ORIGINAL PAPER

DOI: 10.26794/2304-022X-2025-15-1-105-121
UDC 001.895:378:334(045)
JEL O32, I23, D83

The Integral Assessment of Interorganizational Innovation Effectiveness Using Fuzzy Sets Method

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ABSTRACT

In the current economic environment, the effective operation of higher education institutions is difficult to imagine without collaboration with organizations from the real sector of the economy, particularly in the context of innovation generation. Decision-makers responsible for the development of academic-industrial partnerships require modern methods to assess the potential effectiveness of such interactions. This study aims to develop a fuzzy-set-based integral aggregation model for evaluating the effectiveness of interorganizational innovations. The research contributes to scientific novelty through the following key solutions: the development of a hierarchical structure of integral indicators for assessing interorganizational innovation effectiveness; the selection of components and the evaluation of their significance using Fishburne's weighting method; the creation of a fuzzification database to transform precise numerical values into fuzzy sets; the construction of an equation system to quantify non-standardized components values to term sets membership degree and the formulation of a calculation method for intersection points of non-inversive indicators.

The results of the conducted research has practical value and are possible to be used by both academic institutions and organizations in the real sector of economy for a preliminary assessment of interorganizational collaboration effectiveness in innovation generation. Future research by the author in this field will be aimed at testing the developed model refining it, and further systematizing and algorithmizing the results for efficient use in interorganizational innovation management.

Keywords: interorganizational innovations; fuzzy sets method; integral assessment; innovation effectiveness; innovation management; academic institutions; real sector economy; academic industrial partnership

For citation: **Ivashchenko A.A. The integral assessment of interorganizational innovation effectiveness using fuzzy sets method. *Upravlencheskie nauki = Management* Sciences. 2025;15(1):105-121. DOI: 10.26794/2304-022X-2025-15-1-105-121**

INTRODUCTION

The terminological results obtained by the author of this article earlier [1] indicate that interorganizational innovations arise when there is alignment between the goals of the real sector of the economy and higher educational institutions (universities). In accordance with the priority areas for the development of the Russian economy and, in particular, the strategies in the field of digital transformation developed by the state authorities of the Russian Federation,[1] many problems in the scientific and educational sector are related to the absence of a number of innovative digital services, platforms, and tools. For this reason, the modern domestic system of science and education faces challenges in increasing the level of digitalization and ensuring the growth of digital maturity. The real sector of the Russian economy, in turn, faces the problem of creating conditions both for increasing investments in the development of innovative technologies and for enhancing the level of cooperation between organizations. The tasks associated with the mentioned challenges can be addressed by the academic-industrial partnership of these economic segments based on innovation generation. However, such interaction inevitably necessitates the evaluation not only of the effectiveness of implementing innovations in the activities of the university and the real sector organization separately but also of the resulting synergistic effect.

The inconsistency in expectations regarding the outcomes of such interactions signals the presence of uncertainty, which is one of the most significant factors in the process of managing interorganizational innovations [2, 3]. For the success of this process, both quality planning and the presence of alignment among economic agents in the context of achieving set commercial and non-commercial goals are required.

Therefore, when assessing the effectiveness of inter-organizational innovations, it is necessary to take into account the factor of uncertainty, the reduction of which is facilitated by fuzzy set theory. The use of fuzzy tools is particularly promising, partly due to the presence of a system that combines specific components that cannot be clearly formalized and components that have different dimensions [4–6].

Thus, fuzzy logic, stemming from the theory of fuzzy sets first proposed by L. Zadeh in 1965, can be used as an effective tool for managing interorganizational innovations [7]. The necessity of creating a system of components for evaluating the effectiveness of inter-organizational innovations allows for a departure from classical Boolean set theory and binary Boolean logic, favoring instead extended fuzzy logic. The latter, within the framework of the developed axiomatic system, provides the opportunity to characterize fuzzy categories associated with intermediate and integral indicators, as a result of which the generalized multiple representation of the integral indicator, first described in [8], is transformed into a formula (1).

$$Int_{\mu} = \left\{ \begin{array}{c} y_{\mu}^{1} = \left\{ x_{t}^{11}, x_{t}^{12}, \ldots, x_{t}^{1j_1} \right\} \\ y_{\mu}^{2} = \left\{ x_{t}^{21}, x_{t}^{22}, \ldots, x_{t}^{2j_2} \right\} \\ y_{\mu}^{3} = \left\{ x_{t}^{31}, x_{t}^{32}, \ldots, x_{t}^{3j_3} \right\} \\ \ldots \\ y_{\mu}^{i} = \left\{ x_{t}^{i1}, x_{t}^{i2}, \ldots, x_{t}^{ij_n} \right\} \end{array} \right\}, \quad (1)$$

where: Int_{μ} — integral indicator calculated using unclear logic;

y_{μ}^{i} — intermediate indicators i, used to determine the integral indicator;

$x_{\mu}^{ij_n}$ — non-binary elements j, n-set of which determines intermediate indicators y_{μ}^{i}.

Int_{μ} is a universal set that includes subsets y_{μ}^{i}, consisting of non-binary elements $x_{\mu}^{ij_n}$.

[1] Digital Transformation Strategies.Ministry of Digital Development of Russia. 2024. URL: https://digital.gov.ru/ru/activity/directions/1064/ (accessed on 10.01.2025).

Integral indicators mostly contain a hierarchical system of components. In this regard, there is a need to use either specific fuzzy tools designed for working with hierarchical division systems or a fuzzy inference method that will allow for the effective transformation of non-binary elements and intermediate indicators into integral indicators of the performance of inter-organizational innovations.

RESEARCH METHODOLOGY

In this study, the following designations of integral indicators and their components are used:

1. Integral indicators

Int_S — synergy result index. It demonstrates the potential result synergy of interorganizational interaction depending on external conditions (created for generating innovations) and the degree of their use by the university as the main driving force of innovative activity.

