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Запропоновано нечіткий метод формування портфеля заходів в області розвитку людського капіталу університету. Розглянуто модель, цільовою функцією якої є інтегральний показник, що оцінює просування по досягненню цільових значень показників завдань університету. Змінними, за якими проводиться оптимізація, є булеві змінні включеності в портфель заходу, спрямованого на розвиток людського капіталу співробітників підрозділів університету в певний момент часу

Ключові слова: людський капітал, економіко-математичне моделювання, стратегічні заходи, управління університетом, нечітко-множинний підхід

Предложен нечеткий метод формирования портфеля мероприятий в области развития человеческого капитала университета. Рассмотрена модель, целевой функцией которой является интегральный показатель, оценивающий продвижение по достижению целевых значений показателей задач университета. Переменными, по которым проводится оптимизация, являются булевы переменные включенности в портфель мероприятия, направленного на развитие человеческого капитала сотрудников подразделений университета в определенный момент времени

Ключевые слова: человеческий капитал, экономико-математическое моделирование, стратегические мероприятия, управление университетом, нечетко-множественный подход

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DEVISING A FUZZY MODEL FOR COMPILING A PLAN OF ACTIVITIES AIMED AT DEVELOPING HUMAN CAPITAL IN UNIVERSITY

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1. Introduction

Managing sustainable development of a university is aimed at fulfilling of the tasks arising from strategic objectives and interrelated with the main indicators of the effectiveness of activity of universities. This is possible, among other factors, through competent and reasonable investment of available resources.

In this case, one of the priority areas of investment is the human capital of the university, which exerts decisive influence on the implementation of the university development strategy. Human capital is one of the most important and, at the same time, very specific resource, which makes it rather difficult to assess effects that occur at a change in its magnitude. At present, world system of the higher education undergoes a transition from the translation of knowledge to a diversified university, whose basis of the educational process and economics is formed by research work and innovative activity. These changes further increase the importance of human capital and investment strategy in the field of its development.

Decomposition of strategic objectives to the level of structural divisions of the university leads to the necessity

to form an investment strategy and an optimal plan of activities in the field of human capital for each structural unit. In connection with this, a relevant task is the development of an instrumental component of the theory of human capital, which would make it possible:

– to achieve maximum progress in fulfilling strategic tasks of the university through the development of human capital;

– to make optimal use of available financial resources;

– to take into account the uncertainties of external and internal environment that affect achievement of the results.

2. Literature review and problem statement

In the present study, human capital will be understood as a set of inborn abilities and acquired knowledge, skills, and attainments of the individual, ensuring his effective functioning as a production development factor. In most studies into various aspects of modeling a human capital, a number of properties of human capital are highlighted. These properties indicate that the process of investment is an integral part of its development. The result of investing in human capital is the acquisition of new knowledge and skills or development of the existing ones, which leads to the growth of human capital, labor productivity and income.

Scientific works in the field of modeling the human capital development can be divided into three enlarged groups:

– estimation of the magnitude of human capital. For example, in paper [1], a model of estimation of intellectual potential was proposed based on determining integral ratings by the level of development and stability of the values of basic indicators of territorial development in the system of other territories, taking into account the entropy of indicators. A scale for measuring human capital was proposed in article [2], taking into account the aspects related to competence, attitudes, skills, leadership and organizational memory;

– analysis and assessment of the impact of various areas of investment (activities) on the development of human capital. Thus, for example, in paper [3], a technique for finding the most profitable methods of motivation of employees' work activity was proposed, based on the personnel controlling system. In the paper [4] various approaches to formation of the educational environment from the point of view of maximum development of human capital were considered. In article [5], a method of financing the development of human capital was proposed, through higher education by receiving additional income taxes from the higher minimum wage. An analysis of the impact of professional education and training on the development of human capital in China was conducted in paper [6]. In article [7], a concept of lifelong learning in Benin was developed, combining formal and informal education systems, was developed and its impact on the development of human capital was analyzed;

– analysis and assessment of the impact of human capital on performance efficiency of the socio-economic system. For example, in paper [8], a model was proposed for assessing effectiveness of the relationships between human capital, knowledge management, and other factors aimed at improving a company's productivity. In work [9], the influence of investments in human capital on the organizational effectiveness of pharmaceutical companies in Kenya was established. In article [10], regression models were constructed between staff records and organizational indicators in Nigeria. In paper [11], the impact of college education on the development of human capital and, thereby, on stimulating economic growth in the region was assessed. In article [12], the relationship between the level of education of employees of the firm, labor productivity, and wages of its employees was studied.

Despite a significant number of studies that address modeling of the human capital development, the existing methods and models:

– do not make it possible to proceed to determining an optimal plan of activities, which in one way or another contribute to an increase in the magnitude of human capital, because in the previous studies, separate areas of investing in human capital were considered, rather than all together;

– do not take into account the actual multi-period nature of the process of investing in human capital;

– do not fully account for the existing uncertainties that arise when making management decisions;

– do not assess the impact of human capital on the progress in achieving strategic tasks facing a university's structural unit (that is, do not make it possible to assess effectiveness of the work of the structural subdivision of a non-profit organization).

