DOI: 10.63550/ICEIP.2025.96.94.091

Assessment of the Stability of the Functioning of the Partner Integrated Structure

Svetlana V. Frolova[a], Elena M. Deberdieva[b]
Industrial University of Tyumen, 38 Volodarsky st., Tyumen, 62500
frolovasv@tyuiu.ru, deberdievaem@tyuiu.ru

Keywords: Efficiency assessment, partner integrating system, oil machine building, theory of fuzzy sets, methods of economic modelling, hierarchy analysis method, consortium, sustainable development.

Abstract: Modern oil and gas engineering companies have to solve the most difficult task – to be competitive in terms of import substitution of equipment for the fuel and energy complex (FEC). When integrated with representatives of metallurgy, fuel and energy complex, scientific and engineering companies, machine-building enterprises get the opportunity to produce innovative products that will meet the ever-increasing demands of the fuel and energy complex. However, the unification process does not always give a positive synergistic effect, which determines the search for methods to assess the efficiency of such processes. This article presents the results of a study of the efficiency of the functioning of integration structures. The author's definition of "partner integration" is given. A new approach to assessing the efficiency of a potential partner integration structure in the form of a consortium based on a combination of fuzzy number methods and hierarchy analysis is shown. The system of indicators of the model for assessing the efficiency of the integration structure based on the concept of sustainable development in accordance with the principles of science, practicality and brevity is established. The object of the study is the enterprises of petroleum engineering, which are designed to provide innovative equipment to enterprises of the fuel and energy complex. The subject of the study is the efficiency of integration structures in the form of a consortium as the most appropriate in conditions of high uncertainty and for a limited time. The purpose of the study is to assess the efficiency of the functioning of the integration structure of the partnership of industrial enterprises based on economic modeling methods. This paper uses a combination of qualitative description and quantitative analysis to determine criteria for assessing indicators based on a fuzzy model, as well as a hierarchy analysis method. The method of fuzzy set theory makes it possible to formalize and process various heterogeneous factors in conditions of lack of data and more accurately determine the efficiency. Based on the analysis of data from 4 real-life consortia, the efficiency of the functioning of the integration structure in the form of a consortium was confirmed: According to the adopted trapezoidal scale, the efficiency score was 0.641, which corresponds to the "above average" interval.

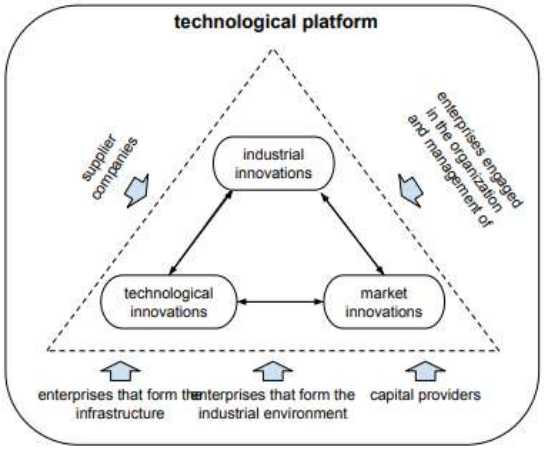
1 INTRODUCTION

Modern oil and gas engineering companies have to solve the most difficult task – to be competitive in terms of import substitution of equipment for the fuel and energy complex (FEC). When integrated with representatives of metallurgy, fuel and energy complex, scientific and engineering companies, machine-building enterprises get the opportunity to produce innovative products that will meet the ever-increasing demands of the fuel and energy complex. Integration processes in industry have recently become quite widespread due to the expected synergistic effect of using the key advantages of potential participants (1). Industrial integration has led to changes in innovative models of traditional industries, characteristics of market demand and behavior of enterprises in the field of competition and

[a] https://orcid.org/0000-0001-5222-9956
[b] https://orcid.org/0000-0003-1051-8789

cooperation, has made a significant contribution to the development and evolution of new types of business (22). Based on the analysis of the many definitions of the term integration proposed by the researchers, we formulated our own vision of this concept. In our opinion, partner integration should be understood as the formation of production and innovative communications for the mutually beneficial exploitation of resources, including human resources, as well as the concentration of capital, complementary agreements, and strengthening competitiveness on a temporary basis. The integration of industrial enterprises through partnership is a preferable strategy compared to mergers and acquisitions, since it is based on the voluntary participation of the parties, is temporary and allows to adapt to changing external conditions.