Int_U — integral indicator of the effectiveness of inter-organizational innovations for a higher education institution. It shows their potential effectiveness from the university's perspective, depending on its resource base and the alignment of innovation activity results with the demands of the current economic situation.

Int_B — integral indicator of innovation effectiveness for the real sector of the economy. It reflects the potential effectiveness of inter-organizational innovations from the perspective of an organization in the real sector of the economy, taking into account its financial capabilities and the results of its scientific and innovative activities.

2. Intermediate indicators

K — the letter designation of the intermediate indicator.

A — the intensity of the development of solutions for the current technological paradigm.

B — the level of research integration of a higher education institution.

C — level of result compliance.

G — level of resource provision.

Components within intermediate and integral indicators

Ki — an alphanumeric designation of a component.

A*i* — components of the intermediate indicator A, $i \in [1;12]$.

B*i* — components of the intermediate indicator B, $i \in [1;7]$.

C*i* — components of the intermediate indicator C, $i \in [1;5]$.

G*i* — components of the intermediate indicator G, $i \in [1;2]$.

D*i* — components of the integral indicator Int_B, $i \in [1;4]$.

For the structure of integral indicators with hierarchies, the most suitable method is the fuzzy matrix method of integral convolution developed by A.O. Nedosekin and O.B. Maksimov [9, 10]. Based on the mentioned methodology, steps have been formulated, the sequential execution of which will allow for the assessment of all proposed integral indicators:

Step 1 — creating a hierarchical structure of integral indicators.

Step 2 — defining membership functions for each evaluated integral indicator and the associated intermediate indicators.

Step 3 — deriving linguistic variables, forming term sets of their values, and fuzzy value scales for conducting expert evaluation.

Step 4 — defining the set of components for each integral indicator.

Step 5 — evaluation of the significance level of components from the resulting set.

Step 6 — creating the fuzzification base.

Step 7 — conducting fuzzification based on it.

Step 8 — conducting defuzzification of intermediate and integral indicators.

Step 9 — implementation of linguistic identification.

RESEARCH RESULTS

Fig. 1 presents the hierarchical structure of integral indicators developed by the author,

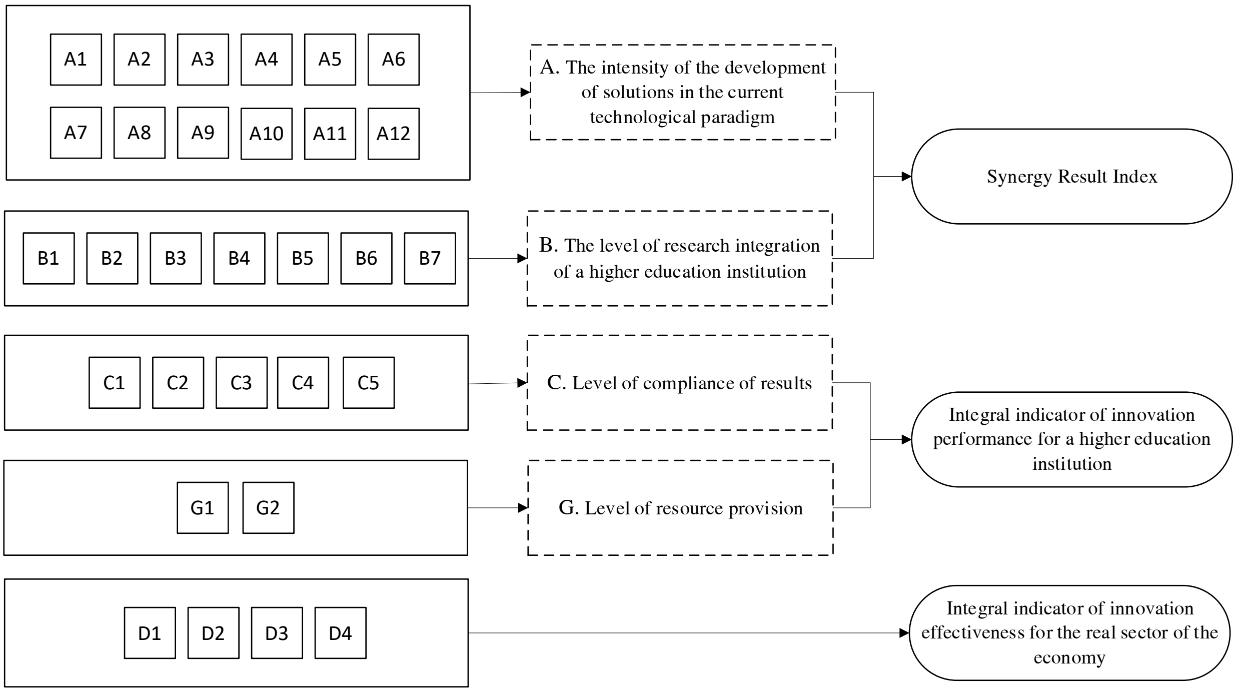

Fig. 1. **The hierarchical structure of integrated indexes of the interorganizational innovation effectiveness**

Source: Compiled by the author.

which includes intermediate indicators used in integral convolution and their components.

Among the wide variety of membership functions [11, 12] for all components and intermediate indicators, it is proposed to use trapezoidal functions (*Fig. 2*). There are two reasons for this: first, their established reliability (due to frequent use by researchers compared to most other membership functions) and, second, the recommendation of the scientific school of A. O. Nedosekin to use these functions specifically when applying the matrix method of integral convolution [13].

This set of trapezoidal functions with term sets of linguistic variable values within the framework of the present study is universal and is used to evaluate three integral and all intermediate indicators, as well as their components.

