DOI 10.33111/nfmte.2022.025

INTELLECTUAL CAPITAL MANAGEMENT OF THE BUSINESS COMMUNITY BASED ON THE NEURO-FUZZY HYBRID SYSTEM

Serhii Kozlovskyi

Vasyl' Stus Donetsk National University
21 600-richchia Str., Vinnytsia, 21021, Ukraine
ORCID: 0000-0003-0707-4996, E-mail: s.kozlovskyy@donnu.edu.ua

Petro Syniehub

Vasyl' Stus Donetsk National University
21 600-richchia Str., Vinnytsia, 21021, Ukraine
ORCID: 0000-0003-2034-2852, E-mail: p.syniehub@donnu.edu.ua

Andrii Kozlovskyi

Vinnytsia National Technical University
95 Khmelnytske Hwy., Vinnytsia, 21021, Ukraine
ORCID: 0000-0001-9697-1511, E-mail: akozlovskyi@vntu.edu.ua

Ruslan Lavrov

PHEI "European University"
16-V Academician Vernadskyi Blvd., Kyiv, 03115, Ukraine
ORCID: 0000-0002-9655-4467, E-mail: lavrus2017@gmail.com

The modern economy needs to address the issue of assessing intellectual capital as the basis for the development of market relations. The search for ways to solve this problem is possible based on the use of soft methods. The aim of the article is to develop a structural model for managing the intellectual capital of the business community based on an appropriate neuro-fuzzy system. Developed on the basis of soft computing methods, an innovative model for estimating intellectual capital of the business community is able to process "non-rigorous", incomplete or distorted input data, work with qualitative concepts, ambiguous and uncertain statements, perform operations with weak formalized economic parameters. The experimental results obtained made it possible to formulate the methods for evaluating the intellectual capital of business communities (or other similar economic systems) characterized by fuzzy relations between input and output parameters, considerable difficulties in formalizing the factors of influence, capability of using linguistic experts' statements for building an information and analytical system,

etc. The developed hybrid neuro-fuzzy system "Board" for evaluating intellectual capital of a business community enables to process both quantitative and qualitative input data, and was built up according to the criteria of digital economy transformation projects.

Keywords: *intellectual capital, management, modeling, fuzzy logic, business community*

JEL Classification: C45, M12, O34

Introduction

Modern economic development is characterized by fundamental changes in the technological basis of societal manufacturing and shift to innovative economics. Special role in this process belongs to the intellectual capital largely defining the structure of the domestic economy, the quality of manufactured goods and services, as well as the efficiency of economic functioning on all organizational levels. The development of the intellectual labour and its proportion in the production processes are becoming the most important factors defining the integration of a country in the world economy, its export capabilities and share in the total world monetary income.

In developed countries, the improvement of scientific technological progress, intellectual and innovative technological production are in the center of attention. According to estimations [1], the share of new technologies in developed countries makes up 85% of the GDP growth, and in the 15-25 the share of digital economy will be 50% of the world GDP. Thanks to highly technological and science capacious goods, these countries are at an advantage in the world economy and labour market, especially under conditions of globalization and digitalization of economic systems.

The current stage of technological development, economy and education calls for tackling the issue of intellectual capital management based on modern mathematical methods. The topicality of the research is determined by the processes of digital transformation in economy, which differ from the previous automatization and informatization periods by the large-scale transformation of business models, structural organizations and interrelation of economic agents. These processes result in emergence

of new digital products, forms of economic organization – digital platforms and ecosystems.

Therefore, nowadays the issue of intellectual capital management in the conditions of digitalization acquires a new meaning in terms of forming effective administrative economic mechanisms of accumulating and increasing intellectual capital of both modern enterprises and business communities.

The issue "intellectual capital" (IC) has certain stages of its development. Bontis, N., director of the Institute for Intellectual Capital Research, in his article [2] indicates that the concept of intellectual capital was first introduced by economist Galbraith, J. [3] in 1967. One of the first works that laid the foundation for independent research on intellectual capital was the book of the Japanese scientist Sakaiya, T. "The value created by knowledge, or the history of the future" [4]. He concludes that knowledge is directly embodied in the majority of created goods and, thus, the economy turns into a system that functions on the basis of the exchange of knowledge and their mutual assessment.

Synthesizing the concepts studied by Petty, R. and Guthrie, J. [5], one can single out the main origins of the theory of the intellectual capital from 1980 to 2000. In particular, a certain dependence of the practice on the fundamentals of the intellectual capital is noted.

In 1997, Edvinsson, L. and Malone, M. published their first book "Intellectual capital" which was a pioneer in this sphere [6]. It reflects the experience of defining, evaluating and managing intellectual capital of a Swedish corporation "Skandia", which was the first to publish in its report the information on intellectual capital.

In the conditions of digitalization of economies, the most relevant is the definition of intellectual capital, proposed by Bontis, N. [2], who regards it from the point of stability of economic development [7].

Nowadays, there are dozens of methods of intellectual capital assessment [8]. Tobin's coefficient q [9] (or Kaldor's rate [10]) can refer to the classical intellectual capital evaluation methods – it is the ratio of the company's market value to the price of its tangible assets substitution (buildings, houses, equipment and stock). To evaluate intangible assets EVA (Economic Value-Added) methods are used [11]. Back in 1989, Finegan, P. proposed the concept of EVA [12], but it

gained popularity only in 1993 with the publication of an article by Tully, S. and Hadjian, A. in "Fortune" journal [13]. This method regards humans rather as assets than value. Although this methods is effective for evaluating intangible assets, it does not answer the question how these values are created and developed.

Another group of popular methods is based on considering various values of intellectual capital to develop the evaluation indicators. As a variant of such an assessment is a popular method Navigator made up by a Swedish insurance company "Skandia", which has practiced in evaluating intellectual capital since 1994. Here we can single out several categories of intellectual capital: human capital, structural capital, relations capital (market capital) [14]. The most common form of the intellectual capital is intellectual property, comprising trade marks, patents, licenses, etc.

