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Assessment of risks of failure to achieve target values of indicators for an organization's intellectual capital based on a fuzzy model

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Abstract

The processes of formation and development of intellectual capital in the digital economy are ill structured processes occurring in conditions of a significant increase in the speed and unpredictability of changes in the external environment. This makes it extremely difficult to use previous experience and probabilistic forecasts when assessing the risks of failure to achieve strategic goals for the development of the intellectual capital of an organization. At the same time, undesirable deviations in achieving these goals can lead to significant negative consequences. In this regard, there is a need to develop appropriate fuzzy methods and models, all of which determines the relevance of this work. The purpose of this study was to develop a fuzzy method for assessing the risks of failure to achieve the strategic goals of an organization in the field of intellectual capital development. The method is based on a fuzzy model developed by the authors which allows us to take into account the uncertainty tolerance of the decision maker. Testing the method on the example of a specific organization showed the possibility of its practical applicability. We provide quantitative assessments and qualitative interpretations of the risk levels of failure to achieve target indicators for the development of the intellectual capital of an organization (a large regional university).

Keywords: intellectual capital, fuzzy model, risks of failure to achieve goals, project portfolio risk management, tolerance to uncertainty

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Introduction

The formation and implementation of strategic goals are the core of the strategic process in an organization [1, 2]. Other key features of the strategic process are strategic reflection (search for the best ways to achieve goals) and strategic actions (implementation of programs, projects, events) [3].

The strategic process (like any other activity of an economic entity) is carried out in conditions of uncertainty, the presence of which leads to the risks of failure to achieve goals.

The system of strategic goals of an organization may include goals that require unconditional fulfillment. Failure to achieve these goals may lead to the termination of its existence. In this regard, the accuracy of assessing the risks of failure to achieve such goals is of critical importance [4]. The presence of risks of failure to achieve the goal requires a reserve of "dead" ("insurance") resources, the use of which is assumed in the event of threats on the way to the goal [5]. Increasing the accuracy of risk assessment will avoid unnecessary "freezing" of resources.

Inaccuracy in assessing the risks of failure to achieve goals may also lead to unnecessary expenditure of resources allocated at the stage of planning strategic actions (formation of development plans and programs, selection of projects). In turn, this may lead to overfulfillment of some goals with corresponding negative consequences [6].

From the standpoint of the operational theory of risk management, the level of risk of deviation from the organization's goals can be considered a characteristic of the quality of management. Within the framework of the theory, economic risk is considered as a category reflecting the measure of the reality of an undesirable deviation from the goals and the amount of losses caused by this deviation. In this case, the assessment of the measure of deviation can be carried out, for example, in the form of additional costs or a decrease in the economic effect caused by the implementation of a management decision [7].

In the theory of economic risk management, the analysis and comparison of information about the economic situation can occur in two different situations (time slices): at the stage of decision preparation and at the stage of decision implementation [7].

For the second stage, the methods for assessing the risks of failure to achieve goals are devoted to identifying and assessing possible obstacles – events in the external environment that prevent the achievement of goals. Depending on the method of assessing obstacles, models can be probabilistic [8–13] or fuzzy [14–18]. There are also models in which the fuzzy approach is supplemented by probabilistic analysis [19].

At the first stage, the generation of decision options (management actions) takes place, the sufficiency (for decision-making) of the available information is assessed, the initial information is supplemented and clarified, the results of applying the selected decisions and their compliance with the set goals are predicted [7].

A management decision (a decision option) is a decision to select from a variety of possible strategic measures (each of which has the necessary resources and certain consequences) a specific set of measures aimed at achieving goals [20]. In most cases, strategic measures can be considered as projects (reconstruction and development), and accordingly, the choice of a set of measures represents the formation of a project portfolio.

Project Portfolio Risk Management (PPRM) is an established field of research that focuses on the processes of identifying and balancing project portfolio risks while striving to maximize the value received by the organization, as reflected in the achieved impact on strategic objectives [21]. Thus, PPRM focuses on the management capabilities of the organization to reduce the negative impact of risks and expand opportunities, taking into account the interdependencies between projects and risks [22–25].

In PPRM, both established and promising research areas can be identified [21]. One of these areas is the development of models and methods for assessing project portfolio risks (PPR).

Existing methods for assessing portfolio risk are based on various approaches to modeling uncertainty. In stochastic models, uncertainty is described by a probability distribution. In fuzzy models, uncertainty is described by a membership function [26]. In non-stochastic game models, an unstructured set of potentially possible values of an elementary event is specified [7].

Risk management theory shifts the emphasis towards the study of ill structured phenomena [7]. At present, these phenomena occur in conditions of a significant increase in the speed and unpredictability of changes in the external environment. This makes it extremely difficult to use previous experience (historical data) [27] and probabilistic forecasts.

In this regard, in recent years, a wide variety of fuzzy models have been actively developed to assess the risks of a project portfolio and take into account the resulting risk assessments when selecting a portfolio. It is worth noting the work of Mohagheghi and co-authors [28], who proposed an original approach to selecting the optimal portfolio of projects to achieve sustainable development goals using interval-valued fuzzy sets to take into account uncertainty and various criteria (indices) reflecting risks. In the work of Shatalova [29], fuzzy models for assessing the comparative effectiveness of innovative projects in the formation of a program for the technological development of an industrial enterprise under conditions of non-stochastic uncertainty, taking into account risks, are proposed. In the work of Zaidouni et al. [30], fuzzy factor analysis is used to predict the risks of an IT project portfolio. The works of Mehlawat et al. [31], Khanjani Shiraz et al. [32], Deng and Yuan [33], Rahiminezhad Galankashi et al. [34], Mohseny-Tonekabony et al. [35], Wang et al. [36], Dehghani [37], Nguyen et al. [38], Abtahi [39], Yang et al. [40] should also be noted.

At the same time, the potential of the fuzzy approach in analyzing project portfolio risks has not been fully realized [21].

Achieving strategic goals leads to a change in strategic potential – "the totality of 'strategic' resources at the disposal of an enterprise that are of decisive importance for the capabilities and boundaries of the enterprise's functioning in certain conditions" [41, p. 352]. In the context of the development of the digital economy, the most important strategic resource of an organization is its intellectual capital.