The realization of the value of an innovative product can be achieved through three processes developing simultaneously: the formation of technological, industrial and market innovations that contribute to the spiral growth of each other (29). Researchers of integration processes currently prefer to use the concept of "ecosystem"(10). In the paper (13), Adner defines ecosystems as "a structure for aligning a multi-stakeholder set of partners who need to interact in order for a focused value proposition to materialize." It is also worth noting that the concept of an ecosystem is considered by numerous authors from several positions: how participants interact to create value, as a digital service platform, as a complex self-developing system (4, 7) (Fig.1).



Source: formed by the authors
Figure 1: The scheme of building an ecosystem of partner integration.

However, the unification process does not always give a positive synergistic effect, which determines the relevance of further search for forms of integration and methods for assessing the efficiency of such processes (5, 8, 9, 12). It should be noted that it is quite problematic to assess the efficiency of integration education due to the individuality of each structure, as well as the high uncertainty of external and internal factors (27). For example, the efficiency of integration production processes may vary depending on different industrial process sites or location regions. When using innovative technologies, the expected level of performance can only be predicted with varying degrees of confidence. Researchers of the efficiency of integration structures usually apply methods of probability theory, estimates based on the calculation of forecast financial indicators (23, 31, 2). In our opinion, it is most preferable to use a combination of methods of fuzzy set theory and hierarchy analysis. Fuzzy set theory is based on the notion that not all data variability can be properly described in terms of frequency of occurrence. In many cases, the subjective degree of reliability of parameter values determines the need for uncertainty modeling (6).

The methods of assessing the efficiency of integration structures in the form of a consortium were identified as the subject of the study. The consortium was chosen as the most appropriate form of integration association with a limited period of operation in conditions of high uncertainty. The aim of the study was to select mathematical modeling methods that allow the most reliable assessment of the efficiency of forming a partner integration structure of industrial enterprises.

A special tool of fuzzy set theory, the linguistic variable, was used in the study. The variable is used to formalize verbal expert assessments when studying the efficiency of potential integration entities. There are 47447 results in the Scopus abstract database in the search for documents that use methods of fuzzy set theory in all areas of science. Over the past 5 years, 1,407 papers have been published in the field of economics, business and management, in which researchers apply the fuzzy sets method. If you use all the replacement names in the search (methods of the theory of fuzzy logic, fuzzy statements, fuzzy definitions), then the number of publications increases by 3 times. Thus, the above method is quite popular and has been tested in many areas of economic research, including in assessing the efficiency of integration processes and entities.

2 METHODOLOGY

This paper uses a combination of qualitative description and quantitative analysis to determine criteria for assessing indicators based on a fuzzy model, as well as a hierarchy analysis method. The method of fuzzy set theory makes it possible to formalize and process various heterogeneous factors in conditions of lack of data and more accurately determine the efficiency. The technique is described in detail in the works (26, 20, 14, 15, 16, 17, 3, 18, 24, 25, 28).

To assess the efficiency of a potential integration structure in accordance with the selected methods, it is necessary to select indicators grouped by signs of sustainable development. Most often, researchers use the terms "high" or "low" efficiency when evaluating it. However, when making a strategic decision on intersectoral integration, top management may not be satisfied with 2 extreme performance assessments. Therefore, it is advisable to use a linguistic scale (pentascale) according to the trapezoidal system of the theory of fuzzy numbers, the so-called term sets. On the scale, the estimated parameters are presented by levels of interval values.