Another example of this group is the method of Intangible Assets Monitor (Sveiby, K.-E. et al. [15]), which divides intangible assets into external and internal structures and employees' competency. The choice of evaluation indicators depends on strategic goals. The most important spheres of applying this method are growth/renovation, efficiency and stability. Many companies develop their indicators by this method.

A separate group of methods presents the so called "third generation" of intellectual capital indicators. While characterizing employee's proficiency, they also take into account their activity coefficient (for instance, the number of days of training), as well as transforming activity (comprehension of better practice through implicit human knowledge). These methods include the IC Index [16] – identification of four main categories of intellectual capital (relations, employees, infrastructure, innovations) and their representation in the hierarchy. IC Rating [17] also relates to this group of methods, and presents a hierarchical structure supplied with a risk factor. The most peculiar feature of these methods is that they enable the managers not only to register value constituents, but also consider some trends and factors lying at the basis of the situation, including risk sensitive ones.

The issue if evaluation and management of intellectual capital was also considered in Project Management methods. They started their

development in the 1950s in decision theory and operations research in the works of Malcolm, D. et al. [18] (Program Evaluation and Review Technique, PERT), Magee, J. [19] (Decision Tree Analysis, DTA), Kelley, J. et al. [20] (Critical Path Method, CPM), Goldratt, E. [21] (Critical Chain Method, CCM), Fleming, Q. and Koppelman, J. [22] (Earned Value Technique, EVT) and others. Thus, it enables to state that all the methods of intellectual capital management have one common problem of incapability of simultaneous consideration of qualitative and quantitative factors. However, this problem can be solved by fuzzy calculations methods [23, 24].

The specificity of project management, in particular, is studied in the works of Turner, R. [25], Antoniuk, L. et al. [26], Zavidna, L. et al. [27], including with the use of fuzzy mathematics tools in the papers by Balan, V. [28] and authors of this article [29].

The aim and tasks of the research

The aim of the article is to develop a structural model for managing the intellectual capital of the business community based on an appropriate neuro-fuzzy system. This model will consider incomplete or subjective quantitative or qualitative information, which will enable to obtain verbalized results of evaluating the intellectual capital of business community.

Results

The study "Small Business Index" [30] proved that businesses acting within any business community are more successful. Such businesses have positive feedbacks, steady dynamics of clients' and sales growth, thus income growth. These companies have a better access to necessary resources, technologies and investments.

The research [31] shows that business community represents different sectors of large, small and middle entrepreneurship, and protects their rights and legal business interests, supports effective communication among them and state administrative bodies on creating favourable business conditions in Ukraine and abroad, provides access to innovative technologies, counselling and other

professional non-income services. The aim of business community is to create and spread innovative knowledge and technologies in business, establishing relations among the economic agents for their better mutual profiting.

The problem of assessing the intellectual capital of business communities is new in modern science. We provide evaluation of intellectual capital on the example of a business community "Board" [32], which is typical for this class of economic agents. "Board" is a business community that provides mutual mentoring and counseling for prompt and effective business decision making of each member. In June 2022 "Board" counted over 1000 members, including 982 Ukrainian and 130 foreign ones.

To evaluate intellectual capital of a business community "Board" by the principles of fuzzy logic [23, 24, 33, 34], we propose an approach (see Fig. 1), within which the corresponding neuro-fuzzy hybrid system (NFHS) is implemented.

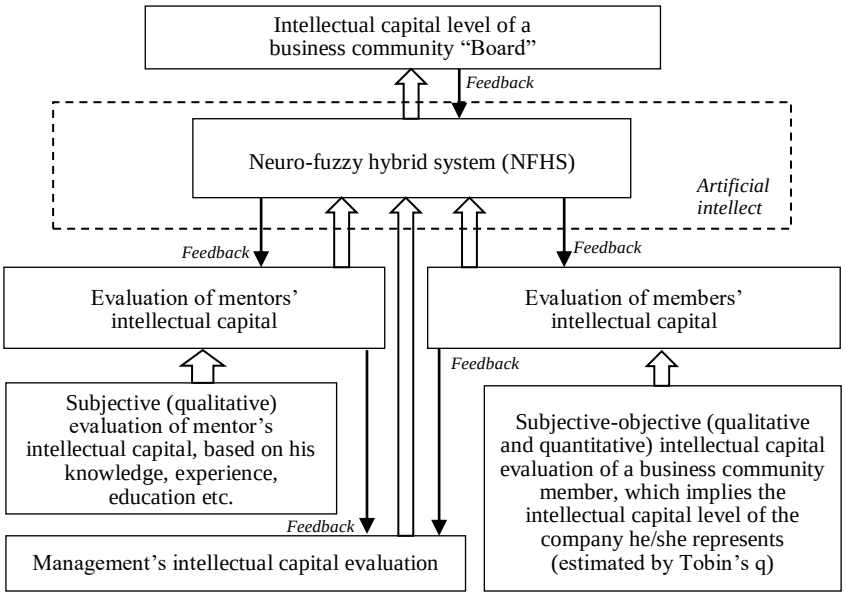

Fig. 1. Hybrid system for evaluating the intellectual capital of the business community

The methods of developing hybrid intellectual systems are based on problem-structured and problem-instrumental methodology, which consists in analysis and decomposition of a complex problem with further synthesis of solutions into structures or program components for the set subproblems. At the basis of these systems suffice it to use "soft" calculations able to process "non-rigorous", incomplete or distorted input data, work with qualitative concepts, ambiguous and vague statements, loosely formalized economic parameters.

To realize the neuro-fuzzy hybrid system in accordance with the approach presented in Fig. 1, the following factors must be determined:

– evaluation of mentors' intellectual capital on the basis of his/her knowledge, education, competencies and experience, defined by the management of business community "Board" on the basis of linguistic qualitative estimation;

– evaluation of the intellectual capital of a business community member, which implies subjective-objective estimation of company's intellectual capital, calculated by Tobin's q, i.e. relation of company's market value to the price of its assets substitution;

– intellectual capital evaluation of community's managers/founders ("Board") on the basis of subjective neurolinguistic estimation of mentors and members of companies. It should be noted that NFHS will have no feedback with this evaluation function to prevent the system collapse, i.e. conflict of estimation values.