The intellectual capital development strategy is part of the overall development strategy of the organization. The set of strategic goals that contribute to the development of intellectual capital is a subset of the set of all strategic goals of the organization. Undesirable deviations in achieving these goals lead to the negative consequences described above. At the same time, assessing the risks of such deviations is significantly more difficult than for most other strategic goals due to the specifics of intellectual capital: a large number of implicit and "qualitative" development factors, a strong dynamic impact of organization's intellectual capital components, etc. [42, 43].

In this regard, it is precisely fuzzy models for assessing the organization's intellectual capital and its components that come to the fore. Considerable attention is paid to such models in the review by Cosa et al. [44]. Of the relevant publications published no earlier than 2020, the following should be noted: Bustamante et al. [45], Kozlovskyi et al. [46], Çevik and Arslan [47], Pokrovskaia et al. [48], Lucchese et al. [49], Gross-Gołacka et al. [50].

At the same time, such an important issue (for the above reasons) as assessing the risks of not achieving the organization's intellectual capital targets remained untouched by the developers of the models.

Thus, the purpose of this study is to develop a fuzzy method for assessing the risks of failure to achieve strategic goals to support management decision-making in the area of developing the organization's intellectual capital.

The work contains four main sections. The first section provides a basic scheme of the method and describes the content of its main stages. The proposed method is based on a fuzzy model, which is described in detail in the second section of the article. The third section presents the results of testing the method using the example of a specific organization (a large regional university). The "Discussion" section formulates the advantages of the method; its contribution to the development of various areas of research; the possibilities and conditions for its use for organizations of various types and industries.

1. The method for assessing the risks of failure to achieve the target indicators of the organization's intellectual capital

The basic scheme of the proposed method for assessing the risks of failure to achieve strategic goals for the development of an organization's intellectual capital (hereinafter referred to as organization's intellectual capital) is shown in *Fig. 1*.

First of all, it is necessary to form a causal field of OIC development indicators according to the previously proposed scheme [51]. The selection of explicit and implicit factors located at the lowest level of the hierarchy and the assessment of their influence are

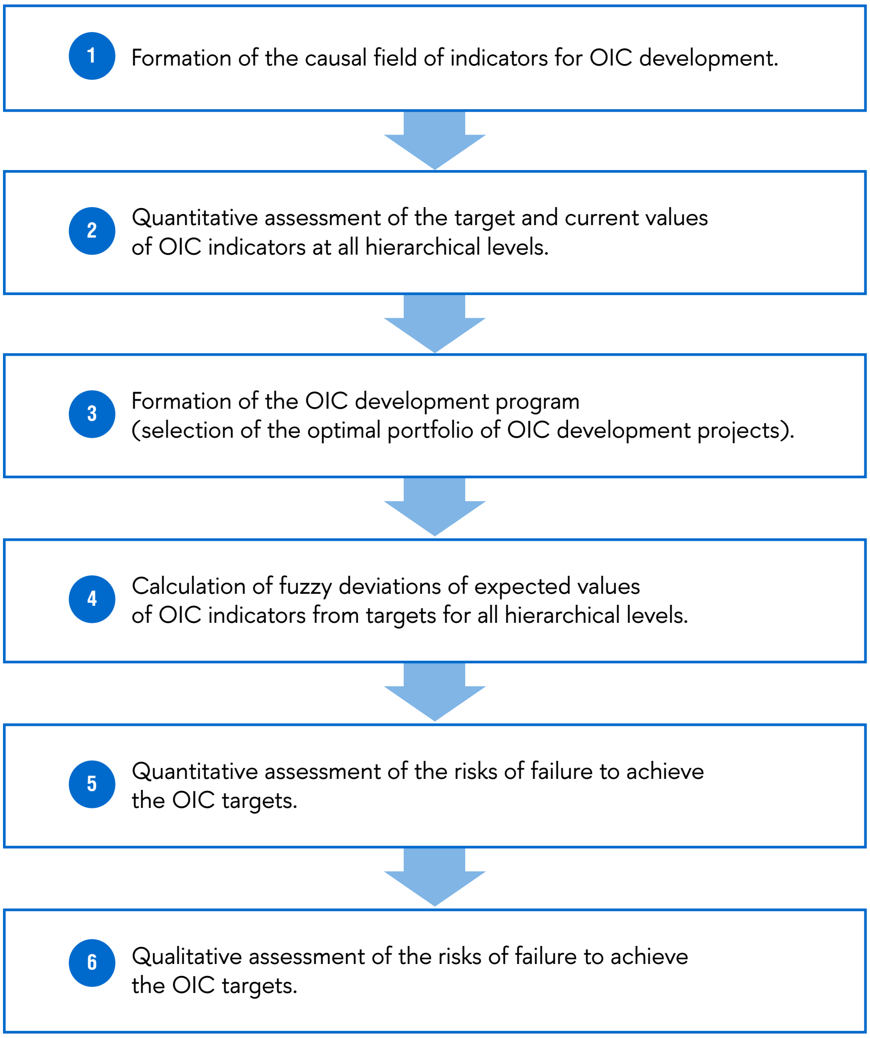

Fig. 1. Basic scheme of the method for assessing the risks of failure to achieve the organization's goals for the development of intellectual capital.

based on the author's fuzzy model. An example of a hierarchical structure of OIC development indicators for a specific organization (university) is given in section 3 (*Fig. 2*) [52, 53].

Some of the OIC indicators of the lowest level of the hierarchy are naturally assessed in quantitative scales. The other part (as well as almost all indicators of the overlying levels) is assessed in qualitative scales. Accordingly, significant difficulties arise in the process of moving up the hierarchy from bottom to top when evaluating the OIC integrated indicators up to the integral indicator of the intellectual capital of the organization as a whole. Another difficulty in assessing the OIC development indicators is related to the emergence of cycles in the hierarchy. In this regard, a fuzzy model was proposed that allows for a quantitative assessment of the OIC development indicators at all hierarchical levels [52].