When using the fuzzy sets method, the authors used the following sequence of steps to assess the level of efficiency of the integration structure:

Step 1. Definition of fuzzy subsets for the pentascale through a trapezoidal system of functions (low, below average, medium, above average, high).

Step 2. Selection of indicators for assessing.

Step 3. Normalization of indicators on the "gray" Pospelov scale from -1 to 1. The closer the value of the indicator on the normalized scale is to -1, the lower the overall efficiency of the integration structure. The use of the Pospelov scale in the study ensures the consistency and completeness of the classifier of linguistic analysis.

Step 4. Introduction of linguistic variables in order to determine the qualitative values of the selected indicators of the efficiency of the functioning of the integration structure. The linguistic variables used in this study are: A (a) – the value of the efficiency of the functioning of the integration structure (IS); B (b) – the value of the weight of a group of indicators in the overall assessment of the functioning of IS; D (d) – the value of each indicator.

Since the trapezoidal membership function was chosen for the linguistic variable as the most understandable and simplest, the membership function of each term(μ) will be determined through the four numbers (i1, i2, i3, i4) and have the form (for variable A).

Example 1:

$$\mu(\mathrm{a}) = \begin{Bmatrix} 0, if\ \mathrm{a} < i_1; \\ \frac{a-i_1}{i_2-i_1}, if\ i_1 \le a < i_2; \\ 1,\ if\ i_2 \le a \le i_3; \\ \frac{a-i_4}{i_3-i_4},\ if\ i_3 \le a < i_4; \\ 0,\ if\ \mathrm{a} > i_4; \end{Bmatrix} \quad (1)$$

Therefore, according to formula 1, with a low value of the efficiency of the IS, A1 will belong to a set of values from 0 to 0.25, while

- the value of μ = 1 if the value of the variable a lies in the range from 0 to 0.15;

- the value of μ=10*(0.25 – a), if the value of the variable a lies in the range from 0.15 to 0.25. If the value of the efficiency of the IS is below the average, A2 will belong to a set of values from 0.15 to 0.45, while:

- the value of μ=1-10*(0.25-a), if the value of the variable a lies in the range from 0.15 to 0.25;

- the value of μ = 1 if the value of the variable a lies in the range from 0.25 to 0.35; - the value of μ=10*(0.45 – a), if the value of the variable a lies in the range from 0.35 to 0.45.

With an average value of the efficiency of the IS, A3 will belong to a set of values from 0.35 to 0.65, while:

- the value of μ=1-10*(0,45-a), if the value of the variable a lies in the range from 0.35 to 0.45;

- the value of μ=1, if the value of the variable a lies in the range from 0.45 to 0.55;

the value of μ=10*(0.65 – a), if the value of the variable a lies in the range from 0.55 to 0.65.

The value of the efficiency of the functioning of the A4 IS corresponding to an above-average level will belong to a set of values from 0.55 to 0.85, while:

- the value of μ=1-10*(0.65-a), if the value of the variable a lies in the range from от 0.55 to 0.65.;

- the value of μ=1, if the value of the variable a lies in the range from 0.65 to 0.75;

- the value of μ=10*(0.85 – a), if the value of the variable a lies in the range from 0.75 to 0.85.

A high value of the efficiency of the functioning of the A5 IS will belong to a set of values from 0.75 to 1, while:

- the value of μ=10*(0.85 – a), if the value of the variable a lies in the range from 0.75 to 0.85;

