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SOLVING THE PROBLEM OF RANKING APPLICANTS FOR A PROJECT TEAM WITH FUZZY ASSESSMENT OF COMPETENCIES AND REQUIREMENTS

The article's **subject** is models and methods for ranking candidates for an IT project team with uncertainty regarding competencies and requirements. The **aim** is to improve the quality of the IT project team by creating and applying models and a method for formalizing the task of multi-criteria ranking of candidates for the team, taking into account the uncertainty of the initial information. **Tasks:** to analyze the relevance of the task of creating models and methods for ranking candidates for the IT project team under conditions of uncertainty; to develop a method for multi-criteria ranking of candidates for the IT project team in a fuzzy formulation; and to solve an example of the task of multi-criteria ranking of applicants for further formation of the IT project team. The **methods** used are the analytic hierarchy process, the line method, and the fuzzy arithmetic method. The following **results** have been obtained. A method of multi-criteria ranking of candidates for an IT project team has been developed, which differs from existing methods by using fuzzy numbers to set the preferences of candidates and assess the generalized competence of each candidate based on comparisons with the reference competence, which improves the ability to evaluate candidates. This method can be used in the first stage of creating an IT project team when candidates for the team are ranked. The task of selecting candidates for further formation of the IT project team has been solved. **Conclusions.** The scientific novelty of the method of multi-criteria ranking of candidates for the project team is that, unlike existing methods, it uses fuzzy ideas about the preferences of candidates when assessing the generalised competence of each candidate based on comparisons with the reference competence, which allows to improve the ability to evaluate candidates. This article considers an example of using the proposed method to solve the problem of selecting candidates to further solve the problem of forming an IT project team under fuzzy evaluation.

Keywords: project team; candidates; competencies; requirements; uncertainty; model; method; ranking; fuzzy numbers.

1. Introduction

1.1. Motivation

The results of statistical studies show that person-job fit in temporary organizations has a positive and significant impact on task performance [1]. The team members' characteristics are the most cited factor for the success of IT projects. This is evidenced by the results of an analysis of 39 papers on this topic [2]. IT projects are characterized by high demands on their executors. These include mastery of modern technologies that are constantly changing, a willingness to acquire new knowledge and skills, knowledge of foreign languages, the ability to work in a team and, at the same time, be responsible for the assigned amount of work, and many others. Specialized online resources offer offers from those who wish to participate in projects. Such offers are collected by HR specialists of companies. However, selecting applicants to perform certain functions in the project and then forming a team

that can meet the project requirements is complex. First, it is necessary to develop requirements for the competencies of an IT project team members. Given that the requirements for the project product and the project itself often change, the requirements for the team's competencies change accordingly during the project. Second, you must assess the competencies of the applicants. Such assessments are usually uncertain and subjective. Third, the task of forming a project team from the candidates should be solved. This task is usually solved by the decision-maker, usually very subjectively. These factors lead to the fact that many IT projects are not completed on time, are over budget, or do not meet customer requirements.

Several studies are devoted to the issues of forming project teams.

1.2. State of the art

The study [3] identified the main behavioral and knowledge factors required by team members to successfully perform relational contracts in

construction. A similar study on relational contracts in the IT domain would be very relevant. Paper [4] proposed using the hierarchy analysis method to solve the problem of selecting a project manager. Factors that influence the creation of an effective IT project team are also considered. Paper [5] proposed a precedent-setting approach to selecting project team candidates. It consists of the fact that when planning the project implementation, an analysis of work that has been performed previously and is close to work planned in the project is carried out. Performers of similar work in the past are involved in the implementation of a new project. It is proposed to estimate the proximity of work to the project as Euclidean distance, considering the weights of the work indicators. The disadvantage of this approach is that past work that was much more complex than the project work may be considered far from the project, although the performers of these works can easily complete the project work. Exaggerating capabilities is especially important when the requirements for project work are uncertain.

This paper also develops methods for forming a project team according to generalised characteristics based on a multi-criteria model. It is proposed to rank the candidates for the project team by determining the normalized values of the criteria used to evaluate the candidates. Next, the sum of the weighted values of these criteria is calculated. The sum of the weighted values of the normalized criteria is used to rank candidates. Fuzzy assessments were not considered. In [6], a method for building formal models of the formation and functioning of project teams was proposed. The proposed method is based on a competency-based and logical combinatorial approach using formal transformations.

The method of forming educational project teams for professional development was proposed by the authors of [7]. The essence of this method is to cross-assess the creativity and personnel risks of the members of such teams. Based on these assessments, the degree of trust in a team member is calculated. It is proposed to include candidates with the highest levels of trust in the team. At the same time, their values should be higher than a certain threshold.

In [8], a method for synthesising a project team in an Agile environment was proposed. In this case, machine learning methods were used to group team members who would work effectively together in an Agile project. The authors proposed an indicator to compare the profile of a team member with a template and identify the highest-rated candidates.

The article [9] presents the hybrid recommendation system ReSySTER based on fuzzy logic, fuzzy set theory, and semantic technologies. The system's recommendations are based on determining the

best team based on the available staff for the project and the competencies required for each work package. The use of ontologies in ReSySTER allows the application of the vocabulary used by experts in this field.

To help a project manager carefully select staff and form a project team that will best ensure the success of the project, the authors of [10] proposed a model that can measure the level of imbalance in the project team before the project begins.

The authors of [10] considered the task of forming a project team in terms of balancing the number of team members belonging to different personality types and ensuring specified levels of abilities. The authors proposed a mathematical model to solve this problem. The objective function of the model is aimed at minimizing the imbalance between the sizes of groups of team members belonging to certain personality types. The constraints of the problem require that the capabilities of each group are not less than the specified ones. The target problem is a linear Boolean programming problem.