Next, according to the chosen methodology, it is necessary to create fuzzy value scales, as well as to designate the magnitudes of all linguistic variables by forming term sets of values for each of them (*Table 1*).

For each variable, a characteristic is presented along with a relation to term sets of values, which, in turn, are based on the corresponding fuzzy value scales.

As a result of accepting the universality of the set of membership functions depicted in *Fig. 2,* the scales of fuzzy values consist of trapezoidal numbers, generically denoted as a_1, a_2, b_1, b_2, where a_1 and b_2 are the abscissas of the vertices of the lower bases of the trapezoids, and a_2, and b_1,— are the abscissas of the vertices of their upper bases.

Let's define a set of components for each integral indicator (*Table 2*).

The presented components of groups A and D were selected based on the results of analyzing the methodologies for calculating the digital readiness index, the ICT development index, the network readiness index, the digital economy and society index, the "Digital Russia" index, and a number of scientific sources offering various ways to assess the effectiveness of innovations for the real sector of the economy, taking into

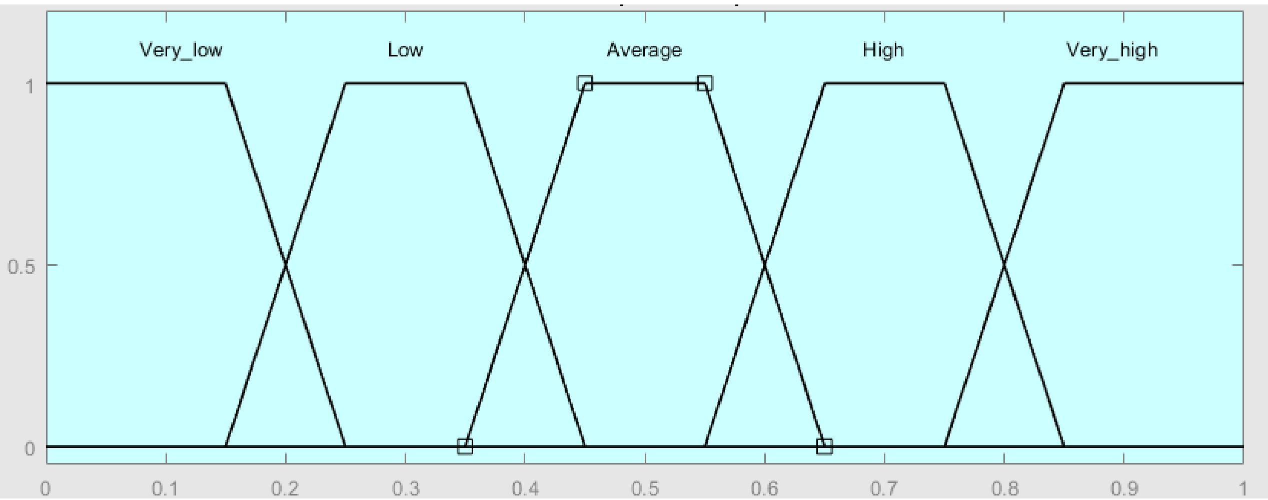

Fig. 2. **The combination of trapezoidal membership functions with the term sets for the linguistic variables**

Source: Developed by the author using the MATLAB application package with the Fuzzy Logic Toolbox extension

account changing external conditions.[2] In an early study by the author, the characteristics of the components used in the calculation of the aforementioned indices were compared, and principles of a systematic approach to the task of selecting components for the proposed integral indicators were suggested [8]. The sources for determining the components of groups B, C, and G are widely recognized global rankings and scientific sources [14–16].[3] Thus, the choice of this particular list of components is determined, firstly, by the use of widely recognized methodologies; secondly, by the successful testing in the author's early studies; and thirdly, by the full compliance with the formulated principles of the systems approach. The selected components with the proposed method of separation fully and adequately characterize the effectiveness of interorganizational innovations.

At the next stage, the significance level of the components is assessed. We will create a system of Fishburne weight coefficients (*Table 3*) using the formula (2):

$$r_i = \frac{2 \times (N - i + 1)}{N \times (N + 1)}, \quad (2)$$

where: r_i — weight coefficient of the i-th component; N — the number of components within a single indicator.

The Fishburne weight coefficient system suggests arranging all components in order of decreasing significance [17], and this is confirmed by the data in *Table 3*. The values of the

[2] Digital Readiness Index. Cisco; 2021. URL: https://www.cisco.com/c/en/us/about/csr/research-resources/digital-readiness.html (accessed on 10.01.2025); the ICT Development Index. ITU; 2024. URL: https://www.itu.int/en/ITU-D/Statistics/Pages/IDI/default.aspx (accessed on 10.01.2025); Network Readiness Index. Portulans Institute. 2024. URL: https://networkreadinessindex.org/ (accessed on 10.01.2025); the Digital Economy and Society Index; 2022. URL: https://digital-strategy.ec.europa.eu/en/policies/desi (дата обращения: 10.01.2025); Index "Digital Russia". SKOLKOVO School of Management. 2018. URL: https://www.skolkovo.ru/researches/indeks-cifrovaya-rossiya/ (accessed on 10.01.2025).

[3] Russian Statistical Yearbook (Rosstat). URL: https://rosstat.gov.ru/storage/mediabank/Ejegodnik_2023.pdf (accessed on 16.10.2024)., Europe's most innovative universities. URL: https://www.reuters.com/graphics/EUROPE-UNIVERSITIES-INNOVATION/010091N 72J7/ (accessed on 16.10.2024); The Impact Rankings. URL: https://the-ranking.s3.eu-west-1.amazonaws.com/IMPACT/IMPACT2023/THE.ImpactRankings.METHODOLOGY.2023_v1.2.pdf (accessed on 16.10.2024); University Innovation Rankings URL: https://www.scimagoir.com/methodology.php (accessed on 16.10.2024); The World University Rankings for Innovation. URL: https://www.wuri.world/_files/ugd/8e5131_708743231b0a45ffacc8470fc959c980.pdf (accessed on 16.10.2024).