This model was developed to assess the current level of OIC. At the same time, it can be successfully used in setting target values for OIC development indicators. Strategic goals in the field of OIC development arise within the framework of the general strategy of the organization, formalized on the basis of a modified Balanced Scorecard [51]. Accordingly, as a rule, crisp target values of the "quantitative" resulting indicators of such goals are known. The values of the "qualitative" resulting indicators are often not explicitly included in the strategy. And in the event that they are somehow established, it is unclear how to determine the target values of various integral OIC development indicators (corresponding to the main components of the OIC, the organization's abilities for certain cognitive activities and various aspects within the framework of certain types of cognitive activities). This is what this model can be used for.

After the fuzzy target and current values of all indicators in the hierarchy have been quantitatively determined, a program for the OIC strategic development can be formed. This program is a set of strategic events (projects), the implementation of which results in the achievement (to one degree or another) of the strategic goals for the OIC development. Thus, the values of the lagging indicators of these goals (indicators of the OIC development) reach the target values or approach them.

In [53], fuzzy optimization models for forming a project portfolio for the OIC development taking into account risks are proposed. Fuzzy optimization problems are reduced to crisp problems of Boolean quadratic programming using the methods proposed in [54–56]. In this case, it is necessary to set the satisfaction degrees for the objective function and each constraint. The satisfaction degrees determine the rigidity of the constraints and can influence the composition of the portfolio. It can be considered that the set satisfaction degrees determine the decision maker's tolerance to uncertainty [57].

The proposed models allow us to form an optimal portfolio of projects for the OIC development (depending on the selected target function and the specified constraints). At the same time, we obtain the expected fuzzy values of all OIC indicators in the hierarchy (when implementing this portfolio). Accordingly, fuzzy relative deviations of expected values from target values (degrees of failure to achieve target indicators) can be calculated.

These deviations reflect the risks of failure to achieve the target indicators of the OIC development. In turn, additional quantitative information can be obtained for convenience and increased accuracy of the qualitative interpretation of the risk level. First of all, each fuzzy deviation can be defuzzified by the selected method. In addition, a deviation fuzziness index can be calculated, which reflects the degree of blurriness of the fuzzy deviation [58].

In [42], a method for interpreting the risk level based on correspondence with the maximum possible value is proposed. Within the framework of an alternative approach, the correspondence coefficients of each fuzzy deviation to the intervals into which the universal set is divided are calculated [18]. The distribution of the correspondence coefficients determines the qualitative risk assessment.

The correspondence coefficients are the relative areas of figures bounded by the membership function curve from above and a given alpha level from below. It is important to note that the choice of the alpha level (as well as the choice of satisfaction degrees) determines the decision maker's tolerance to uncertainty: the lower the alpha, the greater the tolerance. A change in the decision maker's tolerance to uncertainty can lead to a change in the qualitative risk assessments. Moreover, as will be shown below, these changes can be two-sided: for some indicators, with an increase in the alpha level, the risk assessments will increase, while for others, on the contrary, they will decrease. Taking into account the decision maker's tolerance to uncertainty is a significant advantage of the proposed method for assessing the risks of failure to achieve the goals for the OIC development.

2. Fuzzy model

Let a causal field of OIC development indicators be formed. Fuzzy values of "qualitative" indicators of the lowest level are defined. Fuzzification of crisp values of "quantitative" indicators is carried out. Fuzzy inference systems (or simplified procedures [59]) are specified, allowing us to obtain fuzzy values of OIC indicators of all hierarchy levels. Target values are defined and current values of all indicators are calculated [52].

Let scenarios of possible changes in the internal and external environment be given, their fuzzy probabilities be defined. A set of possible projects for the OIC development are formed, and their budgets are fuzzy. Changes in the current values of the indicators of the lowest level (and, through them, all indicators in the hierarchy) are determined as a result of the implementation of each project for each scenario [53].

Note that the values of all the OIC indicators (except for the lowest level of the hierarchy), scenario probabilities, project budgets and changes in the indicators of the lowest level are Gaussian fuzzy numbers. The values of the indicators of the lowest level are trapezoidal fuzzy numbers.

We are formulating a program for the OIC development based on one of the proposed fuzzy optimization models (which are fuzzy Boolean quadratic programming problems) [53]. Let us recall that the models differ in their objective functions (maximization of specific utility or minimization of portfolio risk) and constraints (on the total budget of the development program, on the value of the program risk, or on the value of the expected specific utility). Let us also recall that the composition of the optimal project portfolio depends on the specified satisfaction degrees (on the objective function and constraints). For the selected optimal portfolio, we have expected fuzzy values of all OIC indicators.

We calculate the degree of failure to achieve the OIC target indicators as relative deviations of expected values from the target ones as follows:

$$\Delta_i = \frac{IC_i^T - IC_i^E}{IC_i^T}, \tag{1}$$

where

Δ_i is degree of non-achievement of the target value of the i-th OIC indicator;

IC_i^T is target value of the i-th OIC indicator;

IC_i^E is expected value of the i-th OIC indicator.

Note that in the general case, due to the fuzziness of the variables,

$$\Delta_i \neq 1 - \frac{IC_i^E}{IC_i^T}.$$

It is important to note that if $IC_i^E > IC_i^T$ (for the chosen fuzzy set comparison method), there may still be risks of not achieving the target value of the i-th indicator. In this case, we will calculate the fuzzy relative deviations of expected values from target values using the formula:

$$\Delta_i = \frac{IC_i^E - IC_i^T}{IC_i^E}. \tag{2}$$

Let $IC_i^T > IC_i^E$. Then $(\xi_i; \eta_i) \subseteq (a_i, b_i)$, where $(\xi_i; \eta_i)$ is the support of the fuzzy set Δ_i, a_i is the infimum of the support of the fuzzy set

$$\frac{IC_i^T - IC_i^T}{IC_i^T},$$

b_i is the supremum of the support of the fuzzy set

$$\frac{IC_i^T}{IC_i^T}.$$

If $IC_i^E > IC_i^T$, then a_i should be taken as the infimum of the support of the fuzzy set

$$\frac{IC_i^E - IC_i^E}{IC_i^E},$$

and b_i should be taken as the supremum of the support of the fuzzy set

$$\frac{IC_i^E}{IC_i^E}.$$

Let's consider bijections $f_i:(a_i;b_i)\to(0;1)$,

$$f_i(x)=\frac{x-a_i}{b_i-a_i}. \tag{3}$$

These mappings allow us to move from fuzzy deviations $\varDelta_i$ to fuzzy sets $\varDelta_i'$ whose supports are subsets of the interval (0;1).