The NFHS will be developed basing on the thesis, that the main principle of flexible project management of digital transformation is the process of predictive recognition of problem situations and group work on measures considering the interests of stakeholders (all members of business community). Formalization of this process is realized by the presence of feedback, which implements problem-predictive management (see Fig. 1).

In June 2022, when the NFHS was being developed, the general number of business community "Board" members and mentors makes up 1000 persons (these data will be used as a basis for modeling).

To assess the intellectual capital of the business community, the following variables of NFHS were defined:

– $S_{1...n}$ – subjective evaluation of the intellectual capital of the mentors of the business community "Board" (the scale from 0 to 100 points), which is formed basing on the opinions of the business community managers (where n is the mentors number);

– $T_{1...h}$ – subjective-objective evaluation of the intellectual capital of the companies with the membership in the business community "Board", calculated by Tobin's q and presented by the members of business community (h is the number of companies);

– $K_{1...3}$ – subjective-objective evaluations of the intellectual capital of three founders of the business community "Board" based on survey of expert estimations of mentors and members. To simplify the calculations, the general integral estimation of the founders of the business community "Board" will be done. At the moment of starting gathering information, the level of the managers'/founders' intellectual capital made up 93 points by a 100-point scale.

In line with methodological approaches to development of neuro-fuzzy systems [23, 24, 33-38], we will build NFHS for evaluating the intellectual capital of the business community "Board" in the form of an "inference tree" (see Fig. 2). It has the following designations: M – integral evaluation of the mentors' intellectual capital; U – integral evaluation of the members' intellectual capital; K – integral evaluation of the intellectual capital of the business community managers/founders; IKB – integral evaluation of the intellectual capital of the business community "Board".

The nods of the "inference tree" are interpreted in the following way: the root f_{IKB} corresponds to the level of the intellectual capital of business community "Board"; terminal nods are the corresponding factors of influence; non-terminal nods (double circles) represent integral indicators calculated on the basis of the partial influence factors that they include. All nodes of the "inference tree" are described by linguistic variables.

For the description of the quantitative input parameters $\{T_1 \ldots T_h\}$ we used the calculations, performed by the members of the business community "Board"; for the description of the qualitative parameters S, M, U, K and IKB, scores on a 100-point scale were used.

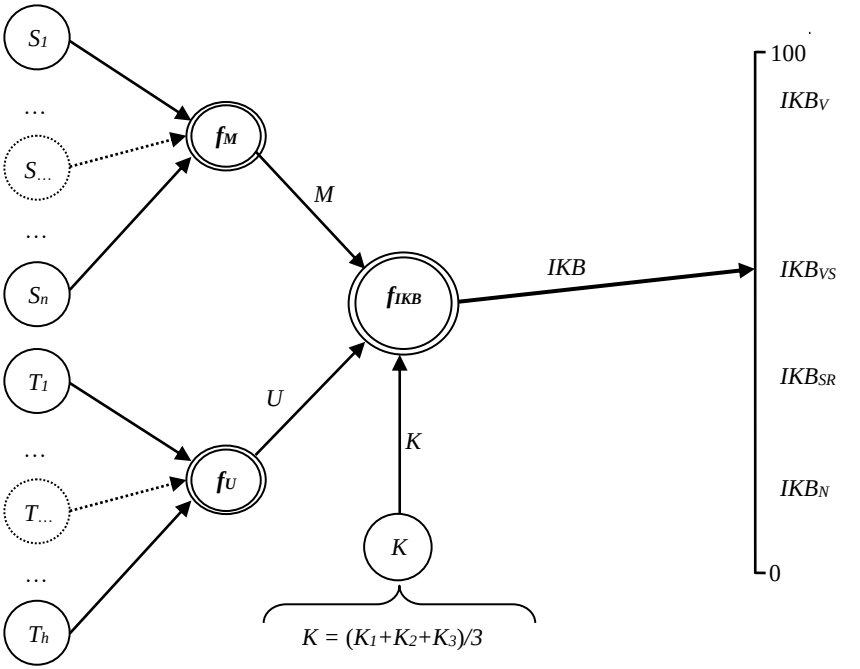

Fig. 2. Structure of the NFHS evaluation of the intellectual capital of the business community "Board"

The neurolinguistic evaluation with the corresponding scale of changes for the input factors and output indicator is demonstrated in Table 1. Table 1 also shows the values of the parameters of the bell-shaped membership functions of all variables according to [39, 40]:

$$\mu^{T}(x)=\frac{1}{1+\left[\frac{x-b}{c}\right]^{2}}, \qquad (1)$$

where b and c are the parameters of bell-shaped membership function: b – coordinate of function maximum; c – coefficient of stretching/ concentration.

The choice of membership function of bell-shaped type (1) is predetermined by its simplicity and flexibility, since it has only two parameters and simple derivative, which makes it more convenient for further NFHS tuning.