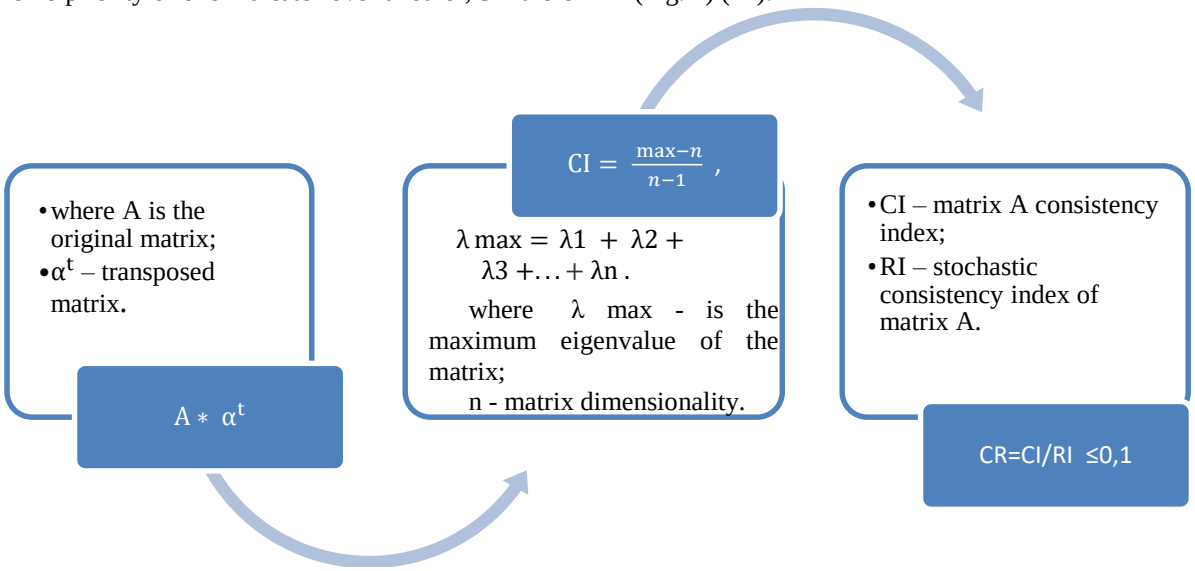
- the value of μ=1, if the value of the variable a lies in the range from 0.85 to 1.

In all other cases, the value of μ =0.

Step 5. Determining the weight of the contribution of each of the indicators to the overall assessment of

the level of efficiency of the integration structure, as well as each group of indicators by analyzing the hierarchy.

The hierarchy analysis method has been used for quite a long time since the late 70s of the 20th century, when it was developed by the American mathematician T. Saati at the University of Pittsburgh. The range of application of this method is quite extensive when it comes to the problem of experts choosing their number of alternatives. The method is implemented by building a hierarchy of indicators through a set of matrices of paired comparisons for the global purpose of analysis and for each of the sublevels (groups of indicators). Traditionally, the matrix element is defined as the priority of one indicator over another according to the author's intensity scale from 1 to 9. Where 1 – there is no priority of one indicator over another; 3 – there is some preference for the significance of one indicator over another; 5 – significant or strong significance of the indicator with the one being compared; 7 – obvious or very strong preference for the significance of one indicator over another; 9 – absolute significance of one indicator over another. If, when comparing one indicator with another, a value of 5 is obtained, then when comparing the second indicator with the first, we get the opposite value – 1/5. For each of the paired comparison matrices, the eigenvectors are calculated according to the geometric mean, then weighted by the total value when calculating the indicator weight. At the same time, it is necessary to determine the level of consistency of the expert's opinion in the logic of paired comparison. To do this, the consistency index is calculated, which should be less than or equal to 0.1 (Fig. 2) (21).



Source: formed by the authors

Figure 2: Algorithm for calculating the coefficient of consistency of expert opinions.

Step 6. Determining the value of the linguistic variable B, the set of term values is similar according to formula 1. The value B itself is obtained by multiplying the weight of the indicator by the middle of the interval of the term carrier B.