The authors of [11] proposed a model to form an Agile software development team. This model involves two stages: determining project characteristics and assessing the characteristics of the formed development team. Among the project characteristics, the authors considered project size and criticality. The method considers the following team characteristics: knowledge, skills, abilities, experience, personality traits, and attitude.

In [10], the authors proposed a synergistic team composition model. The proposed model considers each team member as an agent. The authors characterize each such agent by the following properties: identifier, gender, personality and set of competences. Personality includes 4 personality traits. The set of competencies includes knowledge, skills, personal values, and attitudes. This model addresses the issues of task distribution and team qualification assessment [12].

The authors of [13] proposed a mathematical model for selecting a project team. The model is two-criteria. The first criterion aims at maximizing the skills of the least qualified team member. The second criterion was added to maximize team size. Both criteria in the model are fuzzy. In addition to the objective functions, the model contains explicit constraints. The constraints include restrictions on the project budget, the maximum number of teams in which a candidate can participate, the allowable time of candidate involvement, and the inadmissibility of combining candidates who do not want to work together in one team.

The authors of [14] proposed a mathematical model for the problem of forming a project team regarding the dissemination of acquired knowledge in an organization. The model contains three objective

functions. The first objective function is to maximize knowledge dissemination in the organization. The second objective function minimizes the cost of the project. The third objective function is to minimize the deviation of the individual's workload from the desired workload in the organization. The model constraints require that one employee from each department is assigned to the project. The constraints stipulate that the employee's skill level cannot be lower than the level required to complete the task. The model also contains restrictions that prohibit exceeding the budget of each project and the maximum allowable workload for performers. In general, the mathematical model belongs to nonlinear 0-1 integer programming.

Study [15] proposed a mathematical model of the problem of selecting candidates for a project team that considers individual knowledge, complementarity of candidates' knowledge, and teamwork effectiveness. The model contains objective functions and constraints. The first objective function maximizes the team's competencies by considering the weighting of the criteria used. The second objective function maximizes collaboration. This considers the number of projects in which candidates participated together as well as the number of communications between candidates in the past. The model sets limit on the complementarity of candidates' knowledge and the number of team members. The proposed model is a multi-objective 0-1 quadratic programming model.

Previous studies [16, 17] proposed a model for determining the cohesion of an IT team based on so-called "role patterns" and the fuzzy logic paradigm. In addition, [16] proposed a model for selecting team members based on solving an optimization problem with fuzzy objective functions and fuzzy constraints.

The authors of [18] proposed a modified fuzzy approach to selecting project team members that combines decision-making models based on several criteria with dynamic weights for each parameter. To solve this problem, they used the Intuitionistic Fuzzy Soft Set (IFSS) apparatus.

In [19], a multi-criteria genetic fuzzy grouping algorithm was proposed to solve the problem of team formation.

Paper [20] also presented a fuzzy multi-agent model for creating a team based on nine roles defined by the Belbin typology, using the strengths and ideal responsibilities for each team member role. A previous study [21] proposed a fuzzy approach to support the selection of distributed development teams with technical skills to implement software modules in distributed software development projects. The difference is that this approach considers the various selection policies adopted to identify technically qualified teams.

Lexicographic ranking methods [22] are used to rank candidates for an organisation or team. The lexicographic solution (the best alternative) is Pareto-efficient. However, the excellent value on the less important criterion for some alternatives does not allow us to compensate for the loss on the more important criterion. This feature can play a negative role when ranking candidates in the case of insignificant differences in the importance of the criteria. In the case of equal importance of criteria, the problem will have no solution within the framework of lexicographic ranking.

1.3. Objective and Approach

An analysis of the cited works showed that the authors proposed using the analytic hierarchy process in a crisp statement, lexicographic ranking, multicriteria optimization methods, and methods based on fuzzy sets to select project team candidates. However, in the known works, it was not possible to find an approach that would allow the use of fuzzy representations of candidates' competencies in comparison with the benchmark for multi-criteria ranking of candidates, taking into account fuzzy competency requirements.

This paper aims at improving the quality of an IT project team by creating and applying models and a method for formalizing the task of multi-criteria ranking of team candidates with consideration of uncertainty in the initial information. The objectives of the work included: analyzing the relevance of the problem of creating models and methods for ranking candidates for an IT project team under uncertainty; developing a method of multi-criteria ranking of candidates for an IT project team in a fuzzy setting; and solving example of the problem of multi-criteria ranking applicants for further formation of an IT project team.

In Section 2, we describe a multi-criteria ranking method for ranking project candidates under fuzzy product and project requirements, and under fuzzy candidate competency assessments. In Section 3, we consider an example of using the proposed method to rank five individuals applying for an IT project. We will then discuss the findings and summarize the results.

2. A method for multi-criteria ranking of candidates for an IT project team in a fuzzy setting

Paper [23] proposed a solution to the problem of forming an IT project team in three stages. At the first stage, the requirements for the project product are analyzed, the product backlog is formed, tools (technologies) for developing the project product are identified, the complexity of the work and the time required to complete it are assessed, the requirements

for team candidates are determined, their competencies are assessed and the candidates for the project team are ranked.

In the second stage, input data are generated to create project team options. That is, the competencies of the candidates, the time during which each candidate can be involved in the project, the cost of their working hours, and the project requirements with their weights are specified. A certain set of candidates can be considered a team option if they satisfy all the project requirements.

In the third stage, the task of evaluating the formed team options and selecting the best option is solved.

Defining and assessing core competencies should ensure a comprehensive approach to candidate selection that allows for the creation of an effective team for the successful implementation of the project. Therefore, this process should involve a team effort involving the project manager, technical lead, recruitment specialists, and, if necessary, the direct client or stakeholders at various levels.