Table 1

VARIABLES OF NFHS FOR EVALUATING THE INTELLECTUAL CAPITAL OF THE BUSINESS COMMUNITY "BOARD"

Factor	Symbol	Range of changes	Linguistic estimation (term), value range	Values of *b* and *c* of membership function (1)	
				b	*c*
Mentors' IC estimation	$S_1 \ldots S_n$	0…100	Low (*N*), 0…50	25	30
			Medium (*Sr*), 50…75	65	40
			High (*V*), 75…100	85	20
Members' IC estimation	$T_1 \ldots T_h$	0…3	Low (*N*), 0…0.5	0.4	1
			Medium (*Sr*), 0.5…1.2	0.9	1.2
			High (*V*), 1.2…3	1.8	1.4
Integral estimation of IC of managers of the business community	*K*	0…100	Low (*N*), 0…50	25	33
			Medium (*Sr*), 50…75	67	37
			High (*V*), 75…100	82	25
Integral estimation of mentors' IC	*M*	0…100	Low (*N*), 0…50	20	30
			Medium (*Sr*), 50…75	63	40
			High (*V*), 75…100	85	15
Integral estimation of members' IC	*U*	0…100	Low (*N*), 0…50	27	35
			Medium (*Sr*), 50…75	60	40
			High (*V*), 75…100	82	25
Integral estimation of IC of the business community "Board"	*IKB*	0…100	Low (*N*), 0…40	20	25
			Medium (*SR*), 40…60	50	20
			Higher than medium (*VS*), 60…80	70	25
			High (*V*), 80…100	90	15

The presented in Fig. 2 connections can be described in the following functions in general form:

$$M = f_M(S_1 \ldots S_n); \quad (2)$$

$$U = f_U(T_1 \ldots T_h); \quad (3)$$

$$K = (K_1+K_2+K_3)/3, \quad (4)$$

where $K_{1\ldots3}$ are the subjective-objective evaluations of the intellectual capital of the three founders of the business community "Board" based on expert estimations of mentors and members. The founders who manage this business are evaluated by both members and mentors on the basis of a closed survey. The points obtained are reduced to the arithmetic mean first for each founder, and then the total score K averaging over them (4).

The value of the output indicator IKB, i.e. the level of IC of the business community "Board", can be given in the formula:

$$IKB = f_{IKB}(M, U, K). \quad (5)$$

Using experts' recommendations [32] and basing on the certain economic situation, the intellectual capital of the business community "Board" can be characterized according to the following levels on a 100-point scale:

- IKB_V (80-100] – high IC (class A);
- IKB_{VS} (60-80] – IC higher than medium/average (class B);
- IKB_{SR} (40-60] – medium IC (class C);
- IKB_N [0-40] – low IC (class D).

The next stage of building NFHS of evaluating IC of the business community "Board" is building the membership functions for all factors and the output indicator. The membership functions are descriptive ones, which define the range of change in the values of variables (input and output) by terms (linguistic estimations of indicators, which are proper names for the corresponding fuzzy sets). For instance, Fig. 3 demonstrates the membership functions for all linguistics terms of the output indicator (the levels of intellectual capital of the business community "Board").

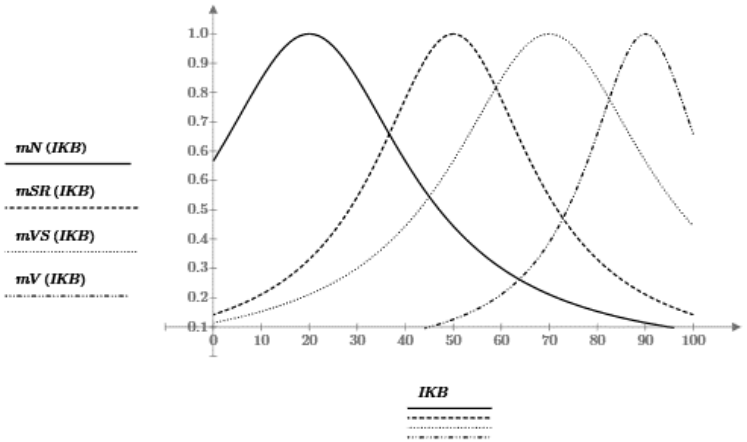

Fig. 3. Membership functions for the output indicator
(intellectual capital levels of the business commuity "Board")

To form the final equation of NFHS on evaluating the intellectual capital of the business community "Board" by neurolinguistic modeling methods, in addition to describing the influencing factors, it is necessary to define the dependencies and the impact of these factors on the output indicator. For this purpose, on the basis of expert data, hierarchical knowledge bases were developed that implement dependencies in formulas (2), (3), (5). These dependences are "If-Then" rules [23, 24, 33-40]. Partial examples of these hierarchical knowledge bases are given in Tables 2-4.

Table 2

A SEGMENT OF KNOWLEDGE BASE FOR EVALUATING THE MENTORS' IC OF THE BUSINESS COMMUNITY "BOARD"

S_1	S_2	S_3	…	S_n	M	w
N	*N*	*N*	…	*Sr*	*N*	w_1
Sr	*N*	*Sr*	…	*N*	*N*	w_2
Sr	*Sr*	*Sr*	…	*N*	*Sr*	w_3
Sr	*V*	*N*	…	*N*	*Sr*	w_4
…	…	…	…	…	…	…
V	*V*	*V*	…	*V*	*V*	w_{49}
V	*V*	*Sr*	…	*V*	*V*	w_{50}

Table 3

A SEGMENT OF KNOWLEDGE BASE FOR EVALUATING THE MEMBERS' IC OF THE BUSINESS COMMUNITY "BOARD"

T_1	T_2	T_3	…	T_h	U	w
N	*N*	*N*	…	*Sr*	*N*	w_{51}
Sr	*N*	*Sr*	…	*N*	*N*	w_{52}
Sr	*Sr*	*Sr*	…	*N*	*Sr*	w_{53}
Sr	*V*	*N*	…	*N*	*Sr*	w_{54}
…	…	…	…	…	…	…
V	*V*	*V*	…	*V*	*V*	w_{999}
Sr	*V*	*Sr*	…	*V*	*V*	w_{1050}

As mentioned above, the evaluation of the intellectual capital of management/founders of the business community "Board" is performed on the basis of expert evaluations of surveyed mentors and members. Value *K* is equal to the average value of mentors' and members' assessments on a scale from 0 to 100 points. As for March-April 2022, the integral level of IC of managers/founders made up 93 points.

The knowledge base of the final equation of NFHS for evaluating the intellectual capital of the business community "Board" is presented in Table 4.