Table 1

The descriptions, the term sets and the scales for the linguistic variables

Indicator designation	Characteristic of linguistic variable	Estimation of term set	Trapezoidal number scales
	Linguistic variable "Result Synergy"		
Int_S	The synergy effect is absent, or its influence is minimal due to the low level of research integration in the university and the weak development of solutions regarding the current technological structure. The effectiveness of innovation generation depends solely on the research base of the real sector organization	Very low	(0; 0; 0.15; 0.25)
	The influence of the synergy effect is minimal due to the low level of research integration in the university and the weak development of solutions regarding the current technological structure. The effectiveness of innovation generation is almost entirely dependent on the research base of the real sector organization	Low	(0.15; 0.25; 0.35; 0.45)
	The average value of the synergy effect, determined more by the neutral influence of the external environment and the level of research integration of the university, or by the high variability of the term sets of intermediate indicators	Average	(0.35; 0.45; 0.55; 0.65)
	The synergy effect has a positive impact due to the sufficiently intensive development of solutions regarding the current technological order and the research integration of the university	High	(0.55; 0.65; 0.75; 0.85)
	The synergy effect has a very strong influence on the effectiveness of innovations due to the high-intensity development of solutions regarding the current technological structure and the complete (or nearly complete) research integration of the university	Very high	(0.75; 0.85; 1; 1)
	Linguistic variable "Intensity of development of solutions of the current technological paradigm"		
A	Decisions regarding the current technological structure are either not made or are made extremely slowly. The external conditions for generating innovations are minimal or nonexistent	Very low	(0; 0; 0.15; 0.25)
	Low intensity of decision-making regarding the current technological paradigm. The favorability of external conditions for generating innovations is below average	Low	(0.15; 0.25; 0.35; 0.45)
	The intensity of decision-making regarding the current technological structure is at an average level. A significant portion of economic agents is implementing new digital technologies to activate innovative activities	Average	(0.35; 0.45; 0.55; 0.65)
	High intensity of decision-making regarding the current technological paradigm. The digital innovation environment fosters the generation of innovations within its boundaries	High	(0.55; 0.65; 0.75; 0.85)
	The development of the current technological paradigm is characterized by very high or maximally possible intensity. The digital innovation environment significantly contributes to the generation of innovations within its framework	Very high	(0.75; 0.85; 1; 1)

Table 1 (continued)

Indicator designation	Characteristic of linguistic variable	Estimation of term set	Trapezoidal number scales
	Linguistic variable "Level of research integration in higher education institutions"		
B	The university is not integrated or is poorly integrated into the digital innovation environment and practically does not use the existing external conditions for generating innovations. The potential synergy of the result cannot be above average even under favorable external conditions. The effectiveness of innovation generation in this situation largely depends on the organization of the real sector of the economy	Very low	(0; 0; 0.15; 0.25)
	Low degree of research integration at the university. It does not utilize all the opportunities of the external environment, which indicates either a low interest in generating innovations or being in the initial stages of integration into the digital innovation environment	Low	(0.15; 0.25; 0.35; 0.45)
	The degree of the university's integration into the digital innovation environment is sufficient for the successful generation of innovations as a result of interorganizational interaction, provided that there is proper support from the real sector of the economy	Average	(0.35; 0.45; 0.55; 0.65)
	A high degree of research integration of the university into the digital innovation environment. The synergy effect can be extremely high with a decent level of development of the innovative activities of the real sector organization	High	(0.55; 0.65; 0.75; 0.85)
	The university is fully (or almost fully) integrated into the digital innovation environment. The potential synergy of the result can be very high, provided that the intensity of decision-making regarding the current technological paradigm is similar	Very high	(0.75; 0.85; 1; 1)
	Linguistic variable "Effectiveness of innovations for higher education institutions"		
Int_U	The extremely low level of innovation effectiveness in interaction with the university is explained by the lack of both interest in innovative activities and the possibility of their implementation	Very low	(0; 0; 0.15; 0.25)
	Low innovation performance for the university, either due to weak interest in generating innovations or the lack of necessary resource base	Low	(0.15; 0.25; 0.35; 0.45)
	The average effectiveness of innovations in interaction with the university, determined by the average levels of compliance of results and resource provision, or by directly opposite values of the term sets of these parameters	Average	(0.35; 0.45; 0.55; 0.65)
	The effectiveness of inter-organizational innovations when interacting with a university is high due to a sufficient level of resource provision and a high level of result compliance	High	(0.55; 0.65; 0.75; 0.85)
	The effectiveness of inter-organizational innovations when interacting with a university is very high due to the high level of resource provision and the complete alignment of the results of innovative activities with the demands of the digital innovation environment	Very high	(0.75; 0.85; 1; 1)

Table 1 (continued)