For example:

- The Project Manager (PM) is responsible for the overall management of the project and identifying the key competencies required for project successful delivery. Collaborates with other participants to clarify requirements;
- Tech Lead: This person defines technical competencies and collaborates with other roles to determine the level of technology proficiency required for the project. May create technical tests or tasks to assess candidate skill levels;
- HR Specialist, Recruiter: Responsible for creating a candidate profile, including soft skills and other aspects. Organises the process of recruitment and pre-selection of candidates;
- Client or Stakeholders - If necessary, specify requirements and expectations for the final product or service. They may influence the definition of key competencies, depending on project specifics.

The process of developing competencies is determined by the following stages:

Analysing the project requirements:

- collecting and analyzing requirements from the client and stakeholders;
- defining project goals and milestones.

Identification of key competencies:

- PM and Tech Lead work together to define technical and non-technical competencies;
- consideration of project specifics, technologies to be used, and skills required to implement them.

Assessment and level of competencies:

- define qualitative and quantitative competencies levels. For example, technical competencies may have

levels (Junior, Intermediate, Senior) and soft skills are assessed on a scale (e.g. 1 to 5).

The candidate profile is created:

- the HR specialist, with the PM and Tech Lead, creates a detailed candidate profile, including the required competencies and levels;
- including requirements for experience, education, certifications, etc.

Preparation of assessment tools:

- development of terms of reference, tests, and interview scripts to test candidates' competencies;
- identifying methods for assessing soft skills, such as group interviews, psychological tests, etc.

This paper proposes models and a method that allow solving the problem of multi-criteria ranking of candidates with unclear ideas about their competencies and project requirements. This means that this method can be used in the initial stages of creating an IT project team.

Let's assume that there is a certain set of candidates $C = \{c_p\}$, $p = \overline{1, n}$ for a role in a software development project team and a set of competencies present in them $Q = \{q_t\}$, $t = \overline{1, m}$. The candidate's score for a parameter q_t can be determined using a survey, questionnaire, exams, and other methods. In this study, we consider fuzzy assessments of candidate competencies and competence requirements to be the agreed opinions of experts. In some cases, the evaluation is carried out by a single expert.

To compare the competences of the candidates, we propose using the method of pairwise comparison [24].

The preferences of each competency $q_t \in Q$, $t = \overline{1, m}$ candidate are most conveniently determined using triangular fuzzy numbers [25]

$$A_{\Delta} = \langle a, \alpha, \beta \rangle_{\Delta}, \quad (1)$$

where a is the modal value of this number, α – is the left coefficient of fuzziness, β – is the right coefficient of fuzziness. A triangular fuzzy number is a special case of a $(L-R)$ -type fuzzy number [25]. Using the scale [24], in this case, for example, we will have that in terms of competence q_t , candidate D has a significant advantage over candidate M. This advantage can be specified using a triangular fuzzy number $A_{\Delta} = \langle 5, 1, 2 \rangle_{\Delta}$. If we compare candidate M with candidate D, the latter will have less competence, which can be represented by the inverse fuzzy number A_{Δ}^{-1} . The parameters of the inverse triangular fuzzy number are defined as follows [25]

$$a_3 = 1/a, \alpha_3 = \beta/a^2, \beta_3 = \alpha/a^2.$$

In our example, we have $A_{\Delta}^{-1} = \langle 1/5, 1/25, 2/25 \rangle$.

Pairwise comparisons of candidates by competence q_t are represented by a diagonal $a_{\Delta ii} = 1, i = \overline{1, n}$ and inversely symmetric $a_{\Delta ji} = a_{\Delta ij}^{-1}, i, j = \overline{1, n}$ matrix

$$A_{\Delta q_t} = \begin{pmatrix} a_{\Delta 11} & a_{\Delta 12} & \dots & a_{\Delta 1n} \\ a_{\Delta 21} & a_{\Delta 22} & \dots & a_{\Delta 2n} \\ \dots & \dots & \dots & \dots \\ a_{\Delta n1} & a_{\Delta n2} & \dots & a_{\Delta nn} \end{pmatrix}, \quad (2)$$

whose elements are triangular fuzzy numbers. The determination of the fuzzy coordinates $w_{\Delta p} = \langle a_p, \alpha_p, \beta_p \rangle, p = \overline{1, n}$, of the eigenvector $\overline{w_{\Delta}}$ in this case is performed by summing the fuzzy elements $a_{\Delta pj} = \langle b_{pj}, \alpha_{pj}, \beta_{pj} \rangle$ of the p -th row according to the following rule [24]

$$a_p = \sum_{j=1}^n b_{pj}, \alpha_p = \sum_{j=1}^n \alpha_{pj}, \beta_p = \sum_{j=1}^n \beta_{pj}.$$

Next, we obtain the coordinates of the priority vector for the t -th competence

$$x_{\Delta pt} = w_{\Delta pt} / \sum_{p=1}^n w_{\Delta pt},$$

where $x_{\Delta pt}$ is the p -th coordinate of the fuzzy priority vector $X_{\Delta t}, x_{\Delta pt} = \langle g_{pt}, \mu_{pt}, v_{pt} \rangle, p = \overline{1, n}, t = \overline{1, m}$.

The division of positive triangular fuzzy numbers $w_{\Delta pt} = \langle a_{pt}, \alpha_{pt}, \beta_{pt} \rangle$ by $S_{\Delta t} = \langle s_t, \phi_t, \eta_t \rangle = \sum_{p=1}^n w_{\Delta pt}$ is carried out according to the following rule [25]

$$g_{pt} = a_{pt} / s_t, \mu_{pt} = \frac{a_{pt}\eta_t + s_t\alpha_{pt}}{s_t^2}, v_{pt} = \frac{a_{pt}\phi_t + s_t\beta_{pt}}{s_t^2}.$$

Accordingly $X_{\Delta t}$, you can select the most competent candidates. To do this, you must compare fuzzy numbers. According to the definition, fuzzy number A is greater than fuzzy number B if any value of the carrier of fuzzy number A exceeds any value of the carrier of fuzzy number B . If this condition is not met, the order relation for fuzzy numbers A and B is

fuzzy. To establish full order in a set of fuzzy numbers, defuzzification is employed [25].