Table 4

KNOWLEDGE BASE FOR EVALUATING THE INTELLECTUAL CAPITAL OF THE BUSINESS COMMUNITY "BOARD"

M	*U*	*K*	*IKB*	*w*
N	*N*	*N*	*N*	w_{1051}
N	*Sr*	*N*	*N*	w_{1052}
Sr	*N*	*N*	*N*	w_{1053}
Sr	*Sr*	*Sr*	*SR*	w_{1054}
N	*V*	*Sr*	*SR*	w_{1055}
V	*Sr*	*N*	*SR*	w_{1056}
Sr	*Sr*	*V*	*VS*	w_{1057}
V	*Sr*	*Sr*	*VS*	w_{1058}
Sr	*V*	*Sr*	*VS*	w_{1059}
V	*V*	*V*	*V*	w_{1060}
V	*V*	*Sr*	*V*	w_{1061}
Sr	*V*	*V*	*V*	w_{1062}

Operations with these knowledge bases, presented in Tables 2-4, are performed in the mathematic package Matlab [41]. In each rule, the membership functions of the input factors to the terms specified in the rule are integrated using the logical operator "And" (implemented by operations of multiplication or minimum) and multiplied by the weight of the rule *w* (in the range from 0 to 1). These weights and the parameters of all membership functions are used to tune the model. The results of calculations of all rules related to one term of the output variable are combined through the logical operator "Or" (summation or maximum operations). So, the linguistic expressions presented in Table 4 correspond to the following fuzzy logic equations:

$$\begin{aligned}
\mu^{N}(IKB) &= w_{1051} \cdot [\mu^{N}(M) \cdot \mu^{N}(U) \cdot \mu^{N}(K)] \vee \\
&\vee w_{1052} \cdot [\mu^{N}(M) \cdot \mu^{Sr}(U) \cdot \mu^{N}(K)] \vee \\
&\vee w_{1053} \cdot [\mu^{Sr}(M) \cdot \mu^{N}(U) \cdot \mu^{N}(K)]; \\
\mu^{SR}(IKB) &= w_{1054} \cdot [\mu^{Sr}(M) \cdot \mu^{Sr}(U) \cdot \mu^{Sr}(K)] \vee \\
&\vee w_{1055} \cdot [\mu^{N}(M) \cdot \mu^{V}(U) \cdot \mu^{Sr}(K)] \vee \\
&\vee w_{1056} \cdot [\mu^{V}(M) \cdot \mu^{Sr}(U) \cdot \mu^{N}(K)]; \\
\mu^{VS}(IKB) &= w_{1057} \cdot [\mu^{Sr}(M) \cdot \mu^{Sr}(U) \cdot \mu^{V}(K)] \vee \\
&\vee w_{1058} \cdot [\mu^{V}(M) \cdot \mu^{Sr}(U) \cdot \mu^{Sr}(K)] \vee \\
&\vee w_{1059} \cdot [\mu^{Sr}(M) \cdot \mu^{V}(U) \cdot \mu^{Sr}(K)]; \\
\mu^{V}(IKB) &= w_{1060} \cdot [\mu^{V}(M) \cdot \mu^{V}(U) \cdot \mu^{V}(K)] \vee \\
&\vee w_{1061} \cdot [\mu^{V}(M) \cdot \mu^{V}(U) \cdot \mu^{Sr}(K)] \vee \\
&\vee w_{1062} \cdot [\mu^{Sr}(M) \cdot \mu^{V}(U) \cdot \mu^{V}(K)]. \qquad (6)
\end{aligned}$$

The values of membership functions in the equations (6) are defined by the knowledge bases characterizing the IC of mentors, members and founders/managers of the business community "Board". Fuzzy logic equations (6) are mathematic implementation of NFHS of IC evaluation of the business community "Board".

The defuzzification procedure is the last stage of NFHS development and is a reverse transformation of the received fuzzy estimate into the exact value of the output variable. There are various defuzzification methods, the choice and application of which depends on the object of modeling [35, 40].

Due to the peculiarities of NFHS and the output variable, to calculate its exact value, we will choose the defuzzification method, named "centrifugation method extended" [35]:

$$IKB = \frac{\sum_{i=1}^{n}\left[IKB_{min} + (i-1)\cdot \frac{IKB_{max} - IKB_{min}}{n-1} \right]\cdot \mu_i}{\sum_{i=1}^{n} \mu_i}, \qquad (7)$$

where n is the number of terms of the variable IKB (in our case $n = 4$); IKB_{min}, IKB_{max} are the measurement scale range; μ_i is a membership function value.

Defuzzification procedure provides the final result of the evaluation of the business community "Board" intellectual capital based on the constructed NFHS.

In the mathematic package Matlab 6.1, an experiment was carried out using above mentioned method (developed NFHS). Calculations for evaluation of IC of the business community "Board" amounted to 82 points. According to the obtained results of NFHS calculations on the evaluating IC of the business community "Board", we can state that it refers to a "high IC" class A (obtained 82 points out of 100).

Based on the results obtained, it is possible to formulate the method of evaluation of the intellectual capital of the business community (or/and other economic systems) through the following stages:

– step 1: state the values of influence factors $S_{1\ldots n}$, $T_{1\ldots h}$, $K_{1\ldots 3}$;

– step 2: find the membership levels of influencing factors $S_{1\ldots n}$, $T_{1\ldots h}$, $K_{1\ldots 3}$, K, M, U, corresponding to the linguistic terms by formula (1). The values of the parameters b and c of the membership functions are presented in Table 1;

– step 3: develop the expert knowledge bases for calculating the integral variables M, U and IKB of the NFHS;

– step 4: calculate the integral estimation K of IC of the managers of the business community according to the formula (4);

– step 5: on the basis of the obtained knowledge bases, make calculations to find the output value of NFHS;

– step 6: to carry out defuzzification procedure (7) and find the quantitative output value;

– step 7: when necessary to perform optimization procedure for the NFHS.