Indicator designation	Characteristic of linguistic variable	Estimation of term set	Trapezoidal number scales
	Linguistic variable "Level of result conformity"		
B	The results of the university's activities do not meet the demands of organizations in the real sector of the economy at all. Insufficient attention is paid to innovative activity, and there is a lack of incentives for innovation	Very low	(0; 0; 0.15; 0.25)
	The low level of compliance of the results indicates a poorly developed innovation system at the university and a small incentive for its development	Low	(0.15; 0.25; 0.35; 0.45)
	The level of compliance of the results of the university's innovative activities is sufficient for the development of inter-organizational innovations	Average	(0.35; 0.45; 0.55; 0.65)
	A high level of result compliance, indicating that the university's innovative activities largely meet external demands	High	(0.55; 0.65; 0.75; 0.85)
	The results of the university's activities fully meet the demands of organizations in the real sector of the economy, operating in the same digital innovation environment	Very high	(0.75; 0.85; 1; 1)
	Linguistic variable "Level of resource provision"		
G	Very low level of resource provision, indicating the absence or very small number of applied laboratories and very low publication activity	Very low	(0; 0; 0.15; 0.25)
	Low level of resource provision. This is explained by the presence of a small number of applied laboratories and low publication activity	Low	(0.15; 0.25; 0.35; 0.45)
	The level of resource provision is sufficient for the development of academic-industrial partnerships	Average	(0.35; 0.45; 0.55; 0.65)
	High level of resource provision. This is explained by the presence of a large number of applied laboratories and a fairly high level of publication activity	High	(0.55; 0.65; 0.75; 0.85)
	A very high level of resource provision, indicating the presence of the necessary number of applied laboratories and very high publication activity	Very high	(0.75; 0.85; 1; 1)
	Linguistic variable "Effectiveness of innovations for the real economy sector"		
Int_B	The organization is not interested in innovative activities or is unable to engage in them. Financial resources for generating innovations are also absent or minimal	Very low	(0; 0; 0.15; 0.25)
	The organization has low innovation performance due to limited experience in innovative activities and insufficient financial resources	Low	(0.15; 0.25; 0.35; 0.45)
	The organization possesses sufficient financial resources and experience in innovative developments for potential success when interacting with it for the purpose of generating innovations	Average	(0.35; 0.45; 0.55; 0.65)
	The organization has high innovation effectiveness due to significant experience in innovative activities and financial capabilities	High	(0.55; 0.65; 0.75; 0.85)
	The organization is extremely interested in developing innovative activities due to its vast (possibly unique) experience in innovative developments and their application in its operations. The organization's financial capabilities fully allow for the generation of innovations, including jointly	Very high	(0.75; 0.85; 1; 1)

Table 1 (continued)

Indicator designation	Characteristic of linguistic variable	Estimation of term set	Trapezoidal number scales
	Linguistic variable "Component value"		
Ki	Very low value of the *i*-component of the intermediate or integral indicator	Very low	(0; 0; 0.15; 0.25)
	Low value of the *i*-component of the intermediate or integral indicator	Low	(0.15; 0.25; 0.35; 0.45)
	Average value of the *i*-component of the intermediate or integral indicator	Average	(0.35; 0.45; 0.55; 0.65)
	A high value of the *i*-component of the intermediate or integral indicator	High	(0.55; 0.65; 0.75; 0.85)
	Very high value of the *i*-component of the intermediate or integral indicator	Very high	(0.75; 0.85; 1; 1)

Source: Compiled by the author.

weight coefficients indicate that the lower the ordinal number of a component in the system, the greater the weight assigned to it, regardless of their total number in the group. Note that the Fishburn rule is applied in this study only to the *Ki*-components of integral indicators. Intermediate K indicators are considered equivalent within the boundaries of a single integral indicator.

After selecting the components and assessing the significance levels, it is necessary to create a fuzzification base — a set of trapezoidal numbers ordered according to all possible values of linguistic variables and part of the possible magnitudes of each component (*Table 4*). At the same time, trapezoidal numbers are the result of an expert evaluation, as the fuzzy logic apparatus used involves the participation of experts in the fuzzification and defuzzification of data. The use of trapezoidal numbers is also due to the possibility of establishing a sufficient degree of uncertainty when experts work with fuzzy values.

It should be emphasized that in the case of significant changes in the external environment or changes in the model structure, the fuzzification base must be adjusted each time to ensure the principle of adaptability [8]. Only trapezoidal numbers are included for unnormalized values of the components *Ki*. Three integral and four intermediate indicators take values limited to the range [0; 1], which makes their fuzzification unnecessary. The linguistic identification of integral and intermediate indicators is immediately carried out using the scales from *Table 1*, bypassing the fuzzification stage.

Next, the experts perform fuzzification of the component values using the developed database with the help of the degree of membership calculation system (3):

$$\lambda_{ij} = \begin{cases} 1 \ at\ Ki \le a_1, if\ j = 1 \\ 0 \ at\ Ki \le a_1, if\ j \in [2;4] \\ \dfrac{Ki - a_1}{a_2 - a_1} \ at\ a_1 < Ki < a_2 \\ 0,5 \ at\ Ki = a, if\ a_1 = a_2 \\ 1 \ at\ a_2 \le Ki \le b_1 \\ 0,5 \ at\ Ki = b, if\ b_1 = b_2 \\ \dfrac{b_2 - Ki}{b_2 - b_1} \ at\ b_1 < Ki < b_2 \\ 0 \ at\ Ki \ge b_2, if\ j \in [2;4] \\ 1 \ at\ Ki \ge b_2, if\ j = 5 \end{cases}, \qquad (3)$$

where: λ_{ij} — degree of membership of *Ki* to the term set *j*, $\lambda_{ij} \in [0;1]$; *Ki* — unstandardized component values; a_1 — the abscissa of the vertex of the left corner of the lower base of the fuzzy trapezoidal number function; a_2 — the abscissa of the vertex of the left corner of the upper base of the fuzzy trapezoidal number function; b_1 — the abscissa of the vertex of the right angle of the upper base of the fuzzy trapezoidal number function; b_2 — the abscissa of the vertex of the right angle of the lower base of the fuzzy trapezoidal number function.