In this case, to compare triangular fuzzy numbers, it is necessary to defuzzify them. As the defuzzified values of such numbers, it is proposed to use the abscissa of the centres of mass of triangles, which are limited by the abscissa axis and the graph of the membership function [26]. The abscissa of the centre of mass for a triangular fuzzy number is equal to

$$x_{pt, crisp} = \frac{g_{pt} + g_{pt} - \mu_{pt} + g_{pt} + v_{pt}}{3} = \frac{3g_{pt} - \mu_{pt} + v_{pt}}{3}. \quad (3)$$

It allows you to compare candidates by the t -th competence $t = \overline{1, m}$. The defuzzified priority vector is denoted by $X_{t, crisp}$.

Candidate competencies may have different weights for a project. Let's denote the vector of competence weights $K = (k_1, k_2, \dots, k_m)$. Using competency weights, you can calculate the candidate's generalized competence. In this case, the generalized competence of the p -th candidate is calculated as follows

$$\begin{aligned} Q_{\Delta p} &= \sum_{t=1}^m k_t x_{\Delta pt} = \sum_{t=1}^m k_t \langle g_{pt}, \mu_{pt}, v_{pt} \rangle = \\ &= \sum_{t=1}^m \langle k_t g_{pt}, k_t \mu_{pt}, k_t v_{pt} \rangle = \\ &= \langle \sum_{t=1}^m k_t g_{pt}, \sum_{t=1}^m k_t \mu_{pt}, \sum_{t=1}^m k_t v_{pt} \rangle. \end{aligned} \quad (4)$$

To compare and select the best candidates, the generalized competences must also be defuzzified, for example, by using the abscissa of the centres of mass (3) for triangular fuzzy numbers. The defuzzification result is denoted by $Q_{p, crisp}$.

The use of the proposed pairwise comparisons based on triangular fuzzy numbers does not provide a way to assess the consistency of matrix (2). This is due to the use of the rule for calculating the defuzzified value of a fuzzy number. The defuzzified value for $a_{\Delta ij}^{-1}, i, j = \overline{1, n}$ may not be the inverse of the defuzzified value of $a_{\Delta ij}, i, j = \overline{1, n}$. To use the approach [24] to determine the consistency of the matrix A_{Δ} , it is necessary to apply another rule for calculating the inverse triangular fuzzy number [27], which ensures that

the defuzzified value of the inverse number $a_{\Delta ij}^{-1}$, $i, j = \overline{1, n}$ is equal to the inverse number of the defuzzified original number $a_{\Delta ij}$, $i, j = \overline{1, n}$.

In order to avoid the consistency problem of matrix (2), the "line" method [28] should be used, which consists of comparing all alternatives with one. This method reduces the amount of work of the expert, as only $n-1$ assessments are required instead of $n(n-1)/2$ as in the previous method [24].

According to this method, a vector of comparisons of alternatives $D_e = (d_1, d_2, \dots, d_{n-1})^T$ with the reference alternative e is created. In this case, we consider the comparison of candidates for the project team according to the t -th competence, $t = \overline{1, m}$, with the competence of the candidate e , which is considered to be the reference.

Let us introduce the concept of the absolute weight v_h of alternative h . By absolute weight v_h we mean a quantitative measure of the degree of expression in the h -th alternative of the property described by the selected criterion [28].

The reference alternative has a weight of v_e . If we are talking about comparing how many times an alternative h is superior to alternative e , i.e., a multiplicative comparison is made, then the weight of the alternative h is calculated based on the comparison of the alternative h with alternative e , i.e. d_{eh} , and the weight v_e of the alternative e .

$$v_h = v_e \varphi(d_{eh}), h = \overline{1, n-1}, e \neq h, \quad (5)$$

where $\varphi(d_{eh})$ is an arbitrary monotonic function for which the requirement $\varphi(1) = 1$ is satisfied.

Function (5) can take the form $v_h = v_e d_{eh}$. Next, the priority vector X_t , $t = \overline{1, m}$, for all alternatives according to the t -th competence is calculated, the coordinate of which is equal to

$$x_{pt} = v_{pt} / \sum_{p=1}^n v_{pt}, p = \overline{1, n}.$$

Note that in the multiplicative algorithm of pairwise comparisons, the priority vector does not depend on the value of v_e . These comparisons must be made for each competence $q_t \in Q$, $t = \overline{1, m}$.

In order to consider the different weights of competencies when selecting candidates for the project

team, we calculate a vector of comparisons $D_Q = (d_{Q1}, d_{Q2}, \dots, d_{Q, m-1})^T$ of the importance of competencies q_t , $t = \overline{1, m-1}$ with the reference competency w , $t \neq w$. It is advisable to choose the most important competence as the reference competence according to the opinion of the assessor.

The coordinate of the priority vector K for all competence weights are represented as follows:

$$k_t = z_t / \sum_{t=1}^m z_t, t = \overline{1, m}.$$

The generalized competence of the candidate p , $p = \overline{1, n}$ is calculated as follows

$$Q_{Dp} = \sum_{t=1}^m k_t x_{pt}.$$

Now let's use triangular fuzzy numbers to compare alternatives in the "line" method. As before, a triangular fuzzy number is defined as follows $A_\Delta = \langle a, \alpha, \beta \rangle_\Delta$, where a is the modal value of this number, α – left fuzziness coefficient, and β – right fuzziness coefficient.

