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MODEL OF MULTI-CRITERIA SELECTION OF SCIENTISTS AND HIGHER EDUCATION INSTITUTIONS FOR THE SCIENTIFIC ORGANIZATION

The research formulated the task of selecting potential partners for cooperation within the framework of scientific and educational projects. The formulation of the problem in which each project consists of a finite number of work packages is considered.

To find the generalized aggregated evaluations of applicants, a system of fuzzy logical inference is used, which is built to harmonize the opinions of experts regarding the creation of project groups. This method consists of three stages. At the first stage, fuzzification is carried out through the implementation of the scientist's affiliation function to the direction of scientific research. The second stage of fuzzy logic inference consists of experts forming requirements for candidates for a place in the project group. The final stage involves defuzzification using the center of gravity method.

Keywords: scientific research, partners, choice problem, fuzzy logical inference.

1. Introduction. The formation of scientific communities takes place in the conditions of competition among scientists from all over the world. Scientific societies consist of universities, research institutes and private companies, which form applications for joint grant research. It is possible to distinguish three forms of relations between subjects of scientific communities and between their individual structural subdivisions [1]: competition, neutral relations, and partnership.

The task of finding a partner is relevant in the context of globalization and the intensive development of mobility of scientific communities. In this regard, it is possible to highlight the task of calculating the rating of competitors, evaluating the activities of other companies and institutions that can potentially become partners. The principle of constructing metrics can be used to determine assessments of the subjects of scientific communities and individual scientists. It is important to take into account the fluidity and dynamism of the performance of scientific communities and individual scientists, as well as the specifics of partner activities and the specifics of established competitors.

2. Research review. In the context of globalization due to the intensive development of mobility of scientific communities, it is important to rationalize the choice of partners by: Establishing the possible contributions of partners to the project, evaluating the performance of potential partners according to well-defined criteria, and solving the multi-criteria selection problem.

A partial solution to the first problem for the scientific community is provided in [2]. The paper proposes a method of clustering scientists' publications by scientific fields. Within the framework of this method, two ways of finding the distance between publications are proposed. The first method uses the length of the route in the citation graph between publications. The second method takes into account the calculation of the similarity between publication annotations based on the locally sensitive hashing method.

The second task has also been partially solved for the evaluation of research activity on the basis of the publication activity of scientists. The work [3] proposes a method of finding integral estimates of the scientists' research activity results. The method can be used in carrying out a comprehensive assessment of scientists, higher educational institutions and their structural units. The work [4] proposes a method of a comprehensive evaluation of the results of the activities of higher education institutions, based on the calculation of the generalized volume of the m-simplex, the vertices of which are the evaluations of the activities of higher educational institutions in different categories. In addition to evaluating the results of scientific and research activities, it is important to understand the dynamics of changes in this evaluation in the future.

The work [5] analyzed the latest scientific research, which consists in evaluating the scientific research activity of subjects and objects of scientific environments. The work also defines the main features of partners (universities, research institutes, state authorities, private companies, professional associations and foundations), which determine the methods of communication and cooperation between them. The key factors influencing the creation of joint forms of scientific cooperation are described in works [6]. It is determined that the main factors are the level of reputation of the agents and the specifics of cooperation mechanisms, which may have certain limitations. Mathematical methods of choosing partners for cooperation are described in works [5, 6]. In particular, it is proposed to use the analytical hierarchy method and a modification of the genetic algorithm for this task. Theoretical aspects of the formation of factors regarding the choice of partners for cooperation in innovative projects are given in the work [7]. The process of selecting partners in joint international enterprises is described in [8, 1]. Some aspects of this process can be used to select partners for scientific and educational projects.

3. Formalization of the selection problem. The research formulated the task of selecting potential partners for cooperation within the framework of scientific and educational projects. Each project in this setting consists of a finite number of work packages, for each of which it is necessary to select executors. For each work package of each project, a list of key criteria for partner selection must be formed. To determine the optimal composition of executors of the work packages of each project, the method of aggregation of expert assessments can be used. Based on the results of the expert evaluation, the decision on whether to select performers for the implementation of the relevant package is made by the project manager or the person who makes the decision.

Let a finite set of scientific and educational projects or grants be given as [8]:

$$G = \{G_1, G_2, \dots G_n\},$$

n – the number of projects for which it is necessary to select executors. Let a finite set of potential executors for these projects be given.

$$V = \{v_1, v_2, \dots, v_t\},$$

t – is the number of potential performers as subjects of the educational and scientific environment. Executors can be scientists, project managers, research institutions, institutions of higher education, etc.