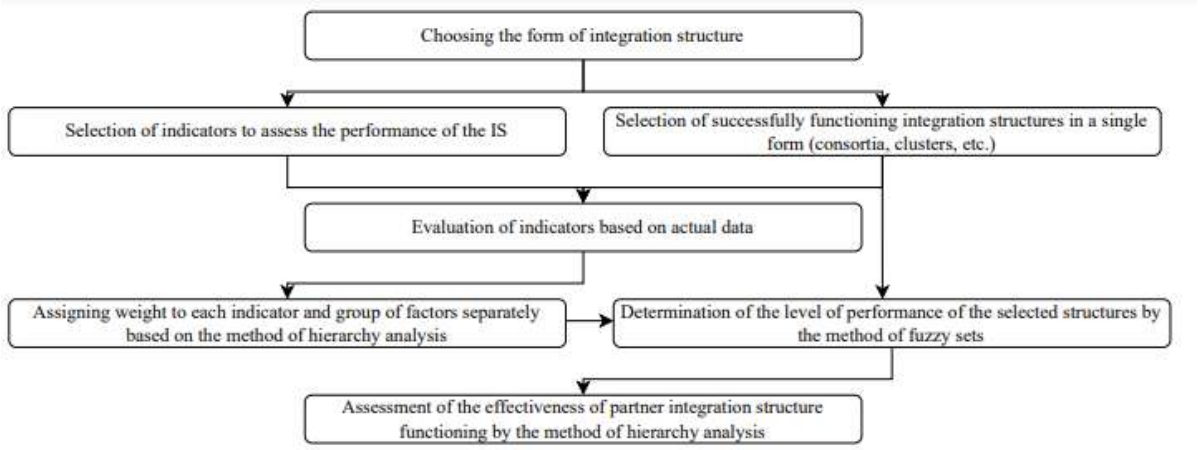
Step 7. Calculation of the value of the linguistic variable A, the sets of values of the term are calculated similarly according to formula 1. The value of A is obtained by multiplying the weight of the indicator group by the middle of the interval of the carrier of the term B.

Step 8. Interpretation of the obtained values of the linguistic variable A in accordance with the selected trapezoidal scale according to the level of efficiency of the IS functioning. Specialists and managers of various levels of machine-building companies, including those belonging to integration structures, scientists studying the problems of integration processes in industry, can act as experts to assess the level of efficiency of IS functioning. Quantitative and qualitative indicators are evaluated by experts on a 10-point scale, which is quite easy to transform into a scale from 0 to 1 for evaluating a linguistic variable.

3 DISCUSSION OF RESULTS

The authors developed the scheme of assessment of the efficiency of a potential integration structure based on the methods of fuzzy sets and hierarchy analysis (fig. 3).