We will determine the advantages of candidates over some of them, who have been selected as a "reference" candidate, using the scale [24] or another scale. In this case, we assess how many times the competence q_t of the candidate h exceeds the competence e of the "reference" candidate, i.e. we will perform a multiplicative comparison. In this case, the vector of competence preferences q_t will be of the form $D_{\Delta q, e} = (d_{\Delta 1}, d_{\Delta 2}, \dots, d_{\Delta, n-1})^T$, $q_t \in Q$, $t = \overline{1, m}$. The candidate whose competences are known most accurately should be selected as the "reference" candidate. In this case, when comparing alternative h with alternative e , we use fuzzy numbers, i.e., d_{eh} will be a fuzzy number of the form $d_{\Delta eh} = \langle a_{vh}, \alpha_{vh}, \beta_{vh} \rangle$.

Let's give the reference alternative e a weight v_e . We assume that the weight v_e is an crisp number. The weight of the alternative h in this case is equal to

$$v_{\Delta h} = v_e d_{\Delta eh} = v_e \langle a_{vh}, \alpha_{vh}, \beta_{vh} \rangle. \quad (6)$$

The coordinate of the priority vector $X_{\Delta t}$ for all alternatives for the t -th competence will be

$$x_{\Delta pt} = v_{\Delta pt} / \sum_{p=1}^n v_{\Delta pt}, p = \overline{1, n},$$

where $\sum_{p=1}^n v_{\Delta pt} = < \sum_{p=1}^n a_{vpt}, \sum_{p=1}^n \alpha_{vpt}, \sum_{p=1}^n \beta_{vpt} > .$ So

$$x_{\Delta pt} = \frac{< a_{vpt}, \alpha_{vpt}, \beta_{vpt} >}{< \sum_{p=1}^n a_{vpt}, \sum_{p=1}^n \alpha_{vpt}, \sum_{p=1}^n \beta_{vpt} >} =$$

$$= < \frac{a_{vpt}}{\sum_{p=1}^n a_{vpt}}, \frac{a_{vpt} \sum_{p=1}^n \beta_{vpt} + \alpha_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2},$$

$$\frac{a_{vpt} \sum_{p=1}^n \alpha_{vpt} + \beta_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2} >, p = \overline{1, n}.$$

To establish a complete order for the coordinates of the priority vector, it is proposed to use defuzzification $x_{\Delta pt}, p = \overline{1, n}$.

In order to take into account the weights of different competences and determine the generalised competences of each candidate, it is necessary to assess the vector $D_Q = (d_{Q1}, d_{Q2}, \dots, d_{Q, m-1})^T$ of importance of competences $q_t, t = \overline{1, m-1}$ in comparison with the reference competence $w, t \neq w$. If the comparison of importance is performed in a crisp version, the generalized competence of candidate p can be represented as follows:

$$Q_{\Delta p} = \sum_{t=1}^m k_t x_{\Delta pt} =$$

$$= < \sum_{t=1}^m k_t \frac{a_{vpt}}{\sum_{p=1}^n a_{vpt}}, \sum_{t=1}^m k_t \frac{a_{vpt} \sum_{p=1}^n \beta_{vpt} + \alpha_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2},$$

$$\sum_{t=1}^m k_t \frac{a_{vpt} \sum_{p=1}^n \alpha_{vpt} + \beta_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2} >, p = \overline{1, n}. \quad (7)$$

Once the generic competence values have been calculated for each candidate, the defuzzified generic competence values should be converted to the

defuzzified values, for example, using the abscissa of the centres of mass (7) for triangular fuzzy numbers.

For each indicator $t = \overline{1, m}$, you need to set a value that meets the project requirements. Let \bar{q}_t be a numerical assessment of the requirements expressed by the indicator $t = \overline{1, m}$, that is, \bar{q}_t expresses the desired level of the t -th characteristic of the performer in the context of the project requirements. Considering the subjective nature of forming such an assessment, we employ a fuzzy assessment that corresponds to the expression "indicator t should be approximately at the level of \bar{q}_t or higher". To formalise such assessments, we introduce a fuzzy set \bar{Q}_t , defined as the set of ordered pairs of the form $< q, \mu_{Q_t}(q) >$, where $q \in Q$ is an element of the scale adopted in the project, and $\mu_{Q_t}(q)$ is a membership function that corresponds to each of the elements $q \in Q$ with some real number from the interval $[0, 1]$. The fuzzy set \bar{Q}_t defines the desired characteristics of team candidates in the context of project requirements by the k -th indicator. We define the membership function $\mu_{Q_t}(q)$ as follows

$$\mu_{Q_t}(q) = \begin{cases} 0, & q \leq \bar{q}_t - \Delta \bar{q}_t; \\ \left(\frac{q - \bar{q}_t + \Delta \bar{q}_t}{\Delta \bar{q}_t} \right)^\alpha, & \bar{q}_t - \Delta \bar{q}_t \leq q \leq \bar{q}_t; \\ 1, & \bar{q}_t \leq q; \end{cases} \quad (8)$$

where $\bar{q}_t \in Q$ is the desired crisp level of the t -th indicator, $t = \overline{1, m}$, $\Delta \bar{q}_t$ is the deviation from the level \bar{q}_t of that is acceptable from the project's point of view, Q is the evaluation scale, α is a parameter. We will assume that $\alpha = 1$.

To form a set of candidates based on the assessment of their competencies in accordance with the project requirements, you need to compare the requirements for the candidate and the assessment of the candidate's competencies.