The proposed cognitive approach to developing NFHS is an effective instrument for modeling and visualizing managerial decisions on the development of complex economic systems (for instance, evaluation of the intellectual capital) through integration of quantitative factor analysis and expert evaluation of qualitative indicators and systemic relations between them. The potential of the cognitive approach to solving economic problems is determined by infeasibility of some methods of economic forecasting and extrapolation in conditions of complex, instable, irregular or crisis economic situation [42]. The standard methods are meant for defining steady trends, therefore any available transition processes can distort modeling results.

The developed NFHS of evaluating IC of the business community "Board" can be regarded as a typical one for the given class of objects. The methods proposed in its construction can be applied for evaluation of other economic processes characterized by fuzzy relations between input and output parameters, significant difficulties at formalization of influence factors, possibility to use experts' linguistic expressions for building a system, etc.

On the basis of the obtained results we will develop an economic mechanism of managing the IC of the business community "Board" in conditions of digitalization, which will refer to the category of "flexible management models" (see Fig. 4).

The mechanism of managing the intellectual capital of the business community "Board" is based on the fact that the management of business community evaluates and elects mentors as the main IC bearers. These have to pass their knowledge and skills to other members of business community. The manager-mentor relationship is of utmost importance for the success of the business community, especially in a highly competitive environment. While endorsing decisions on evaluating IC of managers and mentors of the business community "Board", it is also important to take into consideration differences of opinion between experts (mentors), because these have restricted rationality, which does not concern their proficiency.

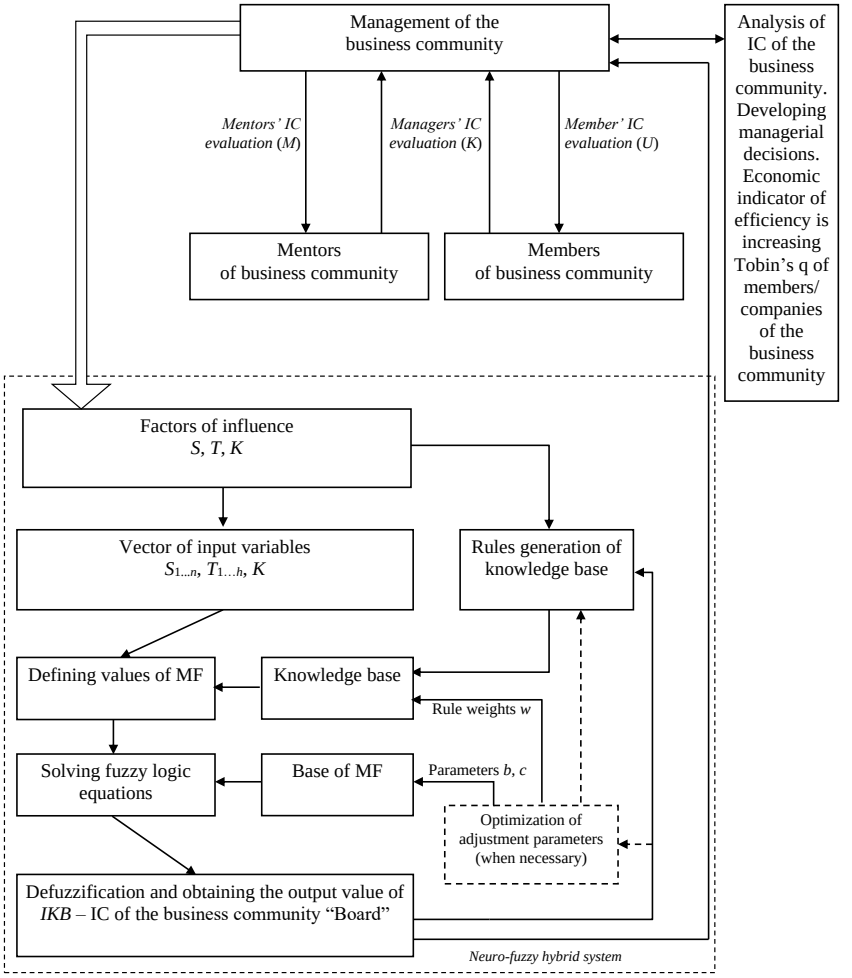

Fig. 4. IC management of the business community "Board"

The relation manager-member in this model is of lesser value, since the main task of business community is to spread innovative knowledge and technologies. Therefore, a member can have any IC, but must aspire to increase and capitalize it in his own business (although in certain conditions, the management of business

community can influence it indirectly, not accepting candidates with a low IC as a member). The member's IC level is calculated by his Tobin's q, which is the most economical factor in the system. The aim of business community is to increase the member's Tobin's q incorporating knowledge technologies. In their activity, the management of the business community monitors a member's Tobin's q. If it shows growth, it testifies the rise of the intellectual capital of the whole business community.

Thus, it is a simultaneous aim of both a member and the management, while the mentor acts as a means of achieving it. It is on the basis of the NFHS, does the management of the business community makes corresponding managerial decisions, mainly involving mentors with certain competencies and knowledge, who can influence the performance of other members of the business community. Thus, there is a bilateral connection between the management, mentors and members of the business community in the system of general IC evaluation, as seen from Fig. 4. But it should be noted once again that the main element in the management decision-making system is the business community's management.

Conclusions and prospects of further research

Cognitive approach [43] on the basis of neuro-fuzzy methodology is an effective mechanism of modeling the managerial decisions for the development of complex economic systems, to which we refer the process of managing the intellectual capital of business communities due to integration of the analysis of quantitative factors and expert evaluations of system relations among them. The perspectivity of applying the cognitive approach to solving economic problems (not only IC evaluation and management) is explained by infeasibility of some methods of economic forecasting (extrapolation) in conditions of difficult, instable, ambiguous, irregular or crisis dynamics of the economic situation development. To solve this problem, hybrid neuro-fuzzy techniques are best suited, which served as the basis for the author's approach and the developed NFHS for evaluating the intellectual capital of the business community "Board".

