are average, and competition – low. That is, it can be argued that the influence of each factor has its own contribution, but financial and economic indicators can be considered the most influential, followed by personnel, education, and competition. Without limiting judgment, several rules of the fuzzy knowledge base are considered above, which take a common integrated indicator, i. e.: low, high, and average. It is obvious that it is possible to indicate and comment on different variants of the values of the linguistic input variables and the output variable, which are implemented in the work. It can be considered that our results adequately describe the process, and as a result, the obtained fuzzy model can be used in subsequent studies. The use of a fuzzy knowledge base allows obtaining not only the terms of the variables but also the values of the membership functions. Of course, these values can be both high and not very high, but when working with fuzzy models, when the input data are of a fuzzy nature, the membership functions act as expert assessments that make it possible to make certain decisions.

It is obvious that it is possible to cite the results of numerical experiments obtained at the lower levels of the hierarchy. We shall present some of them without visualization: implications and compositions.

Note that for each integrated risk factor, the full base of rules was used, the approximate number of which was more than two dozen.

Without limiting judgment, we shall present the results of numerical experiments for the integrated risk of the political and economic factor (X_2). Input data to the fuzzy model are: x_{21} – change in the political situation; x_{22} – economic stability; x_{23} – change of state policy priorities. According to Table 1, we have the intervals of variation in these independent vari-

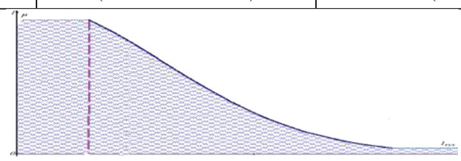
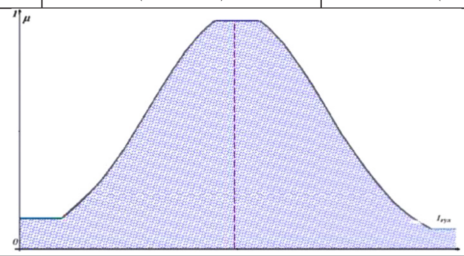
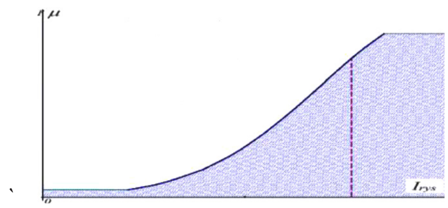
Table 2

Input data for a fuzzy logic inference system

Value of each clear independent variable	Value of the term of each clear independent variable	Value of the integrated risk term of the corresponding factor, X_j, $(j=\overline{1,5})$	Value of the general integrated risk and the value of its term
$x_{11} = 0.0821$	(L)	$R(X_1) = L$	$I_{rys} = 0.236$ (L)
$x_{12} = 0.1894$	(L)		
$x_{13} = 0.3063$	$(L \vee M)$		
$x_{21} = 0.0522$	(L)	$R(X_2) = L$	
$x_{22} = 0.1136$	(L)		
$x_{23} = 0.1119$	(L)		
$x_{31} = 0.0984$	(L)	$R(X_3) = L$	
$x_{32} = 0.2164$	(L)		
$x_{33} = 0.4475$	(M)		
$x_{41} = 0.0821$	(L)	$R(X_4) = L$	
$x_{42} = 0.1136$	(L)		
$x_{43} = 0.1239$	(L)		
$x_{51} = 0.0985$	(L)	$R(X_5) = L$	
$x_{52} = 0.0682$	(L)		
$x_{53} = 0.1894$	(L)		

Table 3

Results of numerical experiments for the hierarchical knowledge base of the general integrated exponent