Any project consists of a number of work packages

$$G_i = \left\{g_1^i, g_2^i, \dots g_{r_i}^i\right\},$$

r_i – the number of work packages of the project G_i, $i = \overline{1,n}$, which are executed in a certain sequence and linked by results. For the execution of each of these work packages, it is necessary to select executors who have the experience and competence to complete the package in a timely and efficient manner. That is, it is necessary to find the following sets of potential performers:

$$W\left(g_j^i\right) = \left\{v_d \in V \,\middle|\, \left(v_d, g_j^i\right) \in Q^i\right\}, Q^i \subset V \times G_i, j = \overline{1, r_i}, i = \overline{1,n}, d = \overline{1,t}.$$

For each work package of each project, a list of key partner selection criteria must be created. That is, the vectors of evaluation criteria will have the form:

$$f^{ij}(v) = \left(f_1^{ij}(v), f_2^{ij}(v), \dots, f_{N_{ij}}^{ij}(v)\right), v \in V,$$

N_{ij} – the number of evaluation criteria of potential partners of work packages g_j^i projects G_i, $j = \overline{1, r_i}$, $i = \overline{1,n}$.

Some criteria are maximized, so we denote the set of indices of such criteria by $J_1^{ij} = \{1, 2, \dots, h_{ij}\}$. Other criteria with indexes $J_2^{ij} = \{h_{ij}+1, h_{ij}+2, \dots, N_{ij}\}$ – are minimized $J^{ij} = \{1, 2, \dots, N_{ij}\}$, $J_1^{ij} \cup J_2^{ij} = J^{ij}$. Then

$$\sum_{k \in J_1^{ij}} \lambda_k f_k^{ij}(v) \to \max, \sum_{k \in J_1^{ij}} \lambda_k = 1,$$

$$\sum_{k \in J_2^{ij}} \delta_k f_k^{ij}(v) \to \min, \sum_{k \in J_2^{ij}} \delta_k = 1,$$

for each package and project, the limit of the set of potential executors is built $v \in V^{ij}$,

$$V^{ij} = \left\{ v \in V \left| y_u^{ij}(v) \geq \rho_u^{ij},\ u = \overline{1, z_{ij}}, j = \overline{1, r_i}, i = \overline{1, n} \right. \right\},$$

where z_{ij} – is the number of threshold values for the constraint vector function $y_u^{ij}(v)$.

The coefficients λ_k and δ_k determine the importance of each of the criteria in the calculation of the comprehensive assessment.

The decision on whether to select executors for the implementation of the relevant package is made by the project management team or the person who makes the decision. To determine the optimal composition of executors of the work packages of each of the projects, the method of aggregation of expert assessments can be used.

Let the given set of experts

$$E = \{E_1, E_2, \ldots, E_s\},$$

s – is the number of experts. Each of the experts compiles the preferences of potential performers considering the vector of criteria. An incomplete preference profile is allowed. Let $\xi_{c,b}^{ij}$ – is the average frequency of occurrence of each of the advantages among potential performers v_c and v_b, $c \neq b$, $v_c \in V$, $v_b \in V$. Then we get preference matrices of the form:

$$\Psi^{ij} = \begin{pmatrix} \xi_{1,1}^{ij} & \xi_{1,2}^{ij} & \cdots & \xi_{1,t}^{ij} \\ \xi_{2,1}^{ij} & \xi_{2,2}^{ij} & \cdots & \xi_{2,t}^{ij} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{t,1}^{ij} & \xi_{t,2}^{ij} & \cdots & \xi_{t,t}^{ij} \end{pmatrix},$$

$$j = \overline{1, r_i}, i = \overline{1, n}.$$

It is possible to obtain an ordered list $v_{k\,1}^{ij} \succ v_{k\,2}^{ij} \succ \ldots \succ v_{k\,t}^{ij}$, $k_1 < k_2 < \ldots < k_t$, $k_q \in \{1, 2, \ldots, t\}$, $v_{k_q}^{ij} \in V^{ij}$, $q = \overline{1, t}$ of potential performers for each package g_j^i of project G_i using methods of collective formation, based on the matrix of pairwise comparisons.

Taking into account the specified list, the project manager selects specific performers and forms a working group.

The general statement of the problem may change depending on which partners are considered. Potential partners can be universities, research institutions, private companies, state organizations, individual scientists. Depending on the objectives of such partners in the project, it is possible to choose appropriate criteria for their evaluation. In particular, for scientists, the evaluation criterion can be publication activity on a topic that meets the tasks of the corresponding work package. In this case, the set of all publications of a potential partner will be denoted by

$$Q(v_d) = \{q_e \in Q \mid (v_d, q_e) \in T\}, T \subset V \times Q, e = \overline{1, M}, d = \overline{1, t},$$

where P – is the set of all publications of scientists that are available in the database, $M = card(P)$.

The set of publications in which the scientist's publications are cited will be denoted by

$$C(v_d) = \left\{ q_e \in Q \mid (q_e, pq) \in C, q_E \in Q(v_d), E = \overline{1, M}, e \neq E \right\}, e = \overline{1, M},$$

where $C \subset Q \times Q$ define citations of the publication.