We calculate the fuzziness indices of the sets using a given method [60]. We denote them θ_i. We perform defuzzification of fuzzy sets $\varDelta_i'$ using one of the selected methods. The resulting crisp values are denoted by ω_i.

We divide the interval (0; 1) into h intervals (0; ξ_1), (ξ_1; ξ_2), ..., (ξ_{h-1};1) (these intervals may be equal, but in general this is not necessary).

We calculate the coefficients of correspondence of fuzzy sets $\varDelta_i'$ to these intervals ($0 \leqslant \alpha < 1$). We denote them $\delta_1^i,\delta_2^i,\ldots,\delta_h^i$.

For $\alpha = 1$, δ_j^i is the measure of intersection of the core of the fuzzy set $\varDelta_i'$ and the interval (ξ_{j-1};ξ_j). As a defuzzification method for a single alpha level, it is reasonable to use the mean maximum method.

A qualitative assessment of the risk of failure to achieve the target value of the i-th OIC indicator occurs in a given linguistic scale based on the distribution of coefficients $\delta_1^i,\delta_2^i,\ldots,\delta_h^i$. If $IC_i^T > IC_i^E$, then the higher the correspondence coefficients with smaller lower indices and the smaller the coefficients with larger lower indices, the lower the risk level, and vice versa. If $IC_i^E > IC_i^T$, then the risk level is lower, the smaller the correspondence coefficients with smaller subscripts and the larger the coefficients with larger subscripts.

Also taken into account are ω_i and θ_i. Note that the smaller θ_i, the more reliable the qualitative risk assessments obtained, and vice versa.

In the future, a formalized procedure for determining a certain integral coefficient (as a function of variables $\delta_1^i, \delta_2^i, \ldots,\delta_h^i,\omega_i, \theta_i$) may be proposed, on the basis of which the interpretation of the risk level will occur. However, the selection of such a function is complicated by the non-monotony in the general case of the sequence $\delta_1^i,\delta_2^i,\ldots,\delta_h^i$.

3. Approbation of the method

The method was tested on the example of a large regional university (Vladivostok State University, VVSU). Using the example of this university, some fuzzy models were previously tested which formed the basis of the method we developed [51–53].

The hierarchical system (causal field) of OIC development indicators is shown in *Fig. 2.* "Qualitative" OIC indicators at the lowest-level of OIC hierarchy are highlighted in yellow, while "quantitative" OIC indicators are marked in green.

The target values of the "quantitative" indicators were taken from the university's strategy, and the current values were taken from the management accounting system. The crisp current and target values have been fuzzified using the method proposed in [52]. Previously, the current values of the "quality" indicators were also obtained in the form of Gaussian fuzzy numbers [52]. Their target values were determined in a similar way (*Table 1*).

Next, fuzzy target and current values of the OIC indicators of all higher levels of the hierarchy were calculated. For this purpose, among other things, the bases of fuzzy production rules for the lowest-level of the hierarchy were formed. The target and current values of the university's intellectual capital indicators at all levels of the hierarchy, defuzzified using the center of gravity method, are presented in *Table 2.*

At the next step, a set of strategic measures (projects) was formed that contribute to the development of the intellectual capital of the university. The project budgets were expertly assessed in a given linguistic scale. Weighted average expert estimates of project budgets in the form of fuzzy Gaussian numbers are shown in *Table 3.*

Most of the projects (projects 1, 2, 3, 5, 8) are clearly aimed at increasing the human capital of the university.