Thus, there is a shortage of tools to justify creation of a portfolio of activities in the area of human capital development of an organization for the maximum possible achievement of strategic tasks. The optimal plan of activities should be formed taking into account initial parameters and specifics of the business units of an organization, the planning horizon, existing resource constraints and uncertainties. This necessitates development of new methods and models.

3. The aim and objectives of the study

The goal of present work is to develop an economic-mathematical method for the formation of an optimal portfolio of strategic activities that contribute in one way or another to the development of human capital of an organization.

To accomplish the goal, the following tasks were set:

– to devise a fuzzy optimization model that makes it possible to achieve the target values of strategic objectives of business units to the maximum extent;

– to develop a method for finding a solution to the model, taking into account a significant number of constraints and optimization variables and a fuzzy assignment of part of its parameters;

– to perform approbation of the model on the example of the Vladivostok City University of Economics and Service, Russia.

4. Method for the formation of a portfolio of strategic activities in the area of human capital development of the university in a fuzzy statement

At present, competent management of such a socio-economic system as a university implies the existence of a program of strategic development. At the same time, this program has a complex character aimed at meeting the needs of stakeholders. One of the development priorities of the program is the accumulation of human capital, which is of significant importance for the main stakeholder groups. In turn, implementation of strategic activities in the field of

human capital development should lead to the advancement of target values of indicators of strategic tasks of structural divisions of the university. At the same time, specifics of the structural unit of the university determine a varying degree of participation of each of them in achieving strategic objectives of the university, and the differences in the degree of participation are reflected in the set of strategic tasks, their indicators and target values.

Thus, an objective function of the model should take into account the set of strategic objectives facing structural divisions of the university. Strategic objectives arise as a result of decomposition of strategic objectives of the university to the level of structural subdivisions. Each strategic objective is assigned with indicators. There is a target value on the assigned planning horizon for an indicator.

As an objective function, we shall consider the weighted average of levels of achieving the target values of indicators of all strategic tasks:

$$U(t)=\frac{\sum_{k=1}^{K}\left(\sum_{n=1}^{N}\left(\sum_{l=1}^{L_k}\frac{P_{kln}(t)}{\overline{P}_{kln}}\cdot\xi_{kl}\right)\cdot\varphi_k\right)}{N},\quad t=0,1,2,...,T, \qquad (1)$$

where $P_{kln}(t)$ is the value of the l-th strategic task of the n-th structural unit within the k-th strategic objective of the university at a moment in time t; $\overline{P}_{kln}$ is the target value of the l-th strategic task of the n-th structural unit within the k-th strategic objective of the university on the assigned planning horizon; ξ_{kl} is the coefficient of significance of the l-th strategic task within the framework of the k-th strategic objective of the university; φ_k is the coefficient of significance of the k-th strategic objective of the university; K is the quantity of strategic objectives of the university; L_k is the number of strategic tasks within the framework of the k-th strategic objective of the university; N is the quantity of structural units of the university; T is the planning horizon.

Weighted coefficients of the significance of strategic objectives and tasks are determined by experts using verbal assessments and taking into account the experts' competence levels.

In order to find a value of the integral indicator, functional dependences are constructed that make it possible to find the achieved values of the indicators of strategic tasks at a moment of time t depending on the structures and levels of human capital of structural divisions of the university:

$$P_{kln}(t)=f_{kln}\left(D_{1n}(t),D_{2n}(t),...,D_{I_n n}(t)\right), \qquad (2)$$

where $D_{in}(t)$ is the level of human capital of the i-th employee of the n-th structural unit of the university; I_n is the number of employees of the n-th structural unit of the university.

The given dependences are found employing the regression analysis methods from a sample of statistical data and some expert assumptions. It should be noted that an example of the constructed dependences for a certain set of strategic tasks is given in paper [13].

It is important to note that the human capital of an employee is understood as the totality of his inborn abilities and acquired knowledge, skills and attainments that enable effective and rational functioning of the employee as a production factor of development. In this case, the level of human capital is its quantitative assessment determined from the following formula:

$$D_{in}(t)=\sum_{j=1}^{J}x_{inj}(t-1)\cdot\alpha_j+\sum_{j=1}^{J}\left(\sum_{r=1}^{R}\Delta x_{inj}^{r}(t)\right)\cdot\alpha_j, \qquad (3)$$

$$D_{in}(0)=\sum_{j=1}^{J}x_{inj}(0)\cdot\alpha_j,$$

where $x_{inj}(t)$ is the value of the j-th characteristic of human capital of the i-th employee of the n-th structural subdivision of the university at a moment of time t; $\Delta x_{inj}^{r}(t)$ is the change of $x_{inj}(t)$ through the r-th direction of investment; α_j is the weight coefficient, characterizing the importance of the j-th characteristic of human capital; J is the number of characteristics describing the employee's human capital; R is the number of investment directions (four areas are considered: $r=1$ – education, $r=2$ – healthcare, $r=3$ – reproduction, $r=4$ – image). A detailed description of the indicators is given in article [13].

Next, we shall consider a multi-period process. At each moment of time t, the university invests financial resources in activities that affect human capital of structural units, in order to improve its level. The human capital of the university available at a moment of time t generates obtaining of a certain rent, part of which, at a moment of time (t+1), along with the investments planned under strategic development program, is directed to the further increase in human capital through activities.