On the set of candidates, we can define the assessment of each candidate's compliance with each project requirement as the intersection of two fuzzy sets: project requirements \bar{Q}_t and candidate competencies \tilde{C}_{pt} . Then, according to [25], the fuzzy set \tilde{X}_{pt} , which is an assessment of the compliance of the p -th candidate with the requirements for the indicator $t = \overline{1, m}$, is formed as a set of ordered pairs $< x, \mu_{\tilde{X}_{pt}}(x) >$, where $x \in Q$, and $\mu_{\tilde{X}_{pt}}(x)$ is a membership function defined as follows:

$$\mu_{\tilde{X}_{pt}}(x) = \min_{x \in Q} \{ \mu_{Q_t}(x), \mu_{\tilde{C}_{pt}}(x) \},$$

$$t = \overline{1, m}, p = \overline{1, n}. \quad (9)$$

A graphical interpretation of the "compliance" of the p -th candidate with the project requirements is presented in Fig. 1. A specialist will be considered a candidate if at least one criterion meets the project requirements, namely, for the p -th candidate, among the sets of matching assessment \tilde{X}_{pt} , there is at least one set in which $\mu_{\tilde{X}_{pt}}(d_{pt})$ has a value of at least v_t (where v_t is the threshold, for example $v_t = 0.8$). The threshold defines the minimum value of the membership function that allows the user to meet the project requirements.

Then we can form a matrix of candidates' compliance with project requirements. The matching matrix is constructed from the membership functions obtained as the intersection of the membership function for the p -th candidate by the t -th indicator and the membership function of the t -th requirement for candidates, $p = \overline{1, n}$, $t = \overline{1, m}$. The formed matrix of all candidates can be defined as follows

$$\text{Conf} = \left(\mu_{\tilde{X}_{pt}}(x) \right)_{\substack{p=\overline{1, n}, \\ t=\overline{1, m}}} = \begin{pmatrix} \mu_{\tilde{X}_{11}}(x) & \mu_{\tilde{X}_{12}}(x) & \dots & \mu_{\tilde{X}_{1m}}(x) \\ \mu_{\tilde{X}_{21}}(x) & \mu_{\tilde{X}_{22}}(x) & \dots & \mu_{\tilde{X}_{2m}}(x) \\ \dots & \dots & \dots & \dots \\ \mu_{\tilde{X}_{n1}}(x) & \mu_{\tilde{X}_{n2}}(x) & \dots & \mu_{\tilde{X}_{nm}}(x) \end{pmatrix}$$

For each element of the Conf matrix, it is necessary to calculate the coordinate of the mode value of the membership function of the fuzzy set of the p -th candidate's compliance with the t -th requirement, that is $d_{pt}(\tilde{X}_{pt})$

$$d_{pt}(\tilde{X}_{pt}) = \begin{cases} \text{absent, if } a_{pt} + \beta_{pt} \leq \bar{q}_t - \Delta\bar{q}_t; \\ \frac{q_t \beta_{pt} + \Delta\bar{q}_t a_{pt}}{\beta_{pt} + \Delta\bar{q}_t}, \text{ if } a_{pt} < q_t \text{ and } a_{pt} + \beta_{pt} > \bar{q}_t - \Delta\bar{q}_t; \\ a_{pt}, \text{ if } q_t \leq a_{pt}. \end{cases} \quad (10)$$

The value v_t for the p -th candidate is calculated by the expression

$$v_{pt} = \begin{cases} \text{absent, if } a_{pt} + \beta_{pt} \leq \bar{q}_t - \Delta\bar{q}_t; \\ \frac{a_{pt} + \beta_{pt} - \bar{q}_t + \Delta\bar{q}_t}{\beta_{pt} + \Delta\bar{q}_t}, \text{ if } a_{pt} < q_t \text{ and } a_{pt} + \beta_{pt} > \bar{q}_t - \Delta\bar{q}_t; \\ 1, \text{ if } q_t \leq a_{pt}. \end{cases} \quad (11)$$

Then you can build a matrix $A = (d_{pt}(\tilde{X}_{pt}))_{\substack{p=\overline{1, n}, \\ t=\overline{1, m}}}$, the elements of which correspond to the coordinates of the modes (10) of the functions of membership of candidates' competencies to project requirements for competencies.

3. Solving the problem of multi-criteria ranking of candidates for an IT project team using fuzzy initial data

Let's consider the process of selecting candidates for further formation of the IT project team. Let's keep in mind that, as a rule, the result of a competency comparison is not crisp. A decision maker can only roughly estimate the extent to which one specialist's competence

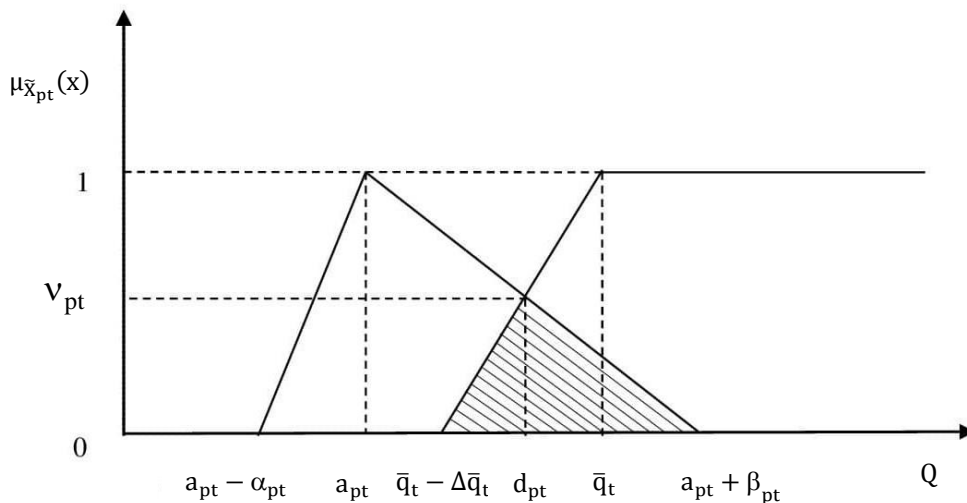


Fig. 1. Graphical interpretation of membership function $\mu_{\tilde{X}_{pt}}(x)$

is greater or lesser than another's. In this case, it is convenient to use fuzzy triangular numbers to compare the competences of applicants. Requirements for the competences of applicants are also often fuzzy. They are set using the membership functions of form (8). To solve this problem, we will use the "line" method in the fuzzy version proposed in this paper. For the indicators of requirements for candidates' competencies, we also choose a continuous scale from 0 to 4 (where 4 is the best possible score) and define the values $q_t \in Q$ – the desired crisp level of the t -th indicator $t = \overline{1, m}$, and Δq_t – the deviation from the level q_t that is acceptable from the project's point of view. Fuzzy assessments of the requirements for competence indicators are presented in Table 1. The number of indicators is $m=5$.