DOI: 10.63550/ICEIP.2025.96.94.091

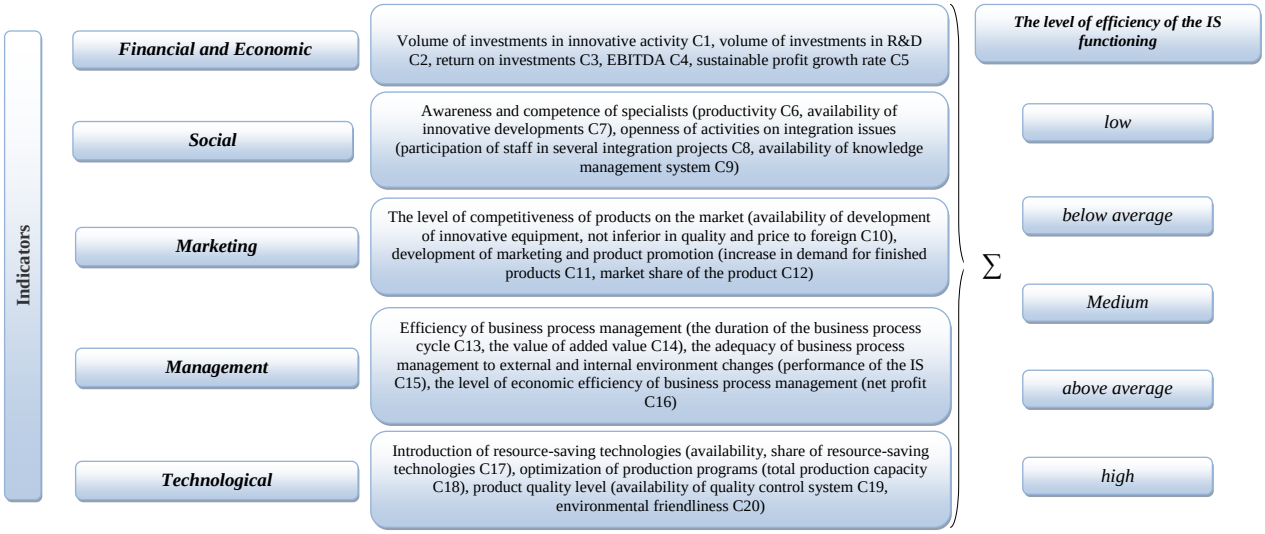


Source: formed by the authors

Figure3: Assessment of the efficiency of a potential integration structure based on the methods of fuzzy sets and hierarchy analysis.

Based on the strategic goals of the oil engineering enterprises, they select the form of the integration structure and potential partners for the creation and sale of innovative products for the fuel and energy complex. We consider it advisable to implement an integration structure in the form of a consortium, since, first of all, there is no need to change the form of legal ownership, and the duration of interaction can be determined by the participants themselves.

Accordingly, due to step 2 of the above methodology, it is necessary to select indicators to assess the efficiency of functioning, depending on the specifics of potential participants. Today it is especially important to analyze the efficiency of economic systems from the point of view of sustainable development. According to the UN Convention, the transition to sustainable development is a key task for countries, society and individual enterprises (11, 19, 30). The list of indicators of sustainable development may vary depending on the object of the study. For an oil and gas engineering enterprise, the system of such indicators is shown in Fig. 4.



Source: formed by the authors

Figure 4: Recommended indicators for assessing the level of integration structure of industrial enterprises (taking into account the concept of sustainable development)-format is not suitable for translation.

DOI: 10.63550/ICEIP.2025.96.94.091

Therefore, unlike the generally accepted indicator systems, which mainly assess the level of economic development, the proposed system of integration indicators is aimed at analyzing the impact of the integration factor on the overall economic development of the association's participants.

In parallel with the selection of indicators, alternatives are being selected to assess 4 actually functioning consortia at a given time. After that, the expert expresses his opinion on each of the selected indicators, taking into account the complex level of functional groups: financial, economic, social, marketing, managerial, technological. The choice of these groups in the assessment of the efficiency determines the stability of the functioning of a potential partner integration structure.

Based on the above-described methodology of fuzzy sets and hierarchy analysis, we will assess the level of their efficiency. According to step 3, the value of each of the 20 indicators on the carrier is determined [0;1], step 4 - the values of the belonging function of the linguistic variable. For example, for 1 consortium, the value of the indicator C1=0.8, the formula 1 μ14. 15= 0.5, the rest μ11,12,13=0.

When assessing the weight of each term of the linguistic variable, the contribution of each indicator in the general group of indicators was determined (step 5). Thus, for the group of financial and economic weights, 5 indicators were determined by experts (0,13; 0,07; 0,5; 0,26; 0,04). Similarly, the weights of indicators in other groups are set. At step 6, taking into account the value of the linguistic variable membership function and the weight of each indicator in the group, the weight of the term of the linguistic variable is calculated. According to 1 consortium of the group of financial and economic indicators, the weight of term b is (0,038; 0,256; 0,504; 0,133; 0,067).

Step 7. After completing each iteration of the process of phasification and dephasification of linguistic variables, an assessment of their effectiveness was calculated for all four selected integration structures. By the method of hierarchy analysis (MHA), the forecast values of the indicators were compared with those of each of the four selected integration structures, after which the corresponding values of the linguistic variable were determined (Table 1.).