Activities in the area of human capital development can be categorized into four groups (in accordance with directions of investing in human capital): education, health, reproduction, and image building. In this case, the given activities, taking into account the channels of influence, described in paper [13], lead to some extent to the growth of human capital.

In equation (3), the level of human capital of an individual employee of the university's structural unit at a moment of time t depends on the value $\Delta x_{inj}^{r}(t)$. In this case, the given changes depend on the volume and structure of financial resources invested in the activities in the area of human capital development and characteristics of the employee. Taking into account considerations given in article [13], it is proposed to use the following formula to determine Δx_{inj}^{r}:

$$\Delta x_{inj}^{r}(t)=\lambda_{inj}^{r}\cdot Z(\tau_{in})\times$$
$$\times\frac{\sum_{m=1}^{M_r}y_{inm}^{r}(t-1)\cdot C_m^{r}(t-1)}{B^{r\,norm}\cdot(1+d)^{t-1}}\cdot 10\cdot\left[1-\left(\frac{x_{inj}(t-1)-10}{90}\right)^{s}\right], \qquad (4)$$

where λ_{inj}^{r} is the coefficient of influence of the r-th direction of investment on the j-th characteristic of human capital of the i-th employee of the n-th structural division of the university; $Z(\tau_{in})$ is the function of assimilation of investments depending on the age of the employee; τ_{in} is the age of the i-th employee of the n-th structural unit of the university at a moment of time t; $y_{inm}^{r}(t)$ is the optimization variable that takes values 0 or 1 (where $y_{inm}^{r}(t)=1$, if the m-th project within *the* r-th direction for the i-th employee of the n-th structural unit of the university is included in the portfolio, and otherwise); $C_m^{r}(t)$ is the cost of implementing of the m-th activity in the r-th direction of investment at a moment of time t; M_r is the number of activities within the r-th direction of investment; $B^{r\,norm}$ is the normalization function of the r-th direction of investment; S is the saturation coefficient; d is the discount rate.

A detailed description of indicators λ_{inj}^{r}, $Z(\tau_{in})$ and $B^{r\,norm}$ is given in papers [13, 14].

The values of part of the model parameters ($x_{inj}(0)$, α_j, ξ_{kl}, φ_k and λ_{inj}^{r}) are determined based on an expert evaluation. It is quite difficult to specify these values in the form of a clear number. At the same time, it is easier for an expert to formulate these values in the form of a verbal assessment, taking into account subjective representations and feelings (based on their nature, expert's experience and statement of the problem). One of the ways to simplify the task is to use a fuzzy-multiple approach. Therefore, for the estimates of these values, we shall apply verbal estimates converted into fuzzy trapezoidal numbers.

For the linguistic variable *Y=<value of the characteristic of the human capital of the employee>* the term set can be written as *V(y)={extremely small; exceedingly small; small; less than average; average; more than average; large; extremely large; exceedingly large; highest possible}*. The membership functions are assigned in the form of fuzzy numbers:

– *W*(*extremely small*)={10; 10; 10; 15};
– *W*(*exceedingly small*)={10; 15; 20; 25};
– *W*(*small*)={20; 25; 30; 35};
– *W*(*less than average*)={30; 35; 40; 45};
– *W*(*average*)={40; 45; 50; 55};
– *W*(more that average)={50; 55; 60; 65};
– *W*(*large*)={60; 65; 70; 75};
– *W*(*exceedingly large*)={70; 75; 80; 85};
– *W*(*extremely large*)={80; 85; 90; 95};
– *W*(*highest possible*)={90; 95; 100; 100}.

For linguistic variables Y^1=*<importance of the characteristic of human capital>*, Y^2=*<importance of the strategic task of the university>* and Y^3=*<importance of the strategic objective of the university>*, the term sets can be written as $V(y^1)=V(y^2)=V(y^3)$=*{very low; low; below the average; average; above average; high; very high}*. The membership functions are assigned in the form of fuzzy numbers:

– *W*(*very low*)={0; 0; 1; 3};
– *W*(*low*)={1; 3; 3; 4};
– *W*(*below the average*)={3; 4; 4; 5};
– *W*(*average*)={4; 5; 5; 6};
– *W*(*above average*)={5; 6; 6; 7};
– *W*(*high*)={6; 7; 7; 9};
– *W(very high)*={7; 9; 10; 10}.

For linguistic variable *Y=<the influence of investment directions on the characteristics of the human capital of university employees>*, the term-set can be written as *V(y)= ={very weak; weak; below average; average; above average; strong; very strong}*. The membership functions are assigned in the form of fuzzy numbers:

– *W*(*very weak*)={0; 0; 0.1; 0.2};
– *W*(*weak*)={0.1; 0.2; 0.2; 0.3};
– *W*(*below average*)={0.2; 0.3; 0.3; 0.4};
– *W*(*average*)={0.3; 0.4; 0.6; 0.7};
– *W*(*above average*)={0.6; 0.7; 0.7; 0.8};
– *W*(*strong*)={0.7; 0.8; 0.8; 0.9};
– *W*(*very strong*)={0.8; 0.9; 1; 1}.