Table 1
Indicators of requirements for candidates' competences

Name of the indicator	Project requirements	
	q_t	Δq_t
Design patterns	3	1
Nest.js	1	0.3
OOP paradigm	2	0.5
S.O.L.I.D Principles	2	0.5
Functional testing	3	1

The compliance of the competence of the p -th candidate with the requirement is determined by the threshold value $v_t = 0.9$ of the membership function (9) $\mu_{\tilde{x}_{pt}}(x)$. That is, when $v_{pt} \geq 0.9$, where v_{pt} is calculated in accordance with (11), we consider that the applicant meets the requirement.

Let's consider 5 people who sent their CVs to participate in the project, i.e. $n=5$. As a reference, we will take the competencies of applicant 2, which are presented in Table 2. We know his capabilities in the most detail.

Table 2
Assessment of competencies of applicant 2

Indicators, t				
1	2	3	4	5
1	1	2	2	4

The competences of the person being compared will be determined in comparison with those of applicant 2. In this case, we assess how many times the competence of applicant p , $p=1,3,4,5$, exceeds the competence of applicant 2, i.e. we will make a multiplicative comparison. In this case, when comparing applicant p with applicant 2, we use fuzzy numbers, i.e.,

d_{2p} will be a fuzzy number of the form $d_{\Delta 2p} = \langle a_{2p}, \alpha_{2p}, \beta_{2p} \rangle$.

The competency comparison results are presented in Table 3.

Assessments of the competences of candidates p , $p=1,3,4,5$ are calculated in accordance with (6). In this case, the competence of an applicant will be defined as the product of the competence v_e of applicant 2 (the standard) and the comparison of the competence of applicant p with the competence of applicant 2, i.e. $d_{\Delta eh}$

$$v_{\Delta h} = v_e d_{\Delta eh} = v_e \langle a_{vh}, \alpha_{vh}, \beta_{vh} \rangle$$

Table 4 shows the competence assessments of the 5 applicants for the role of candidates for the project team.

It should be noted that all applicants have at least one competence that meets the competence requirements. Next, for each competence $t = \overline{1, m}$ a priority vector $X_{\Delta t}$ is calculated for all alternatives (applicants), the coordinate of which is equal to

$$x_{\Delta pt} = v_{\Delta pt} / \sum_{p=1}^n v_{\Delta pt}, \quad p = \overline{1, n},$$

where $\sum_{p=1}^n v_{\Delta pt} = \langle \sum_{p=1}^n a_{vpt}, \sum_{p=1}^n \alpha_{vpt}, \sum_{p=1}^n \beta_{vpt} \rangle$. So

$$\begin{aligned}
 x_{\Delta pt} &= \frac{\langle a_{vpt}, \alpha_{vpt}, \beta_{vpt} \rangle}{\langle \sum_{p=1}^n a_{vpt}, \sum_{p=1}^n \alpha_{vpt}, \sum_{p=1}^n \beta_{vpt} \rangle} = \\
 &= \frac{a_{vpt}}{\sum_{p=1}^n a_{vpt}}, \frac{a_{vpt} \sum_{p=1}^n \beta_{vpt} + \alpha_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2}, \\
 &\frac{a_{vpt} \sum_{p=1}^n \alpha_{vpt} + \beta_{vpt} \sum_{p=1}^n a_{vpt}}{(\sum_{p=1}^n a_{vpt})^2} >, \quad p = \overline{1, n}.
 \end{aligned}$$

The coordinates of priority vectors X_t , $t = \overline{1, m}$, are shown in Table 5.

Table 3

Assessment of applicants' competences compared with those of applicant 2

Applicants, p	Project requirements																			
	q ₁		Δq ₁		q ₂		Δq ₂		q ₃		Δq ₃		q ₄		Δq ₄		q ₅		Δq ₅	
	3		1		1		0.3		2		0.5		2		0.5		3		1	
	Indicators, t																			
	1			2			3			4			5							
	a	α	β	a	α	β	a	α	β	a	α	β	a	α	β					
1	4	1	0	1	0.5	1	0.5	0.25	0.25	1	0.5	0.5	0	0	0.25					
2	1	0	0	1	0	0	2	0	0	2	0	0	4	0	0					
3	3	1	1	1	0.5	1	1	0.25	0.5	1	0.5	0.5	1	0.25	0					
4	1	0.5	1	1	0.5	1	1	0.5	0.5	1	0.5	0.5	0.75	0.25	0.25					
5	3	0.5	0.5	1	0.5	0.5	1	0.5	0.25	1	0.5	0.25	0.75	0.1	0.1					

Table 4

Competence assessments of the applicants

Applicants, p	Project requirements														
	q ₁		Δq ₁	q ₂		Δq ₂	q ₃		Δq ₃	q ₄		Δq ₄	q ₅		Δq ₅
	3		1	1		0.3	2		0.5	2		0.5	3		1
	Indicators, t														
	1			2			3			4			5		
	a	α	β	a	α	β	a	α	β	a	α	β	a	α	β
1	4	1	0	1	0.5	1	1	0.5	0.5	2	1	1	0	0	1
2	1	0	0	1	0	0	2	0	0	2	0	0	4	0	0
3	3	1	1	1	0.5	1	2	0.5	1	2	1	1	4	1	0
4	1	0.5	1	1	0.5	1	2	1	1	2	1	1	3	1	1
5	3	0.5	0.5	1	0.5	0.5	2	1	0.5	2	1	0.5	3	0.4	0.4
Sum of values	12	3	2.5	5	2	3.5	9	3	3	10	4	3.5	14	2.4	2.4