The matrix method involves reducing the obtained values of components into a fuzzy value matrix μ_{Ki} of size *i*×*j* of the form (4), in which the *i*-th row of the matrix contains fuzzified values λ_{ij}, that characterize the degree of membership of each *Ki*-component to the formed evaluations of the term sets μ_j. In the *i*-th row for calculation, the value corresponding to the criterion $\lambda_i \to \max$, is selected, the value of the weighting coefficient w_i is determined, and in the j-th column — the linguistic characteristic of the term set to which K*i* belongs to the greatest extent. According to the same criterion, the corresponding intersection point ω_j for this term set (and linguistic characteristic) is sought.

$$\mu_{Ki} = \begin{pmatrix} \lambda_{11} & \lambda_{12} & \dots & \lambda_{1j} \\ \lambda_{21} & \lambda_{22} & \dots & \lambda_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{i1} & \lambda_{i2} & \dots & \lambda_{ij} \end{pmatrix}. \quad (4)$$

Table 2

The components of the integrated indexes of innovation effectiveness

№	Name of the component
	Components of the intensity of development of solutions for the current technological paradigm
A1	The level of regulatory framework for digitalization processes and innovative processes
A2	The presence of digital economy specialists, % of the total employed
A3	Investments in digital technologies, million rubles
A4	Share of innovative products, % of the total market volume
A5	Level of innovative activity of organizations, %
A6	Share of innovative products owned by Russian rights holders, % of the total market volume
A7	Share of expenses on digital technology development, % of total research and development expenses
A8	Organizations using information protection measures, %
A9	Organizations with a website, %
A10	Organizations using broadband Internet access, %
A11	Organizations using electronic data interchange, %
A12	Organizations using personal computers, %

Table 2 (continued)

№	Name of the component
Components of the research integration level of a higher education institution	
B1	The number of technology parks and business incubators created at the university, units
B2	Number of spin-off companies, units
B3	Number of implemented projects from the real sector of the economy, units
B4	Number of subject collaborations, units
B5	Research income from the real sector of the economy, thousand rubles
B6	Number of item purchases, units
B7	Total amount of item purchases, million rubles
Components of innovation effectiveness for higher education institutions	
C1	Research income, thousand rubles
C2	Number of patents and intellectual property rights owned by the university, units
C3	Number of license agreements, units
C4	Share of research income, % of total university income
C5	Share of income from the use of intellectual property results, % of the university's total income
G1	Number of subject laboratories, units
G2	The number of publications of the university indexed in scient metric databases, units
Components of innovation effectiveness for the real sector of the economy	
D1	Volume of research conducted by the organization and/or on its behalf, million rubles
D2	Weighted relative turnover, million rubles
D3	Number of patents and IP owned by the organization, units
D4	The coefficient of patent utilization in the organization's production activities

Source: Compiled by the author based on data from the Russian Statistical Yearbook (Rosstat). URL: https://rosstat.gov.ru/storage/mediabank/Ejegodnik_2023.pdf accessed on 16.10.2024), calculation methods of Europe's most innovative universities. URL: https://www.reuters.com/graphics/EUROPE-UNIVERSITIES-INNOVATION/010091N72J7/ (accessed on 16.10.2024); The Impact Rankings URL: https://the-ranking.s3.eu-west-1.amazonaws.com/IMPACT/IMPACT2023/THE.ImpactRankings.METHODOLOGY.2023_v1.2.pdf (accessed on 16.10.2024); University Innovation Rankings URL: https://www.scimagoir.com/methodology.php (accessed on 16 October 2024); The World University Rankings for Innovation. URL: https://www.wuri.world/_files/ugd/8e5131_708743231b0a45ffacc8470fc959c980.pdf (accessed on 16 October 2024); [14–16].

Table 3

The system of Fishburne weights for the components of the integrated indexes

Ki	1	2	3	4	5	6	7	8	9	10	11	12	N
No. A*i*	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	12
Weight A*i*	0.15	0.14	0.13	0.12	0.10	0.09	0.08	0.06	0.05	0.04	0.03	0.01	–
No. B*i*	B1	B2	B3	B4	B5	B6	B7	–	–	–	–	–	7
Weight B*i*	0.25	0.21	0.18	0.14	0.11	0.07	0.04	–	–	–	–	–	–
No. C*i*	C1	C2	C3	C4	C5	–	–	–	–	–	–	–	5
Weight C*i*	0.33	0.27	0.20	0.13	0.07	–	–	–	–	–	–	–	–
No. G*i*	G1	G2	–	–	–	–	–	–	–	–	–	–	2
Weight G*i*	0.67	0.33	–	–	–	–	–	–	–	–	–	–	–
No. D*i*	D1	D2	D3	D4	–	–	–	–	–	–	–	–	4
Weight D*i*	0.4	0.3	0.2	0.1	–	–	–	–	–	–	–	–	–

Source: Compiled by the author based on formula (2).

Weight coefficients and intersection points do not make sense to represent in matrix form due to the fact that traditional mathematical rules for working with matrices will not yield the desired result because of incomplete compatibility with the fuzzy integral convolution method used. Instead, a defuzzification formula has been developed to convert fuzzy component values into crisp ones (5):

$$Int_{\mu} = \sum_{j=1}^{n=5} \omega_j \sum_{i=1}^{N} w_i \lambda_{ij} , \qquad (5)$$

where: Int_{μ} — integral or intermediate indicator calculated using fuzzy logic; ω_j — points of intersection corresponding to the membership function *j*; w_i — weight coefficients of the *i*- indicator; λ_{ij} — fuzzy values of the *i*- indicator, selected by the criterion $\lambda_i \to \max$.

As a result of using the matrix method, defuzzification is carried out through double integral convolution of the component values (obtained from the expert's work with the fuzzification base), using not only weighting coefficients but also intersection points.