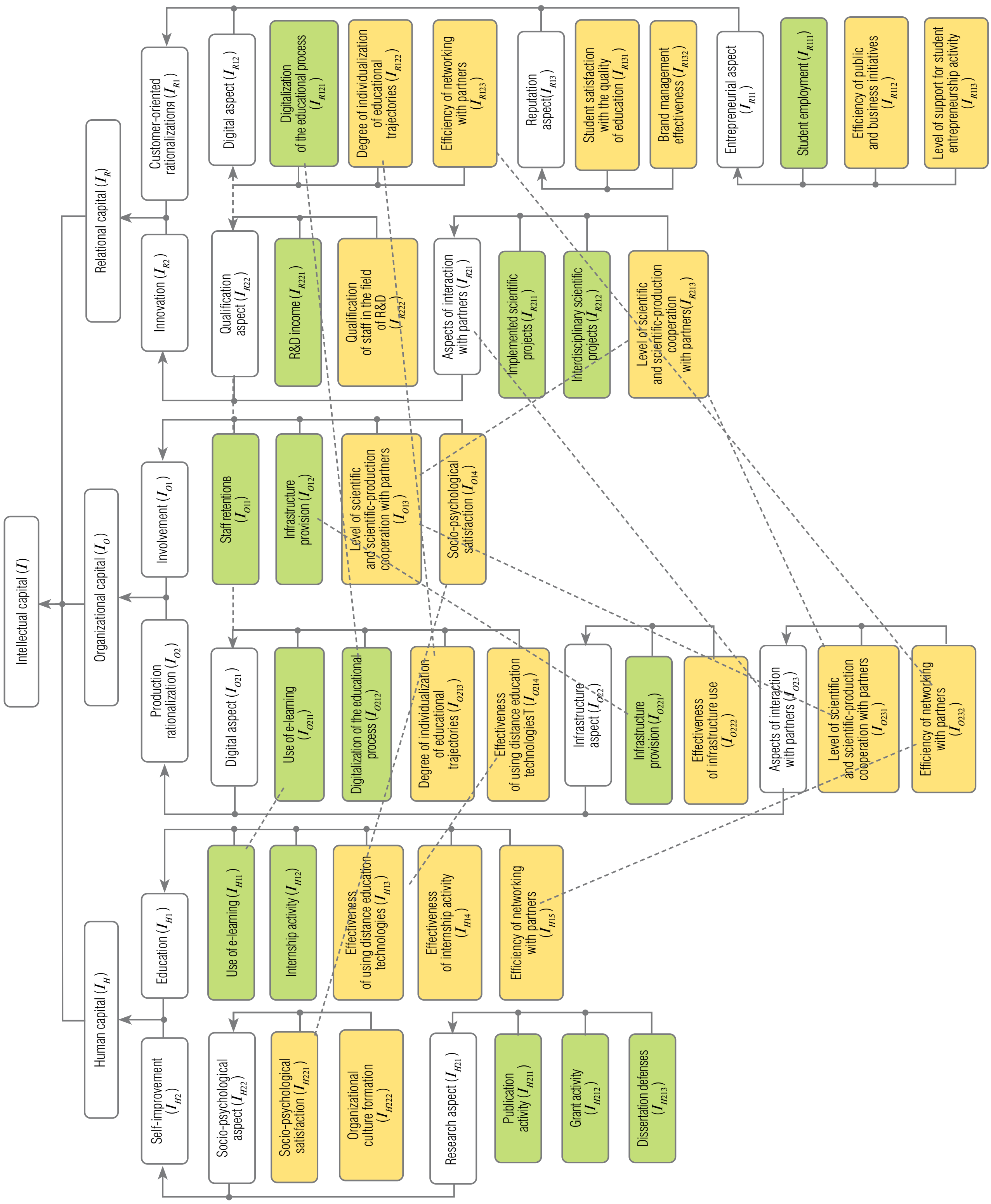

Fig. 2. The causal field of indicators of the university's intellectual capital development.

Table 1.

Current and target values of "qualitative" indicators of the university's intellectual capital[1]

Indicator	Structural component of the OIC	Cognitive activity	Parameters of the approximating Gaussian			
			Current value		Target value	
			μ	σ	μ	σ
Effectiveness of using distance education technologies (I_{H13}, I_{O214})	Human capital	Education	3.1492	0.4778	5.5782	0.6227
Effectiveness of internship activity (I_{H14})	Human capital	Education	1.3452	0.2555	2.7812	0.3451
Socio-psychological satisfaction (I_{H221}, I_{O14})	Human capital, Organizational capital	Self-improvement, Involvement	7.4240	0.8361	8.1243	0.7362
Organizational culture formation (I_{H222})	Human capital	Self-improvement	5.3308	0.5708	6.4687	0.6391
Level of scientific and scientific-production cooperation with partners (I_{O13}, I_{O231}, I_{R213})	Organizational capital, Relational capital	Involvement, Customeroriented rationalization, Innovation	3.1332	0.4081	5.2634	0.6132
Effectiveness of infrastructure use (I_{O222})	Organizational capital	Involvement, Production rationalization	9.0226	0.7395	9.3461	0.6564
Degree of individualization of educational trajectories (I_{O213}, I_{R122})	Organizational capital, Relational capital	Production rationalization, Customeroriented rationalization	1.3452	0.2555	2.6843	0.3154
Efficiency of networking with partners (I_{H15}, I_{O232}, I_{R123})	Organizational capital, Relational capital	Production rationalization, Customeroriented rationalization	3.1492	0.4778	5.5617	0.5996
Student satisfaction with the quality of education (I_{R131})	Relational capital	Customeroriented rationalization	5.3308	0.5708	6.9453	0.6124
Brand management effectiveness (I_{R132})	Relational capital	Customeroriented rationalization	7.3888	0.6720	8.2164	0.7985
Efficiency of public and business initiatives (I_{R112})	Relational capital	Customeroriented rationalization	3.1492	0.4778	5.8041	0.6124
Level of support for student entrepreneurship activity (I_{R113})	Relational capital	Customeroriented rationalization	3.1654	0.5360	5.7926	0.6309
Qualification of staff in the field of R&D (I_{R222})	Relational capital	Innovation	5.3308	0.5708	7.8098	0.7068

[1] A fragment of this table was presented in one of the authors' previous articles [52]. In this article, the last two columns have been added, which provide additionally calculated Gaussian parameters for the target values of the indicators.

Table 2.

Defuzzified target, current and expected values of target indicators of the university's intellectual capital

Fuzzy variable	Current value	Target value	Expected value
I	5.131	6.942	6.408
I_H	5.226	6.933	6.441
I_O	5.012	6.985	5.547
I_R	4.612	6.502	5.862
I_{H1}	2.829	5.218	4.426
I_{H2}	5.515	7.145	7.085
I_{O1}	5.459	6.878	7.464
I_{O2}	5.012	7.035	5.547
I_{R1}	4.612	6.502	5.862
I_{R2}	4.852	7.150	7.938
I_{H21}	4.099	6.517	5.635
I_{H22}	6.660	7.659	8.772
I_{O21}	2.829	5.205	4.454
I_{O22}	7.189	8.214	7.189
I_{O23}	3.939	6.775	4.452
I_{R11}	5.000	7.047	6.463
I_{R12}	2.829	5.440	3.452
I_{R13}	5.341	6.591	6.773
I_{R21}	2.885	5.623	3.672
I_{R22}	5.415	8.393	9.141

At the same time, each of them also affects organizational capital, and almost all of them (except the fifth) affect relational capital (albeit to a lesser extent). Projects 4 and 7 are primarily focused on increasing relational capital, while project 4 also partially affects human and organizational capital (due to the internal stakeholders of the university). Project 6 is primarily designed to ensure the growth of organizational capital, while it also significantly affects the relational capital and, to some extent, the human capital of the university.

Next, three scenarios were considered, the fuzzy probabilities of which are approximated by Gaussians: $\mu = 0.2955$, $\sigma = 0.0318$ (for the pessimistic scenario); $\mu = 0.5238$, $\sigma = 0.0497$ (for the realistic scenario); $\mu = 0.1974$, $\sigma = 0.0226$ (for the optimistic scenario).

Table 3.