<table>
<tr><th>IR of financial factor, X_1 (term value)</th><th>IR of political and economic factor, X_2 (term value)</th><th>IR of personnel factor, X_3 (term value)</th><th>IR of factor of education, X_4 (term value)</th><th>IR of competition factor, X_5 (term value)</th></tr>
<tr><td>0.1553
(Low or Medium)</td><td>0.1079
(Low or Medium)</td><td>0.1974
(Low)</td><td>0.2184
(Low or Medium)</td><td>0.3026
(Low)</td></tr>
<tr><td colspan="3">Total integrated risk (I_{rys}): 0.236
Term value:
Low
Membership function value:
μ(0.236) = 0.8821</td><td colspan="2"></td></tr>
<tr><td>0.4500
(High)</td><td>0.4700
(High)</td><td>0.4700
(Medium)</td><td>0.4500
(Medium)</td><td>0.3900
(Low)</td></tr>
<tr><td colspan="3">Total integrated risk (I_{rys}): 0.493
Term value:
Medium
Membership function value:
μ(0.493) = 0.9701</td><td colspan="2"></td></tr>
<tr><td>0.4026
(High)</td><td>0.47
(High)</td><td>0.7447
(High)</td><td>0.7026
(High or Medium)</td><td>0.8289
(High or Medium)</td></tr>
<tr><td colspan="3">Total integrated risk (I_{rys}): 0.782</td><td colspan="2"></td></tr>
</table>

ables and their corresponding terms. As mentioned above, we use Gaussian membership functions [23] in our work. We give a fragment of the results in Table 4.

The results of numerical experiments allow us to state that if, for example, we choose the value of the political situation as "*low*", economic stability as "*average*" and the change in state policy priorities as "*average*" or "*high*", then we shall get the value of the integrated risk of the political and economic factor approximately "*average*".

Other results in Table 4 can be interpreted similarly.

Thus, the influence of the main factors on the integrated risk in the management of a technical educational-scientific cluster based on the constructed fuzzy model is as follows:

1. Financial factors. Financial risks are important because of their impact on the stability and development of the cluster. The following indicators were taken into account in the fuzzy logic model: Change in budget funding reflects the cluster's sensitivity to changes in state support. For example, low funding (values in the range [0.02, 0.1, 0.2] can limit development and innovation opportunities. Effective use of budget funds ensures transparency and effectiveness of spending. High performance indicators [0.25, 0.55, 0.85] can reduce the overall level of risk. Diversification sources of financing: a wide range of financial resources helps avoid dependence on one source, which reduces financial risks.

2. Political and economic factors. The political and economic situation affects the long-term stability of the cluster. Key indicators: Changing political situation: high risk of political instability [0.6, 0.8, 1.0] may create additional barriers to functioning. Economic stability: the stability of the economy affects investor confidence and the possibility of growth. High economic stability [0.7, 0.9, 1] reduces risk, while low stability contributes to its growth. Changing state policy priorities affects the innovative development and integration of educational programs.

3. Personnel factors. Personnel risks are related to the outflow of personnel, working conditions, and their professional development. Salary level: low salary [0.08, 0.17, 0.35] can lead to the outflow of qualified specialists, which negatively affects the cluster. Working conditions: improved conditions contribute to the reduction of personnel risk, while their deterioration increases the risk. Opportunities for professional development: limited opportunities [0.08, 0.19, 0.33] reduce the attraction of new personnel and the incentive for development.

4. Educational factors. This factor directly affects the quality and competitiveness of graduates. Quality of educational programs: high quality of educational programs [0.5, 0.8, 1.0] reduces educational risk, ensuring compliance with market needs. The use of modern teaching methods: their active implementation [0.48, 0.76, 1] contributes to the development of students' competencies. The level of scientific work: a high level of scientific research increases the reputation and attractiveness of the cluster.

5. Competitive factors. These factors form the overall competitiveness of the cluster. Clarity of positioning in the market: effective positioning increases the attractiveness of the cluster. Competitiveness of products and services: high competitiveness reduces risk and promotes growth. Marketing effectiveness helps maintain reputation and attract new students and investors.

Our results show that each of the listed factors can affect the overall integrated risk of cluster management, and the level of this risk varies depending on the combination of the values of each of the factors. Using the method of fuzzy logic makes it possible to take into account the interaction of these factors and increase the validity of management decisions under conditions of uncertainty.

The results of numerical experiments were obtained using appropriate software, which implements the Mamdani-type fuzzy logical inference algorithm [18].