In this neuro-fuzzy hybrid system for managing IC of the business community, several features are considered – the IC of leaders, mentors and members, which are integrated into one common value using the convolution procedures of the fuzzy logic apparatus.

The organizational and economic mechanism of managing the intellectual capital of the business community can be incorporated in the structure of the management system, which determines the regular firm connections and relations within the community, the main directions of managerial influence, that provide the integrity of the whole mechanism. Like any other management system, the organizational and economic mechanism of managing the intellectual capital consists of two subsystems: ruling and ruled, both being in dialectic interrelation. The ruled subsystem in this case is presented by the intellectual capital and its functions. The structure and the content of the ruling system is the basis of the IC management mechanism of the business community and is realized by the developed NFHS.

The developed neuro-fuzzy hybrid system for managing the intellectual capital of the business community "Board" can be regarded as a typical one for the given class of problems. The methods underlying it can be applied to evaluate other economic processes characterized by fuzzy relations between input and output parameters, significant difficulties at formalization of influence factors, possibility to use experts' linguistic expressions for building a system, etc.

References

1. LETA Capital, & Devar. (2021). *State Of Phygital*. https://global-uploads.webflow.com/6198cb076e036ab5a326fa84/623843d93006dc23e1b05264_STATE%20OF%20PHYGITAL%202021%20BY%20LETA%20AND%20DEVAR.pdf

2. Bontis, N. (2001). Assessing knowledge assets: a review of the models used to measure Intellectual Capital. *International Journal of Management Review*, *3*(1), 41–60. https://doi.org/10.1111/1468-2370.00053

3. Galbraith, J. K. (1967). *The New Industrial State*. Houghton Mifflin.

4. Sakaiya, T. (1991). *The Knowledge-Value Revolution, or a History of the Future*. Kodansha International.

5. Petty, R., & Guthrie, J. (2000). Intellectual capital literature review: Measurement, reporting and management. *Journal of Intellectual Capital*, *1*(2), 155–176. https://doi.org/10.1108/14691930010348731

6. Edvinsson, L., & Malone, M. (1997). *Intellectual Capital: Realizing Your Company's True Value by Finding Its Hidden Brainpower*. Harper Business.

7. Kozlovskyi, S., Baidala, V., Tkachuk, O., & Kozyrska, T. (2018). Managament of Sustainable Development of the Agrarian Sector of the Regions of Ukraine. *Montenegrin Journal of Economics*, *14*(4), 175–190. https://doi.org/10.14254/1800-5845/2018.14-4.12

8. Kasiewicz, S., Rogowski, W., & Kicińska, M. (2006). *Kapitał intelektualny. Spojrzenie z perspektywy interesariuszy [Intellectual capital. View from the perspective of stakeholders]*. Oficyna Ekonomiczna. [in Polish]

9. Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of Money Credit and Banking*, *1*(1), 15–29. https://doi.org/10.2307/1991374

10. Kaldor, N. C. (1966). Marginal Productivity and the Macro-Economic Theories of Distribution: Comment on Samuelson and Modigliani. *The Review of Economic Studies*, *33*(4), 309–319. https://doi.org/10.2307/2974428

11. Chen, S., & Dodd, J. L. (1997). Economic Value Added (EVA^{TM}): An Empirical Examination of a New Corporate Performance Measure. *Journal of Managerial Issues*, *9*(3), 318–333. http://www.jstor.org/stable/40604150

12. Finegan, P. T. (1989). Financial incentives resolve the shareholder-value puzzle. *Corporate Cashflow*, *October*, 27–32.

13. Tully, S., & Hadjian, A. (1993). The real key to creating wealth. *Fortune*, *128*(6), 38–50.

14. Edvinsson, L., & Malone, M.S. (2001). *Kapital intelektualny [Intellectual capital]*. Wydawnictwo Naukowe PWN. [in Polish]

15. Sveiby, K.-E., Annell, E., Axelsson, S., Emilsson, P.-M., Karlsson, H., Wangerud, C.J., & Vikström, S. (1990). *The Invisible Balance Sheet*. Affarsvarlden-Ledarskap.

16. Buenechea-Elberdin, M., Kianto, A., & Sáenz, J. (2017). Intellectual capital drivers of product and managerial innovation in high-tech and low-tech firms. *R&D Management*, *48*(3), 290–307. https://doi.org/10.1111/radm.12271

17. Carnegie, G. D., & Napier, C. J. (2017). The accounting, auditing & accountability journal community in its 30th year. *Accounting, Auditing &*

Accountability Journal, *30*(8), 1642–1676. https://doi.org/10.1108/AAAJ-12-2016-2804

18. Malcolm, D. G., Roseboom, J. H., Clark, C. E., & Fazar, W. (1959). Application of a Technique for Research and Development Program Evaluation. *Operations Research*, *7*(5), 646–669. https://doi.org/10.1287/opre.7.5.646

19. Magee, J. F. (1964). Decision trees for decision making. *Harvard Business Review*, *42*(4), 126-138. https://hbr.org/1964/07/decision-trees-for-decision-making

20. Kelley, J. E., Walker, M. R., & Sayer, J. S. (1989). The origins of CPM: a personal history. *PM Network*, *3*(2), 7–22. https://www.pmi.org/learning/library/origins-cpm-personal-history-3762

21. Goldratt, E. M. (1997). *Critical Chain*. North River Press.

22. Fleming, Q. W., & Koppelman, J. M. (2010). *Earned Value Project Management* (4th ed.). Project Management Institute.

23. Kozlovskyi, S., Mazur, H., Vdovenko, N., Shepel, T., & Kozlovskyi, V. (2018). Modeling and forecasting the level of state stimulation of agricultural production in Ukraine based on the theory of fuzzy logic. *Montenegrin Journal of Economics*, *14*(3), 37–53. https://doi.org/10.14254/1800-5845/2018.14-3.3

24. Matviychuk, A., Lukianenko, O., & Miroshnychenko, I. (2019). Neuro-fuzzy model of country's investment potential assessment. *Fuzzy economic review*, *24*(2), 65–88. https://doi.org/10.25102/fer.2019.02.04

25. Turner, R. (2014). *Handbook of Project-Based Management: Leading Strategic Change in Organizations* (4th ed.). McGraw-Hill.