Then the task of evaluating the productivity of scientific research activity of scientists for their selection to the project is to find for each scientist v_d, based on the given information regarding the citation of his publications, some evaluation b_d, which can be represented in the form of a functional

$$Q^{ij} : V \to R,$$

which is determined depending on the needs of the project and the corresponding project package. The estimate will then look like this:

$$b_d = Q^{ij}\left(Q\left(v_d\right), C\left(v_d\right)\right), d = \overline{1,t}, j = \overline{1,r_i}, i = \overline{1,n}.$$

Then the preferences between scientists v_d are determined by the value of estimate q_d. The greater the value of b_d, the greater advantage the corresponding scientist has for the selection of packages g_j^i of projects G_i into working groups.

If the potential partner is a university or research institute and the scientific component of the activities of the corresponding institution is important for the purposes of the work package, this scheme can also be used. In this case, the evaluation of scientific research activity is calculated for each scientist from a certain structural subdivision, or the university as a whole b_d. And the overall evaluation of the university O will be determined as the average value of the estimates:

$$O = \frac{1}{t}\sum_{d=1}^{t} b_d.$$

One of the international or national indexes can also be used to evaluate universities as potential partners:

– rating of the British consulting company Quacquarelli Symonds (QS);
– the academic ranking of universities in the world, compiled by the Institute of Higher Education of Shanghai Jiao Tong University (Shanghai Ranking);
– Top-200 rating.

Other foundations, associations, and state institutions (for example, ministries, departments, etc.) can also be executors of the project. In this case, the criteria for selecting an executor may include experience in implementing similar projects, the degree of innovation in decision-making, financial ability, assessment of reputation, etc. The evaluation of such criteria can be conducted on the basis of an expert survey, taking into account fuzzy staging.

According to the results of the formation of working groups of project packages, a consortium or project cluster is legally established. It is necessary to take into account the possible participation of stakeholders in the process of project implementation. However, investigating the possibility of including them in the project cluster is a separate task. Since the inclusion of new interested organizations or persons at the stage when the project is already being implemented requires a careful study of the functional responsibilities of the parties, considering the interests of all participants of the project cluster or consortium.

4. Determination of requirements for the method of selecting partners. To solve the problem of choosing partners for cooperation in the framework of scientific and educational projects, it is necessary to develop such a multi-criteria decision-making method that meets the following conditions:

1. Evaluation criteria and alternatives should adequately reflect the complex processes of selecting project executors, should take into account project features, types of executors, etc.
2. Simplicity and clarity in the interpretation of the results of the evaluation of alternatives, that is, the creation of appropriate scales and descriptions of the evaluation results, which would facilitate the work of the person who makes the decision.
3. The ability of the person who makes the decision to choose other alternatives in case the proposed ones do not suit him. This is ensured by introducing clear advantages between alternatives.
4. The possibility of adapting methods or the possibility of using other decision-making methods, as well as exporting the results from one method to another, which would allow to confirm or refute the evaluation results.

5. Development of a method for selecting partners. Let a certain project be at the planning stage, that is, the stage of defining the project environment, and the formulation of the project has already been completed. So, the internal and external factors are determined, the goals and objectives of the project are formed. Then the project can be seen as a set of individual processes, which consist of solving individual tasks of the project. Each of the processes requires resources for its implementation. One of the main resources are task executors.

Let us consider the task of selecting project executors based on a fuzzy expert survey. For simplification, we will assume that each process from the beginning to the end is conducted by one executor. Let us decompose the task of selecting project executors on the subtask of selecting exactly one executor for each of the processes. Let us form a set of persons who can be executors

$$A = \{a_1, a_2, \ldots, a_n\},$$

where n – is the number of persons who can be executors of the process (hereafter referred to as candidates). Each of the candidates can be evaluated based on the list of criteria $c_1, c_2, \ldots, c_k$, k – the number of candidate evaluation criteria. The purpose of the research is to build a method of evaluation and selection of a rational executor among candidates $a^* \in \{a_1, a_2, \ldots, a_n\}$ taking into account a set of criteria. Moreover, the result of applying the method can be either one rational executor a^* or an ordered set of executors $\{a_1^*, a_2^*, \ldots, a_n^*\}$.

The solution, as an ordered set, has a number of advantages. In particular, if a rational candidate refused to participate in the project due to certain external unforeseen factors, the next candidate may be involved in the project.

To evaluate candidates, use a multi-criteria group expert survey. To find the generalized aggregated evaluations of the applicants, the system of fuzzy logical inference (FLI) will be applied. The procedure of fuzzy logic inference consists in defining the mapping of a vector of estimates of input data into a scalar initial value using fuzzy rules.

Fuzzy logical inference consists of three stages.