Table 1: The final values of the assessment of the level of efficiency and for a potential integration structure

Consortium	**The value of the linguistic variable**	**The level of efficiency of the IS operation**	**The weight value according to MHA**
1	0.439	average	0.11
2	0.588	average	0.10
3	0.503	average	0.11
4	0.739	Above average	0.45
Partner consortium	0.641	Above average	0.23

Source: formed by the authors

Step 8. The efficiency of the functioning of a potential integration structure is: 0.439*0.11+0.588*0.10+0.503*0.11+0.739*0.45/ (1-0.23) = 0.641, therefore, the "above average" level with a weight of 91% (and only 9% of the weight belongs to the "average" level) indicates that that the choice of an integration structure in the form of a consortium will have a positive effect and lead to a successful strategic decision. Since the level of "above average" and "high" signals higher efficiency than the assessed analogues.

4 CONCLUSIONS

Thus, it seems advisable to assess the level of efficiency of the functioning of the integration structure through the use of economic modeling methods. The method of fuzzy set theory makes it possible to formalize and process various heterogeneous factors in conditions of lack of data and more accurately determine the efficiency. Based on the hierarchy analysis method, weighting coefficients were calculated to bring the level of efficiency of analogues of the chosen form of integration interaction (in this study of consortia) to the level of assessment of a potential IS in which oil

engineering enterprises are participants. An assessment of the effectiveness of the functioning of a potential integration structure shows an "above average" level, which confirms the choice of an IS form in the form of a consortium. In addition, the "above average" and "high" level of efficiency reduces the risks associated with the integration process. In the future, the study will be supplemented by modeling the contribution level of each potential.

REFERENCES

Avkopashvili, P.T., 2021. Features of functioning of integrated structures of industrial enterprises. *Economics of Sustainable Development*, 4(48), pp. 11-14.

Bekova, A.S., 2021. Corporate efficiency of integration and its impact on the development of the national economy. *Scientific Research Center "Scientific discoveries"*, 7, pp. 343-347.

Dandybaev, S.T., 2021. Fuzzy sets with fuzzy membership functions. *Theory and practice of modern science*, 1(67), pp. 130-133.

Kalenov, O.E., 2021. Development of the concept of ecosystems in economics. Vestnik G.V. *Plekhanov Russian University of Economics*, 18(1/115), pp. 37-46.

Kosova, A.L., 2022. Foreign experience of assessment and forecasting of efficiency of functioning of branches of agroindustrial production in the conditions of integrated cooperative and integration structures. *Agrarnaya ekonomika*, 8(327), pp. 87-96.

Kostikova, A.V., Kuznetsov, S.Y., Terelyansky, P.V., 2023. Application of fuzzy set theory in the task of product competitiveness assessment. *E-Management*, 6(2), pp. 37-48.

Markova, V.D., Kuznetsova, S.A., 2021. Strategies for ecosystem development: analyzing the Russian experience. *Strategic decisions and risk management*, 12(3), pp. 242-251.

Lutchenko, V.G., Khorev, A.I., Belyaeva, G.V., Adrakhovskaya, L.L., 2022. Methodology for assessing the efficiency of enterprise functioning in an integrated structure. *Vestnik Voronezh State University of Engineering Technologies*, 84(1/91), pp. 365-371.

Vorotilova O.A., Pleshakova M.V., Kotova O.V., Popova N.I., 2022. Model of estimation of efficiency of functioning of financial resources of vertically integrated holding. *Vestnik of Moscow State Pedagogical University. Series: Economics*, 3(33), pp. 32-50.

Popov, E.V., Dolzhenko, R.A., Simonova, V.L., 2021. Theory of ecosystem analysis. *Management Issues*, 6(73).

Usenko, L.N., Makarenko, E.N., Guzey, V.A., 2023. Analytical study of the orientation of organizations to achieve sustainable development goals. *Accounting and Statistics*, 2(20), pp. 8-19.

Shelenok, A.V., 2022. Estimation of economic efficiency and financial sustainability of integrated structures in the grain complex of the Saratov region. *Agroindustrial complex: economy, management*, 11, pp. 103-111.

Adner, R., 2017. Ecosystem as structure: a practical concept for strategy. *Journal of Management*, 43(1), January, pp. 39-58.

Akcan, S., Taş, M.A., 2019. Assessing suppliers' environmental performance using SWARA-TOPSIS integrated method to reduce environmental risk factors. *Environmental Monitoring and Assessment*, 191(12), pp. 796.