26. Antoniuk, L., Gernego, Iu., Dyba, V., Polishchuk, Ye., & Sybirianska, Yu. (2017). Barriers and opportunities for hi-tech innovative small and medium enterprises development in the 4th industrial revolution era. *Problems and Perspectives in Management*, *15*(4), 100-113. https://doi.org/10.21511/ppm.15(4).2017.09

27. Zavidna, L., Trut, O., Slobodianiuk, O., Voronenko, I., & Vartsaba, V. (2022). Application of anti-crisis measures for the sustainable development of the regional economy in the context of doing local business in a post-COVID environment. *International Journal of Sustainable Development and Planning*, *17*(5), 1685-1693. https://doi.org/10.18280/ijsdp.170535

28. Balan, V. (2020). Zastosuvannia dynamichnoho nechitkoho space-analizu dlia formuvannia stratehii pidpryiemstva [Application of dynamic fuzzy space-analysis for forming enterprise strategies]. *Neiro-Nechitki Tekhnolohii Modelyuvannya v Ekonomitsi (Neuro-Fuzzy Modeling*

Techniques in Economics), *9*, 26-64. http://doi.org/10.33111/nfmte.2020.026 [in Ukrainian]

29. Kozlovskyi, S., Butyrskyi, A., Poliakov, B., Bobkova, A., Lavrov, R., & Ivanyuta, N. (2019). Management and comprehensive assessment of the probability of bankruptcy of Ukrainian enterprises based on the methods of fuzzy sets theory. *Problems and Perspectives in Management*, *17*(3), 370-381. http://dx.doi.org/10.21511/ppm.17(3).2019.30

30. U.S. Chamber of Commerce. (2021). *Small Business Index, Q4 2021. Index Reaches Pandemic-Era High, as Many See Brighter Future*. https://www.uschamber.com/sbindex/2021-Q4

31. Syniehub, P. (2022). Kontseptsii stvorennya ta pryznachennya biznes-spil'not v ekonomichnomu prostori [Concepts of creation and purpose business communities in the economic space]. *Ekonomika ta suspil'stvo (Economy and Society), 35*, Article 32. https://doi.org/10.32782/2524-0072/2022-35-32 [in Ukrainian]

32. Board. (2022). *Spil'nota Board [Community Board]*. Retrieved July 7, 2022, from https://board.business/

33. Kozlovskyi, S., Nikolenko, L., Peresada, O., Pokhyliuk, O., Yatchuk, O., Bolgarova, N., & Kulhanik, O. (2020). Estimation level of public welfare on the basis of methods of intellectual analysis. *Global Journal of Environmental Science and Management*, *6*(3), 355–372. https://doi.org/10.22034/gjesm.2020.03.06

34. Azarova, A., Radomska, L., & Azarova, L. (2020). Neuro-fuzzy modelling of economic specialties students' speech-communicative professional competence. *Neiro-Nechitki Tekhnolohii Modelyuvannya v Ekonomitsi (Neuro-Fuzzy Modeling Techniques in Economics)*, *9*, 3-25. http://doi.org/10.33111/nfmte.2020.003

35. Rotshtein, A. P., Shtovba, S. D. (2002). Influence of Defuzzification Methods on the Rate of Tuning a Fuzzy Model. *Cybernetics and Systems Analysis*, *38*, 783–789.

36. Matviychuk, A. (2010). Bankruptcy prediction in transformational economy: discriminant and fuzzy logic approaches. *Fuzzy economic review*, *15*(1), 21–38. https://doi.org/10.25102/fer.2010.01.02

37. Zadeh, L. A. (1994). Soft Computing and Fuzzy Logic. *IEEE Software*, *11*(6), 48–56. https://doi.org/10.1109/52.329401

38. Zadeh, L. A. (1997). Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. *Fuzzy Sets and Systems*, *90*(2), 111–127. https://doi.org/10.1016/S0165-0114(97)00077-8

39. Rotshtein, A. (1998). A. Design and Tuning of Fuzzy Rule-Based Systems for Medical Diagnosis. In H.-N. Teodorescu, A. Kandel, & L. C. Jain (Eds.), *Fuzzy and Neuro-Fuzzy Systems in Medicine* (pp. 243-289).

CRC Press. https://www.researchgate.net/publication/245881295_Design_and_Tuning_of_Fuzzy_Rule-Based_Systems_for_Medical_Diagnosis

40. Rotshtein, A. P., & Shtovba, S. D. (2009). Modeling of the Human Operator Reliability with the Aid of the Sugeno Fuzzy Knowledge Base. *Automation and Remote Control*, *70*, 163–169. https://doi.org/10.1134/S0005117909010123

41. Pratap, R. (2016). *Getting started with MATLAB 5: A quick introduction for scientists and engineers* (7th ed.). Oxford University Press.

42. Matviychuk, A. (2012). Obgruntuvannia vyboru naukovoi spriamovanosti zhurnalu (vstupne slovo holovnoho redaktora) [Rationale for Choosing the Scientific Focus of the Journal (Introduction by the Chief Editor)]. *Neiro-Nechitki Tekhnolohii Modelyuvannya v Ekonomitsi (Neuro-Fuzzy Modeling Techniques in Economics)*, *1*, 7–36. http://doi.org/10.33111/nfmte.2012.007 [in Ukrainian]

43. Kozlovskyi, S. V., & Syniehub, P. S. (2022). Kognetyvna otsinka intelektual'nogo kapitalu ekonomichnykh system v ekonomitsi znan' [Cognitive assessment of intellectual capital of economic systems in the knowledge economy]. *Ekonomika ta derzhava*, *8*, 48–55. https://doi.org/10.32702/2306-6806.2022.8.48 [in Ukrainian]

The article was submitted on 2022, September 3