Projects for the development of the university's intellectual capital [53]

Project number	Project name	Project budget (parameters of the approximating Gaussian)	
		μ (million rubles)	σ
1	Conducting training for educators in digital educational technologies, including MOOC creation technologies	12.24	1.71
2	Organization of educators' internships at enterprises	5.18	0.82
3	Enhancement of the system of material and non-material rewards and incentives for personnel	20.93	2.32
4	Identification of requests from stakeholders (applicants, parents, students, employers, teaching community) to the university	3.87	0.45
5	Organization of events (business, creative, sports, professional) aimed at team building	4.21	0.74
6	Development of the university's infrastructure component	18.36	2.17
7	Conducting socially oriented and socially significant activities based on the university	6.53	0.98
8	Comprehensive support for the development of scientific activities at the university	20.34	3.19

Within the framework of the scenarios, changes in the lowest-level OIC indicators are determined as a result of the implementation of each project. Weighted average expert responses in the form of Gaussian fuzzy numbers are partially shown in *Table 4*. The first project is missing from the table, since its implementation leads to changes in the values of only those indicators that other projects do not significantly affect.

The formation of the OIC development program was carried out according to the criterion of the minimum risk of the program with restrictions on the program budget (70 million rubles) and the value of the expected specific utility (0.6) with satisfaction degree of 0.9. The program includes projects with numbers: 1, 2, 3, 4, 8. The expected specific utility of the portfolio is 0.64; the expected budget of the portfolio is 62.56 million rubles.

The calculated expected fuzzy changes in all indicators of OIC development as a result of the implementation of the optimal portfolio allowed us to obtain the expected fuzzy values of OIC development indicators at all levels of the hierarchy (their values defuzzified by the centroid method are shown in *Table 2*). For four indicators ($I_{O1}, I_{R2}, I_{H22}, I_{R13}$), the centers of gravity of fuzzy expected values exceeded the centers of gravity of fuzzy target values, which, as noted above, does not exclude the risks of failure to achieve the target values of the indicators.

Then, using formula (1), fuzzy values of relative deviations of expected values from the target values (fuzzy degrees of non-achievement) were calculated.

Table 4.

Fuzzy changes in the lowest-level indicators of the university's intellectual capital development as a result of project implementation within scenarios (fragment)

OIC indicators / Project numbers	I_{H211}	I_{H221} (I_{O14})	I_{O11}	I_{R111}	I_{R113}	I_{R131}	I_{R132}	I_{R221}	I_{R222}
2				(0.241; 0.020) (0.139; 0.044) (0.078; 0.022)		(0.238; 0.022) (0.132; 0.019) (0.086; 0.011)		(0.152; 0.011) (0.106; 0.046) (0.048; 0.023)	(0.122; 0.011) (0.92; 0.046) (0.037; 0.023)
3	(0.150; 0.023) (0.090; 0.019) (0.035; 0.008)	(0.218; 0.013) (0.152; 0.030) (0.097; 0.011)	(0.225; 0.043) (0.220; 0.012) (0.153; 0.042)					(0.221; 0.048) (0.139; 0.014) (0.053; 0.024)	
4		(0.156; 0.016) (0.124; 0.013) (0.089; 0.009)		(0.231; 0.047) (0.210; 0.043) (0.121; 0.049)	(0.102; 0.046) (0.025; 0.043) (0.014; 0.021)	(0.153; 0.040) (0.075; 0.016) (0.028; 0.043)	(0.134; 0.040) (0.068; 0.044) (0.032; 0.012)	(0.148; 0.011) (0.102; 0.046) (0.051; 0.023)	
5		(0.241; 0.018) (0.141; 0.019) (0.081; 0.014)	(0.042; 0.013) (0.023; 0.006) (0.021; 0.005)						
6		(0.148; 0.015) (0.118; 0.012) (0.076; 0.008)				(0.147; 0.038) (0.091; 0.015) (0.059; 0.007)			
7				(0.136; 0.018) (0.087; 0.009) (0.048; 0.007)	(0.049; 0.037) (0.025; 0.023) (0.016; 0.006)		(0.227; 0.015) (0.210; 0.023) (0.149; 0.011)		
8	(0.205; 0.027) (0.131; 0.031) (0.073; 0.012)		(0.189; 0.016) (0.154; 0.030) (0.097; 0.029)					(0.226; 0.049) (0.204; 0.037) (0.117; 0.012)	(0.233; 0.049) (0.224; 0.037) (0.146; 0.012)

Next, the functions were selected, allowing for the transition from fuzzy deviations to fuzzy normalized deviations (formula (2)), for which the Yager indices of fuzziness with linear Hamming metric [61] (IOF), centers of gravity (COG) and means of maxima (MOM) were calculated.

The interval (0; 1) was divided into five equal intervals (0; 0.2), (0.2; 0.4), ..., (0.8; 1), for which the coefficients of deviation correspondence were calculated (at alpha levels of 0; 0.5 and 1).

Let us give an example of the corresponding calculations for the I_{O2} indicator, which characterizes the cognitive activity "Production rationalization".

The fuzzy normalized deviation of the expected value of the I_{O2} indicator from its target value is shown in *Fig. 3*. The fuzziness index of this fuzzy set is 0.269; center of gravity is 0.493; means of maxima is 0.647.

Table 5 shows the values of the coefficients of correspondence of the fuzzy set to the specified five intervals for different alpha levels.

We present in *Table 6* the calculated coefficients for all indicators and the qualitative interpretations of the risk levels of failure to achieve the target indicators for the development of the university's intellectual capital obtained on their basis (on the linguistic scale {Very Low (VL); Low (L); Medium (M); High (H); Very High (VH)}).

It is easy to see that the resulting qualitative interpretations of risk levels may depend significantly on the chosen alpha level. Thus, for the integral indicator of human capital I_H, the assessment of the risk of failure to achieve its target value changes from "Low" (at $\alpha = 0$) to "Medium" (at $\alpha = 0.5$) and, further, to "High" (at $\alpha = 1$). For the integral indicator of organizational capital I_O, the assessment of the risk of failure to achieve its target value, on the contrary, decreases from "Medium" to "Low" with an increase in alpha. For the I_{H2} and I_{O2} indicators corresponding to the cognitive activities "Self-improvement" and "Production rationalization", with an increase in alpha, the risk assessment increases from "Medium" to "High" (for the I_{O2} indicator, this is even more clearly demonstrated by the results presented in *Table 5*). Here, it is worth noting the low fuzziness index of the Δ'_{H2}, which indicates the reliability of the risk estimates for I_{H2}. At the same time, the risk assessment for the I_{O21} indicator, which characterizes the "Digital aspect" of "Production rationalization", changes from "Low" to "Medium".