It should be noted that in order to determine the values of parameters of the direct evaluation model, an individual expert survey is conducted, based on the use of opinions of independent experts, which makes it possible to determine the values of indicators in a given range of variation. In the case when more than one expert is interviewed, there is a need to consolidate their opinions. To consolidate the opinions of experts who answer a question, we shall apply the following formula:

$$\bar{b}=\sum_{q=1}^{Q} b^q\cdot f\left(c^q\right), \tag{5}$$

where b^q is the estimation of parameter value given by the q-th expert; $f(c^q)$ is the function of significance of the respondent; c^q is the evaluation of level of competence of the q-th expert in assessing the value of parameter b; Q is the number of interviewed experts.

Choosing as a function of significance of expert $\left(c^q\Big/\sum_{q=1}^{Q} c^q\right)$ means "smoothing" of expert assessments in proportion to the given competence estimates. The choice of an increasing, convex downwards, function leads to an increase in the significance of opinions from the more competent specialists.

It should be marked that the following rules of addition, subtraction, multiplication, and a quotient for fuzzy numbers are used:

$$-\ \{a_1;a_2;a_3;a_4\}+\{b_1;b_2;b_3;b_4\}=\{a_1+b_1;a_2+b_2;a_3+b_3;a_4+b_4\},$$

$$-\ \{a_1;a_2;a_3;a_4\}-\{b_1;b_2;b_3;b_4\}=\{a_1-b_4;a_2-b_3;a_3-b_2;a_4-b_1\},$$

$$-\ \{a_1;a_2;a_3;a_4\}\cdot\{b_1;b_2;b_3;b_4\}=\{a_1\cdot b_1;a_2\cdot b_2;a_3\cdot b_3;a_4\cdot b_4\},$$

$$-\ \{a_1;a_2;a_3;a_4\}\div\{b_1;b_2;b_3;b_4\}=\{a_1\div b_4;a_2\div b_3;a_3\div b_2;a_4\div b_1\}.$$

In order to determine weighted significance coefficients, it is necessary to normalize the consolidated estimates.

Considering that a person's abilities tend to decrease without constant training and motivation, we assume the following:

– the lack of investment in human capital in one of the areas of investment (that is, absence of an activity within a particular direction) over an interval longer than two years results in a decrease in the characteristics of human capital influenced by this direction of investment;

– a reduction in the characteristics of the individual does not exceed half of the maximum possible increment in the characteristic over one time interval, which is five units (each characteristic changes on a scale from "0" to "100" [13]).

Formalization of these assumptions takes the form:

$$\sum_{\theta=t-2}^{t}\sum_{m=1}^{M_r} y_{inm}^{r}(\theta)=0\Rightarrow\Delta x_{inj}^{r}(t+1)=-5\cdot\lambda_{inj}^{r}. \tag{6}$$

We shall supplement the optimization model with the following constraints:

– a change in the value of the j-th characteristic of human capital of the i-th employee of the n-th structural subdivision of the university over interval $[t-1; t]$ does not exceed 10 units: $\Delta x_{inj}(t)\le 10$;

– the amount of financial resources the university spends on the implementation of activities in the area of human capital development at a moment of time t is limited by the total amount of financial resources allocated for human capital:

$$\sum_{n=1}^{N}\sum_{i=1}^{I_n}\sum_{r=1}^{R}\sum_{m=1}^{M_r} y^r_{inm}(t)\cdot C^r_m(t) \le \beta(t)\cdot\sum_{n=1}^{N}\sum_{i=1}^{I_n} B_{in}(t)+\hat{B}(t), \qquad (7)$$

where $B_{in}(t)$ is the function of the n-th structural division of financial resources attracted by the i-th employee over time interval [t-1, t] (the function is described in detail in paper [13]); $\hat{B}(t)$ is the volume of investments allocated by the university for strategic activities in the area of development of its own human capital at a moment of time t; $\beta(t)$ is the withdrawal rate at a moment of time t, $0 \le \beta(t) \le 1$;

– annual volume of investments in the human capital of the university is limited by the amount of financial resources allocated under strategic development program:

$$\hat{B}(t) \le B_{budget}(t),$$

where $B_{budget}(t)$ – by the amount of financial resources allocated under strategic development program of the university, at a moment of time t.

Thus, creation of the optimal portfolio of activities in the area of human capital development of the university is proposed to be implemented using the following model:

$$\begin{cases} U(T)=\dfrac{\sum\limits_{k=1}^{K}\left(\sum\limits_{n=1}^{N}\left(\sum\limits_{l=1}^{L_k}\dfrac{P_{kln}(T)}{\overline{P}_{kln}}\cdot\xi_{kl}\right)\cdot\varphi_k\right)}{N}\to\max, \\ P_{kln}(t)=f_{kln}\left(D_{1n}(t),D_{2n}(t),...,D_{l_n n}(t)\right), \\ D_{in}(t)=\sum\limits_{j=1}^{J}x_{inj}(t-1)\cdot\alpha_j+\sum\limits_{j=1}^{J}\left(\sum\limits_{r=1}^{R}\Delta x^r_{inj}(t)\right)\cdot\alpha_j, \\ D_{in}(0)=\sum\limits_{j=1}^{J}x_{inj}(0)\cdot\alpha_j, \\ \Delta x^r_{inj}(t)=\lambda^r_{inj}\cdot Z(\tau_{in})\cdot\dfrac{\sum\limits_{m=1}^{M_r}y^r_{inm}(t-1)\cdot C^r_m(t-1)}{B^{r\,norm}\cdot(1+d)^{t-1}}\cdot 10\times \\ \times\left[1-\left(\dfrac{x_{inj}(t-1)-10}{90}\right)^s\right], \\ \Delta x_{inj}(t)\le 10,\ \hat{B}(t)\le B_{budget}(t), \\ \sum\limits_{n=1}^{N}\sum\limits_{i=1}^{I_n}\sum\limits_{r=1}^{R}\sum\limits_{m=1}^{M_r}y^r_{inm}(t)\cdot C^r_m(t)\le\beta(t)\cdot\sum\limits_{n=1}^{N}\sum\limits_{i=1}^{I_n}B_{in}(t)+\hat{B}(t), \\ \sum\limits_{\theta=t-2}^{t}\sum\limits_{m=1}^{M_r}y^r_{inm}(\theta)=0\Rightarrow\Delta x^r_{inj}(t+1)=-5\cdot\lambda^r_{inj}. \end{cases}$$

Note that the existing methods for solving the optimization problems in a fuzzy statement are not suitable to solve the problems, in which part of the input parameters of the model varies over time. In paper [14], an author's method is proposed for determining the value of an objective function over the assigned planning horizon employing fuzzy-multiple logic for an individual structural unit and with the possibility of unlimited division of optimization variables. It consists of two stages. At the first stage, a structure of the allocation of investment in human capital between employees of the business unit is determined, in terms of investment directions and years in clear numbers. In this case, the values of parameters and of the initial data are the medians of the trapezoidal fuzzy numbers. The problem is solved numerically using the MatLab programming environment. At the second stage, by using the found investment structure and assigning the values of model parameters in the form of fuzzy numbers, according to the recurrent dependences of the model (4) (because the model includes cyclic computational processes), we find the value of integral indicator at a moment of time T by direct calculation. It should be noted that the given method was modified for the totality of structural divisions of the university and for the case of investing, in the form of budgeting, of possible activities in the area of human capital development.

5. Example of formation of the optimal portfolio of strategic activities in the area of human capital development of the university

As an example of the application of the proposed method, we shall consider the following management task facing the heads of structural divisions of the university, performing educational, scientific, managing, and supporting functions.

At the time of working out a strategic development plan of the university on a certain planning horizon, the issue arises about optimal allocation of financial resources among employees of various structural divisions of the university. Note that this allocation is carried out among the activities in the area of human capital development by years.

It is necessary to optimize the allocation of resources in such a way that over a period of 5 years, maximum progress is made in achieving the objectives of the structural divisions of the university, and, consequently, of the university itself.

In the framework of this example, we shall consider three structural divisions at Vladivostok State University of Economics and Service (VSUES), Russia: Department of Mathematics and Modeling; Center of Scientific Research, Projects, and Programs; Center of Image Building and Recruitment of Entrants. Initial parameters of these structural units are given in Table 1.

It should be noted that VSUES is one of the few universities that successfully implemented a full cycle of strategic planning and obtained feasible results [15]. During implementation of results obtained in the course of strategic planning process into operational activities, a method of the system of balanced scorecards was successfully applied. A map of objectives for the structural units of the university is given in Table 2.

We suppose that $\hat{B}(t)$ comprises 4.5 million Russian rubles per year and $\beta(t)$ is equal to 0.1.

Next, the model is actualized by dependences $P_{kln}(t)$. For this purpose, the required functional dependences are constructed using the regression analysis methods for each problem of the structural unit, based on certain assumptions and statistical data on VSUES. Examples of their construction are given in paper [13].

Article [16] provides a list of strategic activities in the area of development of human capital of a structural division of the university. In this case, the set of activities depends on many factors: corporate ethics, territorial features, etc.

Table 1

Initial parameters of the structural units at VSUES

Name of the structural unit	Initial parameters of the structural unit
Department of Mathematics and Modeling	1) *Number of employees of the department* – 23, including: employees holding a scientific degree – 16 (including 4 employees holding a doctorate); employees with academic status – 9 (including 4 employees having the academic title of professor). 2) *The level of human capital of the department* – {51,2; 56,3; 60,2; 63,7}, which indicates the prevalence of employees with a level of human capital above the average at the department. 3) *The average age of staff of the department* – 42 years.
Center of Scientific Research, Projects, and Programs	1) *Number of employees of the center* – 5, including: employees holding a PhD degree – 2; employees holding the academic rank of associate professor – 1. 2) *The level of human capital of the center* – {50,6; 54,6; 59,4; 62,6}, which indicates the prevalence of employees with a level of human capital above the average at the center. 3) *The average age of staff of the center* – 33 years.
Center of Image Building and Recruitment of Entrants	1) *Number of employees of the center* – 15. 2) *The level of human capital of the center* – {42,4; 46,6; 49,3; 51,3}, which indicates the prevalence of employees with a level of human capital below the average at the center. 3) *The average age of staff of the center* – 48 years.