The location and values of the latter depend on the type and number of membership functions in the used set. Researchers often suggest calculating the intersection points using formula (6) [13, 18, 19]:

$$\varpi_j = 0,9 - 0,2 \times (j - 1) , \qquad (6)$$

where: ϖ_j — intersection points corresponding to the function of belonging j with the inverse nature of the indicator; j — the serial number of the belonging function in the aggregate. In addition to the analytical method,

Table 4

The fuzzification base for converting a standard numbers into a fuzzy numbers

Term Set Score	Very Low	Low	Average	High	Very High
Ki	Trapezoidal numbers for evaluating term sets of values of the linguistic variable "Intensity of development of solutions of the current technological paradigm"				
A1	(0; 0; 0.1; 0.3)	(0.1; 0.3; 0.5; 0.6)	(0.5; 0.6; 0.7; 0.8)	(0.7; 0.8; 0.9; 0.95)	(0.9; 0.95; 1; 1)
A2	(0.2; 0.2; 0.4; 0.7)	(0.4; 0.7; 1.3; 1.6)	(1.3; 1.6; 2.1; 2.4)	(2.1; 2.4; 2.7; 3)	(2.7; 3; 3.3; 3.3)
A3	(242; 242; 38638; 77277)	(38638; 77277; 135235; 164214)	(135235; 164214; 222172; 251151)	(222172; 251151; 309109; 347748)	(309109; 347748; ∞; ∞)
A4	(0.1; 0.1; 2.2; 4.4)	(2.2; 4.4; 7.7; 9.3)	(7.7; 9.3; 12.6; 14.2)	(12.6; 14.2; 17.5; 19.7)	(17.5; 19.7; 21.8; 21.8)
A5	(1.1; 1.1; 3.3; 6.6)	(3.3; 6.6; 11.6; 14.1)	(11.6; 14.1; 19; 21.5)	(19; 21.5; 26.5; 29.8)	(26.5; 29.8; 32; 32)
A6	(0; 0; 9; 17.9)	(9; 17.9; 31.4; 38.1)	(31.4; 38.1; 51.5; 58.2)	(51.5; 58.2; 71.7; 80.6)	(71.7; 80.6; 89.6; 89.6)
A7	(0; 0; 2.8; 5.5)	(2.8; 5.5; 9.7; 11.8)	(9.7; 11.8; 15.9; 18)	(15.9; 18; 22.2; 24.9)	(22.2; 24.9; 27.7; 27.7)
A8	(48.2; 48.2; 49.6; 51.9)	(49.6; 51.9; 53; 57.1)	(53; 57.1; 70.5; 73.9)	(70.5; 73.9; 77.2; 80.6)	(77.2; 80.6; 86.1; 86.1)
A9	(29.2; 29.2; 30.1; 33)	(30.1; 33; 32.1; 37.5)	(32.1; 37.5; 46.4; 48.6)	(46.4; 48.6; 50.8; 53)	(50.8; 53; 59.1; 59.1)
A10	(46.6; 46.6; 48; 50.6)	(48; 50.6; 51.3; 56.1)	(51.3; 56.1; 69.2; 72.5)	(69.2; 72.5; 75.8; 79.1)	(75.8; 79.1; 85.3; 85.3)
A11	(28.9; 28.9; 29.8; 34.6)	(29.8; 34.6; 31.8; 40.8)	(31.8; 40.8; 50.3; 52.7)	(50.3; 52.7; 55.1; 57.5)	(55.1; 57.5; 67; 67)
A12	(52.6; 52.6; 54.2; 56)	(54.2; 56; 57.9; 61.2)	(57.9; 61.2; 75.5; 79.1)	(75.5; 79.1; 82.7; 86.3)	(82.7; 86.3; 91.3; 91.3)
Ki	Trapezoidal numbers for evaluating the term sets of values of the linguistic variable "Level of research integration of a higher education institution"				
B1	(0; 0; 0; 0)	(0; 0; 1; 1)	(1; 1; 2; 2)	(2; 2; 3; 3)	(3; 3; 4; 4)
B2	(0; 0; 2; 4)	(2; 4; 7; 9)	(7; 9; 12; 13)	(12; 13; 16; 18)	(16; 18; 20; 20)
B3	(0; 0; 20; 40)	(20; 40; 70; 85)	(70; 85; 115; 130)	(115; 130; 160; 180)	(160; 180; 200; 200)
B4	(0; 0; 15; 30)	(15; 30; 53; 64)	(53; 64; 86; 98)	(86; 98; 120; 135)	(120; 135; 150; 150)
B5	(0; 0; 383; 766)	(383; 766; 1341; 1629)	(1341; 1629; 2203; 2491)	(2203; 2491; 3065; 3449)	(3065; 3449; ∞; ∞)
B6	(0; 0; 0; 0)	(0; 0; 1; 1)	(1; 1; 2; 2)	(2; 2; 3; 3)	(3; 3; 4; 4)
B7	(0; 0; 0; 0)	(1.5; 3; 5.3; 6.4)	(5.3; 6.4; 8.6; 9.8)	(8.6; 9.8; 12; 13.5)	(13.5; 15; ∞; ∞)
Ki	Trapezoidal numbers for evaluating the term sets of values of the linguistic variable "Level of result conformity"				
C1	(0; 0; 272; 544)	(272; 544; 952; 1156)	(952; 1156; 1564; 1768)	(1564; 1768; 2176; 2448)	(2448; 5759; ∞; ∞)
C2	(0; 0; 6; 12)	(6; 12; 21; 26)	(21; 26; 35; 39)	(35; 39; 48; 54)	(48; 54; 60; 60)
C3	(0; 0; 6; 12)	(6; 12; 21; 26)	(21; 26; 35; 39)	(35; 39; 48; 54)	(48; 54; 60; 60)
C4	(0; 0; 5; 10)	(5; 10; 18; 21)	(18; 21; 29; 33)	(29; 33; 40; 45)	(40; 45; 50; 50)
C5	(0; 0; 0.01; 0.02)	(0.01; 0.02; 0.03; 0.04)	(0.03; 0.04; 0.05; 0.06)	(0.05; 0.06; 0.07; 0.08)	(0.07; 0.08; 0.1; 0.1)
Ki	Trapezoidal numbers for evaluating the term sets of values of the linguistic variable "Level of resource provision"				
G1	(0; 0; 1; 3)	(1; 3; 5; 6)	(5; 6; 8; 9)	(8; 9; 11; 13)	(11; 13; 15; 15)
G2	(0; 0; 3061; 6122)	(3061; 6122; 10713; 13008)	(10713; 13008; 17600; 19895)	(17600; 19895; 24486; 27547)	(24486; 27547; 30608; 30608)
Ki	Trapezoidal numbers for evaluating the term sets of values of the linguistic variable "Effectiveness of innovations for the real sector of the economy"				
D1	(0; 0; 17; 34)	(17; 34; 59; 72)	(59; 72; 97; 110)	(97; 110; 135; 152)	(152; 200; ∞; ∞)
D2	(0; 0; 0.2; 0.4)	(0.2; 0.4; 0.7; 0.85)	(0.7; 0.85; 1.15; 1.3)	(1.15; 1.3; 1.6; 1.8)	(1.6; 1.8; 2; 2)
D3	(0; 0; 1; 2)	(1; 2; 3; 4)	(3; 4; 5; 6)	(5; 6; 7; 8)	(8; 9; 10; 10)
D4	(0; 0; 0.02; 0.04)	(0.02; 0.04; 0.08; 0.09)	(0.08; 0.09; 0.13; 0.14)	(0.13; 0.14; 0.18; 0.19)	(0.18; 0.19; 0.2; 0.2)