The first stage is fuzzification. This stage is based on some linguistic variables with corresponding linguistic scales. The main procedure of the stage is to determine the degree of belonging of the input value to each of the linguistic variables.

Consider the mapping obtained as a result of solving the identification of research directions of scientists as a discrete fuzzy mapping, with a membership function determined by the ratio of the number of publications of the author in a given scientific direction to the total number of publications. That is,

$$\Lambda(a_i) = (\eta_b|\mu_b^i), b = \overline{1,\psi}, i = \overline{1,n},$$

a belonging is determined by the formula

$$\mu_b^i = \frac{\|Q(a_i) \cap Y_b\|}{\|Q(a_i)\|},$$

where $Q(a_i)$ is the set of all publications of the scientist a_i, and Y_b – is the cluster of publications corresponding to the direction of scientific research η_b.

The second stage is a mechanism of logical inference. This stage is based on the fuzzy rules that specify the mapping of input fuzzy sets into the output fuzzy set. These rules are formed on the basis of appropriate expert evaluations. There are different procedures for obtaining fuzzy inference, including procedures of Mamdani, Sugeno, Larsen.

Fuzzy rules are formed in the format "If the candidate has the competence η_b with the degree of belonging μ_b, then he meets the requirements of the project with the degree of belonging α". For example, the following rule can be formulated: "If the candidate knows project management methods, then he is an excellent candidate for the position." In the given example of mastery of project management methods - competence η_b, "excellent" is a verbal qualitative assessment. A certain scale should be used to translate qualitative assessments into quantitative values of the membership function. An example of such a scale is given in Table 1. The fuzzy

Table 1.

Scale for verbal evaluation of the statement

№	Verbal qualitative assessment	The value of the membership function
1	Perfectly	0,9
2	Fine	0,75
3	Satisfactorily	0,6
4	Unsatisfactorily	0,35

inference procedure consists in the aggregation of all rules. The process of fuzzy logical inference in the FLI system consists in finding the degree of fulfillment of each rule based on the degree of truth of its premise using the composition $\alpha = \min\{\mu_b\}$. FLI according to Mamdani uses the minimum operator, in the system of FLI according to Larsen based on the product operator.

The final stage – defuzzification consists in transforming a fuzzy value into a clear one. The most common method of defuzzification is the method of finding the center of gravity of a fuzzy set.

Defuzzification occurs using the formula for finding the center of mass

$$\frac{\int\limits_{x_{\min}}^{x_{\max}} x\mu(x)dx}{\int\limits_{x_{\min}}^{x_{\max}} \mu(x)dx},$$

where x is a fuzzy value and $\mu(x)$ – is its membership function. Since we are dealing with a discrete quantity, the Stiltjes integral should be understood as a sum, i.e. the defuzzification occurs according to the formula:

$$\frac{\sum\limits_{b=1}^{\psi} \alpha^i \mu_b^i}{\sum\limits_{b=1}^{\psi} \mu_b^i}.$$

The choice of the executor of the scientific project consists in finding such a scientist who corresponds to the maximum value of defuzzification. An ordered set of executors is constructed from scientists by decreasing defuzzification value.

This approach makes it possible to simplify the selection of potential scientific partners for the creation of a joint project and provides tools for the project manager, which, on a scientific basis, establishes the advantages of partners for the project, as well as for its components.

6. Conclusions and perspectives for further research. The task of selecting potential partners for cooperation within the framework of scientific and educational projects is formulated. Each project in this production consists of a finite number of work packages, for each of which it is necessary to select executors. In practice, project packages have different directions (information dissemination, management, maintaining the stability of project results, scientific research), etc. Forming the criteria for selecting partners for each of the packages is an important task. To find generalized aggregated evaluations of the applicants it was proposed to apply a system of fuzzy logical inference.

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Білощицький А. О., Андрашко Ю. В., Кучанський О. Ю., Файзулін А. Р., Токсанов С. Н. Модель багатокритеріального вибору науковців та зво для організації наукової співпраці.

В дослідженні сформульовано задачу вибору потенційних партнерів для співпраці в рамках наукових та освітніх проєктів. Розглянуто постановку задачі в якій кожен проєкт складається зі скінченого числа робочих пакетів.

Для знаходження узагальнених агрегованих оцінок претендентів застосовано систему нечіткого логічного виводу, який будується для узгодження думок експертів щодо створення проектних груп. Даний метод складається із трьох етапів. На першому етапі фазифікація здійснюється через введення функції належності науковця до напрямку наукових досліджень. Другий етап нечіткого логічного виводу полягає формуванні експертами вимог до кандидатів на місце в проектній групі. На заключному етапі відбувається дефазифікація за допомогою методу центра ваги.

Ключові слова: наукові дослідження, партнерство, задача вибору, нечіткий логічний вивід.

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