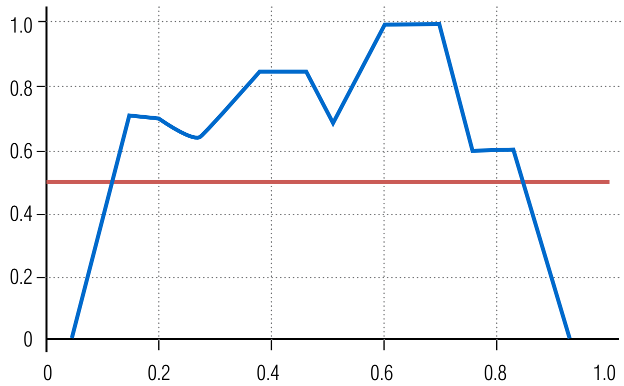

Fig. 3. Fuzzy normalized deviation of the I_{O2} expected value from target value.

Table 5.

Risk assessments of failure to achieve the target value of the I_{O2} indicator

Alpha level	Interval matching coefficients					Interpretation of the risk level
	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1	
0	0.35	0.72	0.81	0.85	0.24	Medium
0.1	0.31	0.69	0.79	0.84	0.20	Medium
0.2	0.27	0.65	0.76	0.72	0.16	Medium
0.3	0.22	0.61	0.73	0.79	0.12	Medium
0.4	0.18	0.54	0.69	0.76	0.08	Medium
0.5	0.13	0.45	0.63	0.71	0.04	Medium
0.6	0.07	0.32	0.54	0.64	0	Medium
0.7	0	0.15	0.40	0.57	0	High
0.8	0	0.04	0.21	0.56	0	High
0.9	0	0	0.06	0.51	0	High
1	0	0	0	0.47	0	High

Table 6.

Risk assessments of failure to achieve the target indicators of the university's intellectual capital

Fuzzy variable	Normalized degree of non-achievement			Interval matching coefficients (α = 0/ α = 0.5/ α = 1)					Interpretation of the risk level (α = 0/ α = 0.5/ α = 1)
	IOF	COG	MOM	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1	
I	0.331	0.464	0.456	0.19 / 0 / 0	0.81 / 0.65 / 0.06	0.95 / 0.92 / 0.64	0.62 / 0.34 / 0	0.08 / 0 / 0	M / M / M
I_H	0.275	0.462	0.598	0.39 / 0 / 0	0.71 / 0.54 / 0	0.81 / 0.67 / 0.21	0.57 / 0.42 / 0.21	0.07 / 0 / 0	L / M / H
I_O	0.362	0.489	0.332	0.13 / 0 / 0	0.85 / 0.71 / 0.70	0.92 / 0.89 / 0.20	0.76 / 0.55 / 0	0.10 / 0 / 0	M / M / L
I_R	0.263	0.464	0.450	0.18 / 0 / 0	0.64 / 0.36 / 0	0.88 / 0.78 / 0.36	0.46 / 0.11 / 0	0.07 / 0 / 0	M / M / M
I_{H1}	0.311	0.428	0.424	0.15 / 0 / 0	0.79 / 0.64 / 0.29	0.85 / 0.77 / 0.52	0.32 / 0.03 / 0	0.00 / 0 / 0	M / M / M
I_{H2}	0.148	0.491	0.613	0.23 / 0 / 0	0.53 / 0.09 / 0	0.56 / 0.12 / 0	0.59 / 0.31 / 0.12	0.05 / 0 / 0	M / H / H
I_{O1}	0.313	0.639	0.634	0 / 0 / 0	0.39 / 0.02 / 0	0.88 / 0.85 / 0.73	0.97 / 0.97 / 1	0.74 / 0.33 / 0.12	L / L / L
I_{O2}	0.269	0.493	0.647	0.35 / 0.13 / 0	0.72 / 0.45/ 0	0.81 / 0.63 / 0	0.85 / 0.71 / 0.47	0.24 / 0.04 / 0	M / M / H
I_{R1}	0.263	0.464	0.450	0.18 / 0 / 0	0.64 / 0.36 / 0	0.88 / 0.78 / 0.36	0.46 / 0.11 / 0	0.07 / 0 / 0	M / M / M
I_{R2}	0.206	0.611	0.604	0.03 / 0 / 0	0.37 / 0 / 0	0.65 / 0.37 / 0.36	0.72 / 0.31 / 0.46	0.57 / 0 / 0	L / L / L
I_{H21}	0.360	0.457	0.450	0.28 / 0.07 / 0	0.77 / 0.59 / 0.29	0.93 / 0.91 / 0.79	0.61 / 0.28 / 0	0.05 / 0 / 0	M / M / M
I_{H22}	0.263	0.530	0.638	0.02 / 0 / 0	0.25 / 0 / 0	0.36 / 0.08 / 0	0.64 / 0.44 / 0.23	0.53 / 0 / 0	L / L / L
I_{O21}	0.312	0.423	0.471	0.21 / 0 / 0	0.83 / 0.70 / 0	0.85 / 0.74 / 0.61	0.27 / 0.02 / 0	0 / 0 / 0	L / L / M
I_{O22}	0.306	0.379	0.375	0.14 / 0 / 0	0.78 / 0.67 / 0.67	0.62 / 0.38 / 0.38	0.07 / 0 / 0	0 / 0 / 0	L / L / L
I_{O23}	0.233	0.518	0.500	0.05 / 0 / 0	0.56 / 0.18 / 0	0.89 / 0.85 / 0.56	0.60 / 0.22 / 0	0.13 / 0 / 0	M / M / M
I_{R11}	0.321	0.403	0.397	0.19 / 0 / 0	0.86 / 0.76 / 0.51	0.80 / 0.71 / 0.45	0.23 / 0 / 0	0 / 0 / 0	L / L / L
I_{R12}	0.312	0.497	0.457	0.04 / 0 / 0	0.59 / 0.34 / 0.12	0.92 / 0.92 / 0.68	0.51 / 0.18 / 0	0.06 / 0 / 0	M / M / M
I_{R13}	0.374	0.564	0.562	0.03 / 0 / 0	0.08 / 0 / 0.4	0.71 / 0.52 / 0.37	0.34 / 0.09 / 0	0.05 / 0 / 0	L / M / M
I_{R21}	0.373	0.511	0.494	0.02 / 0 / 0	0.70 / 0.52 / 0.31	0.94 / 0.94 / 0.94	0.77 / 0.61 / 0.31	0.09 / 0 / 0	M / M / M
I_{R22}	0.277	0.333	0.342	0.34 / 0.01 / 0	0.89 / 0.82 / 0.57	0.54 / 0.25 / 0	0.08 / 0 / 0	0 / 0 / 0	L / L / L