Akram M., Shahzadi G., 2021. A hybrid decision making model using q-rung orthopair yager fuzzy data aggregation operators. Granular Computing, 6(4), pp. 763-777.

Ali, G., Afzal, M., Asif, M., Shazad, A., 2021. Attribute reduction approaches in the framework of interval-valued orthoparametric fuzzy soft system. *Applied Intelligence*, 52(8), pp. 8975-9000.

Asif M., Akram M., Ali G., 2020. Fuzzy Pythagoras matroids with applications. *Symmetry*, 12(3), pp. 423.

Berkaci, R., 2021. Fundamental concepts of fuzzy sets. *In Distance measurement in fuzzy statistical analyses*, pp. 13-33.

Brodney, J., Tutak, M., 2022. Using the open innovation concept to develop a method to improve safety in the mining process: a case study of university-industry integration. *Journal of open innovation: technology, market and complexity*, 8(2), pp. 75.

Bai, K., Dallasega, P., Orzes, G., Sarkis, J., 2020. Technology assessment of Industry 4.0: a sustainability perspective. *International Journal of Production Economics*, 229, pp. 107776.

Deberdieva, E.M., Frolova, S.V., 2020. Integrated risk management at oil industry enterprises. In: IOP conference series: materials science and engineering: International Conference on Modern Trends in Manufacturing Technologies and Equipment 2019, ICMTME 2019, Sevastopol, September 09-13, 2019 Volume 709, 2, Issue 1. Sevastopol: Institute of Physics Publishing House, pp. 022084.

Deberdieva E.M., Frolova S.V., 2020. Integration processes in industry: theoretical approaches and pandemic experience. *In: Journal of Physics: conference series, Krasnoyarsk, Russian Federation*, September 25-October 4, 2020. Vol. 1679. Krasnoyarsk: Institute of Physics and IOP Publishing Limited, pp. 32037.

Kuternin, M., 2019. Comparison of efficiency of different gas industry schemes using mathematical modeling. *University Bulletin*, 10, pp. 124-131.

Liu, Z., Li, L., Li, J., 2019. Q-rank orthopairs of indefinite linguistic split Bonferroni mean operators and their application in multi-attribute decision making method. *International journal of intelligent systems*, 34(10), pp. 2490-2520.

Meksawang, P., Shi, H., Lin, S., Liu, H., 2019. An extended VIKOR fuzzy logic approach for sustainable supplier management and its application in meat industry. *Symmetry*, 11(4), pp. 468.

Moeis, A.O., Desriani, F., Destyanto, A.R. et al, 2020. Sustainability assessment of the Tanjung Priok port cluster. *International Journal of Technology*, 11(2), pp. 353-363.

Hussain, H.Y.B., Bolotin, S.A., Huraini, N.K.R., and Boxan, H., 2023. Regression-based rationing of labor costs based on estimation of their actual values using neural.

Seker, S., Aydın, N., 2021. Evaluation of hydrogen production methods using an integrated MCDM approach under uncertainty. *International Journal of Hydrogen Energy*, 47(8), pp. 3171-3184.

Kiselitsa, E.P., Shilova, N.N., Liman, I.A. et al, 2021. Stimulation of innovative activity of enterprises of agroindustrial complex. In: IOP Conference Series: Earth and Environmental Sciences: agriculture, field, livestock, forestry and agricultural products, Series 2, Smolensk, January 25, 2021. Vol. 723. Smolensk, pp. 032030.

Urein, I., Eguren, H.A., Yustel, D., 2022. Development and validation of a tool for implementing the circular economy in industrial companies: a case study of 30 companies. *Journal of Cleaner Production*, 370, pp. 133318.

Voronkova, O.Y., Sorokina, V.V., Baburin, S.V., 2019. Organizational and economic mechanism of development of integration processes in production and processing of products. *International journal of economics and business administration*, 7(2), pp. 207-214.