Table 4

Results of numerical experiments to obtain the integrated risk of political and economic factors (X_2)

x_{21}	x_{22}	x_{23}	$R(X_2)$
0.0727 (L)	0.0195 (L)	0.02669 (L)	0.218 (L)
0.2926 (L)	0.4805 (M)	0.6922 (M or H)	0.451 (M)
0.906 (H)	0.8457 (H)	0.8808 (M or H)	0.684 (H or M)

Analysis of numerical results and expert evaluations allows us to claim that fuzzy information is formalized and the knowledge base built accurately describes the simulated process of managing a technical educational-scientific cluster (TESC). As a result, it is practical and effective to use fuzzy set methods for modeling the assessment of risk management in the work of a technical educational-scientific cluster. They allow us to describe qualities that are difficult or impossible to measure quantitatively. Fuzzy modeling technologies enable managers to make informed decisions regarding the services of technical educational-scientific clusters under conditions of uncertainty and at the stage of conceptual planning.

Conclusions. Based on our research and the application of a knowledge base for the fuzzy model, the following conclusions can be drawn:

1. Assessment of integrated risk: the results show that integrated risk can be categorized according to different risk factors, such as financial, political and economic, personnel, educational, and competitive factors. This enables a comprehensive analysis based on integrated risk values for each factor, which are defined as "low", "medium", or "high" depending on the combination of input variables.

2. Identification of critical factors: specifically, the results of experiments indicate that high values of integrated risk (for example, in the range from 0.493 to 0.782) arise when several negative factors interact, such as high political instability or economic instability, which increase risks in clusters (both for financial and personnel aspects).

3. Effectiveness of fuzzy set methodology: the use of fuzzy logic methodology allowed us to build an adaptive model capable of processing fuzzy data and providing accurate predictions under conditions of uncertainty. This provides greater flexibility and accuracy in risk management compared to conventional approaches.

4. Practical application of the model: the proposed model could be used for risk management in other sectors where similar uncertainty factors are present. The model could serve as a basis for implementing early warning and adaptation strategies in the face of changing external conditions.

Therefore, the results of our study confirm the effectiveness of using fuzzy logic to assess and manage risks under conditions of uncertainty, providing technical educational-scientific clusters with the opportunity to make informed decisions and reduce potential negative impacts.

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Методика комплексної діагностики ризиків управління технічним освітньо-науковим кластером

С. П. Бажан[1], *Л. Д. Гармідер*[*1], *Л. І. Коротка*[1], *А. І. Криворучко*[2]

1 – Український державний університет науки і технологій ННІ «Український державний хіміко-технологічний університет», м. Дніпро, Україна
2 – ФГ «Тетяна», м. Дніпро, Україна
*Автор-кореспондент e-mail: garm@ukr.net

Мета. Обґрунтування методологічного підходу до оцінювання показника інтегрального ризику управління технічним освітньо-науковим кластером на основі використання механізму нечіткої логіки з метою виявлення проблем в освітньому кластері й надання відповідних рекомендацій щодо їх вирішення.

Методика. Методологічною основою дослідження є класичні положення й фундаментальні праці закордонних і вітчизняних учених, статистичні дані, а також результати оригінальних досліджень із проблем оцінки ризиків розвитку кластерів. У дослідженні використано метод теорії нечітких множин, порівняльний аналіз, абстракцій, узагальнення результатів сучасних теоретичних досліджень, системний і комплексний підхід.

Результати. Запропоновано методичний підхід до оцінки ризиків управління технічним освітньо-науковим кластером, проведені багаточисельні експерименти на основі даних офіційної статистики. Аналіз результатів оцінки основних факторів, що впливають на результати діяльності технічного освітньо-наукового кластеру, дав змогу виявити проблеми у функціонуванні кластеру та позначити шляхи їх вирішення.

Наукова новизна. Удосконалено методичний підхід до оцінки інтегральних ризиків на основі апарату нечіткої логіки, який, на відміну від існуючих, дозволяє інтегрувати методи теорії нечітких множин і нечіткої логіки та дозволяє досягнути більш точних і відповідних результатів у порівнянні з традиційними методами. Запропонований підхід може бути використаний у різних сферах, де потрібна обробка великих обсягів нечіткої інформації.

Практична значимість. Практична значущість дослідження зумовлена можливістю застосування розробленої нечіткої моделі для прийняття управлінських рішень у технічному освітньо-науковому кластері в умовах невизначеності.

Ключові слова: *освітньо-науковий кластер, ризик, нечіткі множини, фактор невизначеності, метод Мамдані*

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