Table 2

A map of objectives for the structural units of VSUES

Strategic objectives	Strategic tasks	Indicators of strategic tasks
1	2	3
Department of Mathematics and Modeling		
Improvement of the quality of educational activities	Increase in the qualitative composition of students accepted to academic year 1	The average score of the Unified State Exam (ESE) of students, accepted for full-time education
	Increase in the popularity of programs for training highly qualified personnel	Number of postgraduates studying in the reporting year, per one full-time employee of professional and teaching staff (PTS) of the department
	Application of modern educational technologies	The proportion of full-time PST of the department applying modern educational technologies in the total number of PTS of the department
	Application of network learning principles	1. Share of educational disciplines of the department using open educational resources in the total number of educational disciplines of the department 2. Number of agreements on cooperation in the implementation of joint professional educational programs per one full-time employee of PTS of the department
	Enhancement of the mechanisms of practice-integrated learning	Share of employment of graduates of the full-time form of education according to the employment service for the reporting year
Implementation of human potential	Advanced training of professional and teaching staff	1. Share of the full-time PTS of the department having a degree of a candidate or doctor of sciences in the total number of the full time PTS of the department 2.The mean value of H-index of the department 2. Number of professional certificates received by PTS over the last 5 years, per one full-time employee of PTS of the department

Continuation of Table 2

1	2	3
Improvement of the quality of scientific activity	Increase in the publication activity of the department	1. Number of publications indexed in the information-analytical system of scientific citations WoS and Scopus, per one full-time employee of PTS over 1 year 2. Number of publications indexed in the Russian information-analytical system of scientific citation (RISC), per one full-time employee of PST over 1 year 3. Number of monographs prepared by full-time PST of the department, per one full-time employee of PST over 1 year
	Improvement of the quality of publication activity of the department	The mean-weighted IF of journals, which published papers by PTS of the department
	Improvement of the quality of application campaigns of the department in the framework of contests of research projects	Number of grants received per 1 year
	Increase in the effectiveness of innovation activities of PTS of the department	1. Number of patents received per PST full-time employee over 1 year 2. Number of registered computer programs, databases, topologies of integrated circuits per one full-time employee of PST over 1 year 3. Number of license agreements for the right to use intellectual property by other organizations per one full-time employee of PST over 1 year
Improvement of financial results	Increase in income from main educational programs	Volume of income for basic professional education programs per year per one full-time employee of PTS of the department
	Increase in the volume of income under contracts for the provision of additional professional education services	Volume of income under contracts for the provision of additional professional education services per one full-time employee of PST of the department over 1 year
	Increase in the amount of funds raised by the department's PST for the fulfillment of contractual research and grants	Volume of funds attracted by PTS for the implementation of contractual research and grants per one full-time employee of PTS rate of the department over 1 year
Center of Scientific Research, Projects, and Programs		
Organization of interaction between the university and external environment	Increase in income volume from all sources of fulfilling R&D	Amount of funds raised for the fulfillment of R&D from all sources over 1 year
	Implementation of application campaigns in the framework of contests pf research projects	Number of prepared and submitted applications to competitions within the framework of Federal Target Program by orders of ministries and organizations over 1 year
		Number of prepared and submitted applications to RHSF (Russian Humanitarian Science Foundation), RFHR (Russian Foundation for Humanitarian Research), RSF (Russian Science Foundation) competitions over 1 year
Center of Image Building and Recruitment of Entrants		
Search and attraction of the most talented schoolchildren and students to the university	Increase in the effectiveness of supplementary education programs (preparatory courses in profile sessions)	1. Volume of the center's income from the supplementary education programs (preparatory courses of profile sessions) per employee over 1 year 2. Number of people who have completed training under supplementary education programs (preparatory courses for profile sessions) over 1 year
	Increase in the qualitative composition of students accepted for academic year 1	The average score of USE of students, accepted according to the results of USE for full-time education

As a result of solving the set problem, we obtained values of $y^r_{inm}(t)$. It should be noted that the total volume of investments in strategic activities in the area of human capital development over 5 years made up 51.5 million Russian rubles. (43.7 % – investments in human capital, planned for the strategic development program of the university for the structural units under consideration, 56.3 % – the funds attracted by the structural units allocated to increasing human capital), of which in the first year – 9; second year – 9.9; third year – 10.5; fourth year – 10.9; fifth year – 11.2. It should be noted that 61 % of investments into strategic activities in the area of human capital development are directed to the Department of Mathematics and Modeling, 18 % – to the Center of Scientific Research, Projects, and Programs, 31 % – to the Center of Image Building and Recruitment of Entrants. Structural charts for the subdivisions under consideration are shown in Fig. 1.