Source: Compiled by the author.

a graphical method for determining intersection points is also applicable [20, 21] — they are equal to the x-coordinates of the midpoints of the upper bases of all membership functions in the set.

When using the formula (6) proposed in several sources and further comparing it with the results obtained graphically, it becomes evident that the results of calculating the nodal coefficients on the fuzzy value vector are inversive. In other words, such a distribution of nodal coefficients is suitable for cases where a low level of the indicator corresponds to a high qualitative characteristic. No indicator or component in the developed system possesses such a property, which necessitates the derivation of the inverse formula (7), yielding non-inversive values of the nodal coefficients. The complete match with the results obtained graphically indicates the correctness of the derived formula:

$$\omega_j = 0,2 \times (1 + j) - 0,3 , \quad (7)$$

where ω_j — intersection points corresponding to the membership function *j* with a non-inversive nature of the indicator; *j* — ordinal number of the membership function in the compiled set.

The result of finding the intersection points for a set of five trapezoidal membership functions (see *Fig. 2*) is presented in *Table 5*.

The purpose of the existence of intersection points lies in the additional reduction of subjectivity in the constructed fuzzy model. Thus, in addition to the already existing uncertainty intervals (which are the sides of the trapezoids used in the fuzzy number model), intersection points add the possibility of recognizing absolute certainty based on the criterion of maximum proximity to them [22].

Intersection points represent node coefficients that serve as an additional weighting system alongside the established Fishburn system [20], with the decision on the application of a particular set being made by an expert. In this model (considering the provided justification), values obtained analytically using formula (7) for non-inversive indicators are used.

At the final stage, after performing the integral convolution, linguistic identification of intermediate and integral indicators is carried out, as a result of which qualitative (linguistic) characteristics are assigned to the already existing quantitative characteristics of the latter.

CONCLUSION

The evaluation of innovation effectiveness is an important task for both the academic and real sectors of the economy, highlighting the need to create methods that facilitate its implementation. Among them is the fuzzy set model devel-

Table 5

The calculation results for the intersection points

The value of *j*	**1**	**2**	**3**	**4**	**5**
Values ϖ_j, obtained analytically using formula (6)	0.9	0.7	0.5	0.3	0.1
Values ω_j, obtained graphically	0.1	0.3	0.5	0.7	0.9
Values ω_j, obtained analytically using formula (7)	0.1	0.3	0.5	0.7	0.9

Source: Compiled by the author.

oped during the research and presented in the article. Its features and limitations can be noted as follows:

1. The use of more than one integral indicator to assess the effectiveness of innovations.

As a rule, in similar studies, a single integral indicator is proposed for calculation, which comprehensively characterizes some aspect of the economic condition or activity of the subject [23–26], but in this case, it was decided to use three without combining them into a single one to avoid unjustified model complexity.

2. The possibility to calculate the result of the interaction between a single higher education institution and a single organization in the real economy sector in one iteration.

Despite this circumstance, the model is universal. This limitation is mitigated by the absence of a restriction on the number of possible iterations, which hypothetically allows for the calculation and evaluation of the effectiveness of innovations applied during interactions, for example, between a university and a group of organizations, by sequentially replacing data Int_B for each of them. The universality of the model is also characterized by the ability to replace data Int_U and Int_S without a significant risk of encountering a lack of necessary information for calculations.

3. The impossibility of accounting for absolutely all factors affecting the effectiveness of inter-organizational innovations.

This limitation arises because the set of components presented in the study is based on the examination and analysis of the most popular international studies, indices, and rankings, although in reality, there are many more sources of this kind. The impact of this limitation was reduced by following the principles of a systems approach, formulated in an earlier study by the author of this article [8].

4.The presence of subjectivity in the use of expert evaluations.

The application of trapezoidal membership functions and intersection points during defuzzification helps reduce the subjectivity of the model, but does not eliminate it completely.

Future research is planned to focus on the testing of a fuzzy-set model for the integral assessment of the effectiveness of inter-organizational innovations with the aim of its further development and improvement.

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Conflicts of Interest Statement: The author has no conflicts of interest to declare.

The article was submitted on 17.10.2024; revised on 10.01.2025 and accepted for publication on 05.02.2025. The author read and approved the final version of the manuscript.