Let us pay special attention to the indicators for which the center of gravity of the expected value exceeds the centroid of the target value (I_{O1}, I_{R2}, I_{H22}, I_{R13}). For all these indicators, at zero alpha, the risk of not achieving the target value is "Low," as well as for the other alphas (excluding only I_{R13}, for which, with an increase in alpha, the risk assessment reaches the value "Medium"). In no case did the risk assessment reach the value of "Very Low," which is apparently due to the fact that the excess of expected values over target values (by centers of gravity) was not very significant. Moreover, for the I_{R13} indicator, this excess turned out to be the smallest, which is why the risk assessment of not achieving its target value reached the "Medium" value.

4. Discussion

Analysis of the results obtained shows the following.

1. The developed method for assessing the risks of failure to achieve target indicators in the sphere of development of the intellectual capital contributes to the instrumental components of the methodology for managing the formation and development of intellectual capital, the theory of economic risk management, as well as PPRM (project portfolio risk management) as an independent area of research. Testing the method on the example of a specific organization (a large regional university) demonstrates the possibility of its practical application.

2. The proposed method is fuzzy. Its use does not require the availability of historical data and probabilistic forecasts and is therefore promising for the study of ill structured phenomena and processes (namely, the processes of formation and development of intellectual capital in the digital economy) in the context of a significant increase in the speed and unpredictability of changes in the external environment.

3. The fuzziness of the method makes it possible to take into account the decision maker's tolerance to uncertainty. This possibility is realized: at the stage of formation of the causal field of OIC indicators (when choosing fuzzy "cut-off boundaries" of explicit and implicit factors and methods of defasification); at the stage of evaluating current and determining target values of indicators (when choosing fuzzy inference systems (bases of fuzzy production rules and fuzzy inference algorithms)); at the stage of forming a OIC development program (when setting limits on risk and choosing satisfaction degrees); at the stage of quantitative assessment and qualitative interpretation of the risk level of failure to achieve the targets for the OIC development (when calculating the coefficients of correspondence of normalized deviations of expected values of indicators from the targets (namely, choosing the alpha level), as well as the possible setting of the formula for calculating the integral risk level). Differences in decision makers' tolerance for uncertainty lead to differences in assessments of the risks of failure to achieve target indicators.

4. The use of trapezoidal fuzzy numbers as membership functions of linguistic scale values ensures simplicity and transparency when conducting expert surveys. In turn, a further transition to Gaussian fuzzy numbers (and, further, arbitrary fuzzy numbers) allows us to level out the shortcomings that arise when using trapezoidal fuzzy numbers (in particular, when reducing fuzzy optimization problems to crisp Boolean quadratic programming problems).

5. The developed method is universal in the sense of possible applicability to various types of organizations of different industry affiliations (all stages of the basic scheme of the method will be standard). At the same time, the specifics of a particular organization will be manifested: in the causal field of OIC development indicators (a set of indicators of the two lower levels of the hierarchy); ways to assess current and determine target values of indicators; approaches to the formation of the OIC development program.

6. The success of the practical use of the method for a particular organization depends not so much on its type and industry affiliation as on the fulfillment of the following requirements. First of all, it is the presence of a formalized organization's strategy, in which strategic goals related to the OIC development are embedded in the hierarchical system of all strategic goals of the organization. In this case, the resulting indicators of strategic goals must be established. The organiza-

tion's management accounting system must include the ability to obtain quantitative values of the necessary indicators. Calculating the values of fuzzy variables requires appropriate software adapted to the given organization.

7. The method is also universal in the sense of its possible applicability to assessing the risks of not achieving the target values of various hierarchical indicator systems with a large number of implicit factors and "qualitative" indicators.

Conclusion

A method for assessing the risks of failure to achieve the OIC target indicators has been developed. The proposed method is based on the following fuzzy models: a fuzzy model for forming a causal field of OIC development indicators in conjunction with the organization's strategy and types of cognitive activity; a fuzzy model for assessing ICO indicators of all hierarchical levels; fuzzy models for optimizing the portfolio of ICO development projects taking into account risks.

The proposed method has the following distinctive features. The OIC indicator system is a multi-level hierarchical system with possible cycles. One of the levels of this system is formed by indicators reflecting the organization's ability to perform various types of cognitive activity linked to the main components of the OIC. At the lowest level of the hierarchy there are explicit and implicit factors of OIC development, the process of identifying which is quite flexible. When determining the current and target values of the OIC indicators, an original method of assessing the "qualitative" indicators and integral indicators of the OIC of all hierarchical levels is used, which allows us, among other things, to obtain numerical estimates of the spread (blurriness) of the calculated values of the indicators. When forming a OIC development program, it is possible to choose various fuzzy optimization models in which risk is taken into account either in the objective function or in fuzzy constraints. The scenario approach to modeling changes in internal and external conditions, which underlies fuzzy models for selecting the optimal portfolio of projects for the OIC development, allows us to obtain expected values of the OIC indicators at all levels of the hierarchy. The proposed method for obtaining additional information when calculating fuzzy deviations of expected values of indicators from target ones allows us to increase the accuracy of the qualitative interpretation of the level of risks of failure to achieve the organization's goals for the development of intellectual capital.

Another significant advantage of the proposed method is the ability to take into account the decision maker's tolerance to uncertainty. This opportunity is realized in the formation of a causal field of OIC indicators, in optimizing the portfolio of OIC development projects and, most importantly, in interpreting the risk levels of failure to achieve OIC development goals.■

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