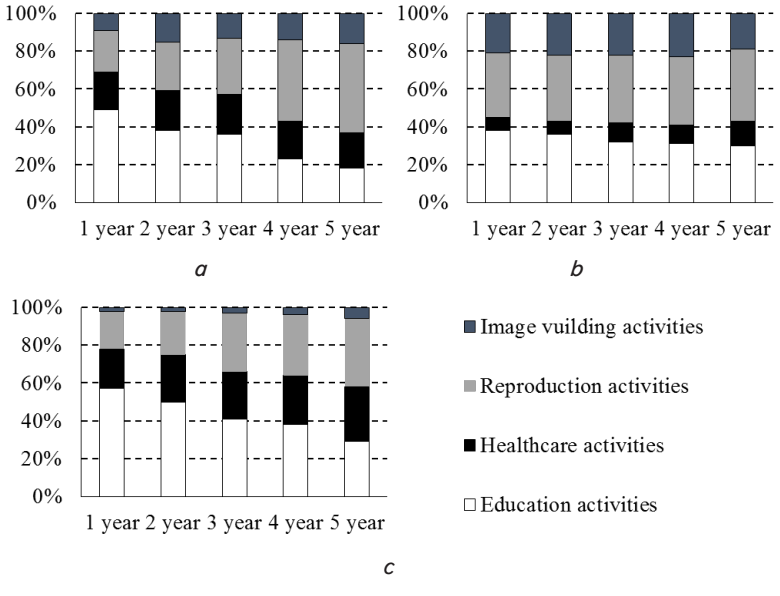

Fig. 1. Structural charts of investment allocation into strategic activities for the development of human capital: *a* – Department of Mathematics and Modeling; *b* – Center of Scientific Research, Projects, and Programs; *c* – Center of Image Building and Recruitment of Entrants

Analyzing the obtained results, the following conclusions can be made:

– 15–20 % of the total volume of investment funds are directed to employees with a low initial level of human capital (up to {20; 25, 30, 35}), with most of the financial resources (40–50 %) being sent to reproduction, 40 % – to education, 15–20 % – to health care, and 1–2 % – to image building;

– 5–10 % of the total volume of investment funds are allocated to employees with an average initial level of human capital (from {20; 25, 30, 35} to 60, 65, 70, 75}), with most of the funds (40–50 %) being given to education, 25–35 % – to reproduction, 15–25 % – to health care, and 5–10 % – to image building;

– less than 2 % of the total volume of investment funds are allocated to employees with a high initial level of human capital (more than {60, 65, 70, 75}), with most of the financial resources (35–40 %) being given to education, 20–25 % – to reproduction, 20–25 % – to health care, and 15–20 % – to image building.

It should be noted that most of the financial resources for the considered structural units of the university fall on educational activities (about 45 %), then about 35 % – to reproduction, about 15 % – to health care, and the rest is directed to the image building activities. This is due to the fact that activities in the areas of education and reproduction are the activities that maximally cover characteristics of human capital and enable growth of their values at minimal cost. Thus, for the existing initial parameters of structural units, these activities are the priority and such make it possible to provide maximum progress in achieving strategic tasks of the structural units.

From the point of view of development of structural divisions and achievement of the set tasks, the following results were obtained:

a) an increase in the level of human capital at the Department of Mathematics and Modeling over 5 years makes up {11.2; 12.5; 13.1; 13.9}. It should be noted that with the existing volume of investments in strategic activities for the development of human capital, the degree of achievement of the strategic objective "Improvement of the quality of educational activities" is {0.85; 0.95; 0.99; 1,02}, "Realization of personnel potential" – {0,92; 0.98; 1.03; 1,06}, "Improvement of the quality of scientific activity" – {0,89; 0.97; 1.02; 1,06}, "Increase in financial results" – {0.78; 0.85; 0.92; 0.99};

b) an increase in the level of human capital at the Center of Scientific Research, Projects, and Programs over 5 years makes up {13.1; 13.9; 14.8; 15.2}. It should be said that with the existing volume of investments in strategic activities in the area of human capital development, the degree of achievement of the strategic objective "Organization of the interaction of the university with the external environment" makes up {0.98; 1.02; 1.05; 1.08};

c) an increase in the level of the human capital at the Center of Image Building and Recruitment over 5 years is {12.2; 13.3; 13.9; 14.5}. It should be noted that with the existing volume of investments in strategic activities in the area of human capital development, the degree of achievement of the strategic objective "Search for and attraction of the most talented students and schoolchildren to the university" makes up {0.95; 1.00; 1.02; 1.04}.

Taking into account the above results, we can make the following conclusions: under the existing initial conditions, the value of integral indicator in 5 years will equal {0.89; 0.96; 1.00; 1,04}, in this case, an increase in its value will make up {0.14; 0.21; 0.25; 0.29}.

In order to assess the degree of risk of failure to achieve strategic objectives, we shall use the following formula:

$$R=\sum_{k=1}^{K}\left(\sum_{n=1}^{N}\left(\sum_{l=1}^{L_k}\frac{S^{lkn}_{risk}}{S^{lkn}_{total}}\cdot\xi_{kl}\right)\cdot\varphi_k\right), \quad (11)$$

where S^{lkn}_{total} is the total area of the figure bounded above by the membership function of trapezoidal fuzzy number; S^{lkn}_{risk} is the area of the figure bounded from above by the membership function of trapezoidal fuzzy number, and by the target value from the right.

Expression $\left(S^{lkn}_{risk}/S^{lkn}_{total}\right)$ yields the degree of risk of failure to reach the target value of the *l*-th strategic task of the *n*-th structural unit within the *k*-th strategic objective of the uni-

versity by the median method. Risk as a whole is defined as a weighted average, taking into account the significance of tasks and objectives.

Thus, the degree of risk of failure to achieve strategic objectives: for the Department of Mathematics and Modeling it is {0.79; 0.83; 0.83; 0.85} (the median is 0.83, therefore, the risk of not fulfilling strategic tasks is much higher than the average), for the Center of Scientific Research, Projects, and Programs it is {0.15; 0.17; 0.17; 0,19} (the median is equal to 0.17, therefore, there is practically no risk of non-fulfillment of strategic tasks); for the Center of Image Building and Recruitment it is {0.22; 0.24; 0.24; 0.27} (the median is equal to 0.24, therefore, there is practically no risk of non-fulfillment of strategic tasks). The overall risk is R={0.45; 0.47; 0.47; 0.50}. The median of the trapezoid is 0.47, therefore, the risk of not fulfilling the strategic objectives of the university is average. This indicates that the target values of some of the strategic tasks of the structural units cannot be achieved. Despite the fact that part of the strategic tasks is overfulfilled, some of them are unattainable at the given amount of funding or at the initial level of human capital.

6. Discussion of results: formation of investment strategy in the area of human capital development of the university

The proposed model makes it possible (after its numerical solution) to form investment strategy in the area of human capital development of structural units of the university at the level of heads of these units. The objective function is chosen in accordance with the strategic tasks facing the structural units.

Investment strategies in the area of human capital development are categorized by two criteria:

a) implementation period: short-term (up to 3 years), medium-term (from 3 to 6 years), and long-term (more than 6 years);

b) a set of strategic tasks of structural units.

Investment strategies in the area of human capital development must answer two main questions:

– what is the structure of the allocation of investments among employees of structural units by strategic activities in the area of human capital development and by years to achieve the maximum possible value of the objective function. The optimal plan of activities is formed depending on the distribution of initial level of human capital, initial age structure of employees of structural units, planning horizon, and the set of strategic tasks of structural units;

– what volume of investments is needed to achieve the maximum possible value of the objective function. The volume of investments is determined depending on the distribution of the initial level of human capital, initial age structure of employees of structural units, planning horizon, and the set of strategic tasks of structural units.

The solutions we found make it possible to formulate a strategy for the units under investigation. This strategy is for the medium-term period (T=5) at the volume of funds under strategic planning program of the university equal to 4.5 million Russian rubles per year and at the withdrawal rate equal to 0.1. Under these conditions, maximal part of investment (about 60 %) is allocated to the Department of Mathematics and Modeling. At the same time, about 45 % of investment fall on strategic activities in the direction of education and about 35 % in the direction of reproduction. A strategy of the Department of Mathematics and Modeling is to "pull the weak links" (employees with a low level of human capital) to the average level of the department. The strategy for the centers is a strategy of "retention" of the existing structure of human capital. Most of the strategic tasks of the structural units will be achieved under existing initial conditions, however, some of them can be achieved only if employees with a high level of human capital are involved.

7. Conclusions

1. The fuzzy optimization model of forming the optimal plan of activities in the area of human capital was developed. The model makes it possible to form a plan of activities in the area of human capital development of structural units of the university. The plan is structured according to time, units, employees, and directions of investment. It makes it possible to maximally achieve the target values of strategic objectives of business units. The strategic objectives of business units are taken from the university's development strategy decomposed to the level of units. To model the uncertainties of the initial data and conditions of the internal and external environment, a fuzzy-multiple approach was used. Some of the input parameters are given in the form of fuzzy trapezoidal numbers, which makes it possible to take into account the diffusiveness of the information and subjective representations of the expert in the task of estimating the parameter and to obtain an estimate of uncertainty in making management decisions. The model is a non-linear programming problem with a large number of constraints and optimization variables.

2. To find a solution to the fuzzy model, a two-stage algorithm was developed. At the first stage, we find a numerical solution to the model in a clear statement. The values of parameters and initial data are the values of the median trapezoidal fuzzy numbers. The problem is solved numerically using the MATLAB programming environment. The second stage implies finding integral indicators in the form of fuzzy numbers. The indicators are computed by direct calculation according to the recurrent dependences of the dynamic model, that is, cyclically from a moment of time t=0 to t=T.

3. As an approbation, the example is examined of determining the optimal portfolio of strategic activities in the area of human capital development for three structural subdivisions of the Vladivostok State University of Economics and Service, Russia (Department of Mathematics and Modeling, Center of Scientific Research, Projects, and Programs, Center of Image Building and Recruitment of Entrants). As a result of the calculations performed, investment strategies were developed in the area of human capital development of structural divisions of the university. They showed, in particular, that in order to fulfill the strategic objective set, the most rational for the department is to develop young employees with a low level of human capital, that is, pulling employees to the mean level of human capital. For the centers, however, a more uniform allocation of investment in human capital is rational, which leads to maintaining the structure of human capital. It is also worth noting that the largest amount of investment over the first two years is allocated on activities related to education. In subsequent years – to activities related to reproduction.

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