Table 5

Values of the coordinates of priority vectors of applicants

Applicants, p	Indicators, t														
	1			2			3			4			5		
	a	α	β	a	α	β	a	α	β	a	α	β	a	α	β
1	0.333	0.153	0.083	0.2	0.24	0.28	0.111	0.093	0.093	0.2	0.17	0.18	0	0	0.071
2	0.083	0.017	0.02	0.2	0.14	0.08	0.222	0.074	0.074	0.2	0.07	0.08	0.286	0.049	0.049
3	0.25	0.135	0.146	0.2	0.24	0.28	0.222	0.13	0.185	0.2	0.17	0.18	0.286	0.12	0.049
4	0.083	0.059	0.104	0.2	0.24	0.28	0.222	0.185	0.185	0.2	0.17	0.18	0.214	0.108	0.108
5	0.25	0.094	0.104	0.2	0.24	0.18	0.222	0.185	0.13	0.2	0.17	0.13	0.214	0.065	0.065
Sum of values	12	3	2.5	5	2	3.5	9	3	3	10	4	3.5	14	2.4	2.4

We will assume that the weights of all competence requirements $k_t, t = \overline{1, m}$, are equal. In this case, the generalised competence of the applicant $p, p = \overline{1, n}$ is calculated in accordance with (7)

$$Q_{\Delta p} = \sum_{t=1}^m k_t x_{\Delta p t} = \langle a_Q, \alpha_Q, \beta_Q \rangle, p = \overline{1, n},$$

where $k_t = 0.2, t = \overline{1, 5}$.

The generalized competence values of all applicants are shown in Table 6.

To compare and select the best candidates, we defuzzify the generalized competences using the abscissa of the centres of mass (3) for triangular fuzzy numbers. The defuzzification results are presented in Table 6. In accordance with the defuzzified values of the generalized competences, we select the best three candidates to further solve the problem of forming an IT project team. In this case, these are candidates 3, 5, and 2.

Table 6

Values of applicants' generalized competences

Applicants, p	Generalised competence			
	a_Q	α_Q	β_Q	Defazified value
1	0.169	0.131	0.141	0.172
2	0.198	0.07	0.061	0.195
3	0.232	0.159	0.168	0.235
4	0.184	0.152	0.171	0.19
5	0.217	0.151	0.122	0.208

4. Discussion

One of the crucial stages of developing a project team is the preliminary ranking of possible applicants for participation. Such a ranking is often necessary because the number of applicants can be very large, measured in hundreds of people. Because of ranking applicants according to many criteria, you can select a certain number of "best" candidates for which to solve the optimization problem of forming a project team. This article is devoted to solving the problem of ranking candidates according to many criteria with fuzzy ideas about candidates' competencies and project requirements.

The analysis of the known works on ranking alternatives by many criteria did not reveal an approach that would allow the use of fuzzy representations of candidates' competencies in comparison with the

standard for multi-criteria ranking of candidates taking into account fuzzy requirements for competencies.

To solve the problem of multicriteria ranking alternatives with crisp criteria values, the analytic hierarchy process [24] is widely used. However, when the criteria values are fuzzy and given in the form of traditional triangular fuzzy numbers, there is no way to assess the consistency of the pairwise comparison matrix. Without controlling the consistency of this matrix, the use of the [24] method may yield false results.

One way to solve the problem of multi-criteria ranking alternatives is the "line" method. This paper proposes a variant of this method for fuzzy criterion represented by triangular fuzzy numbers. The method allows consider the different weights of competencies for a project.

Simultaneously with the ranking of candidates, competencies are checked for compliance with the project requirements, which are represented by fuzzy numbers.

An example of using the proposed method to rank five people applying to participate in an IT project is provided. For comparison with the reference candidate, fuzzy triangular numbers are used. The requirements for the competencies of the candidates are given in fuzzy numbers.

5. Conclusions

Building an IT project team is a complex and responsible task. The success of a project largely depends on its solution. This paper considers the task of ranking candidates for an IT project team according to many criteria with unclear data about their competencies and requirements. A method to solve this problem is proposed. The scientific novelty of the method of multi-criteria ranking of candidates for the project team is that, unlike existing methods, it uses fuzzy ideas about the preferences of candidates when assessing the competence of each candidate based on comparisons with the reference competence and fuzzy ideas about the requirements for competence, which allows improving the ability to evaluate candidates. This paper considers an example of using the proposed method to solve the problem of selecting candidates to further solve the problem of forming an IT project team under fuzzy evaluation. Note that the example is illustrative. The number of applicants for the example was chosen based on the ability to clearly present the calculations in the form of tables on the pages of the journal.

In the future, it is planned to combine the method of ranking candidates proposed in this paper with the methods of optimizing the IT project team composition

set out in [23, 29] and on their basis to create information technology to support decision-making when forming project teams.

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Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence technologies when creating their work.

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РОЗВ'ЯЗАННЯ ЗАДАЧІ РАНЖУВАННЯ ПРЕТЕНДЕНТІВ У КОМАНДУ ПРОЄКТУ ПРИ НЕЧІТКОМУ ОЦІНЮВАННІ КОМПЕТЕНТНОСТЕЙ ТА ВИМОГ

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Росім Абдуллаєв

Предметом вивчення статті є моделі та метод ранжування кандидатів у команду ІТ-проєкту в умовах невизначеності компетентностей та вимог до них. **Метою** роботи є підвищення якості команди ІТ-проєкту шляхом створення і застосування моделей та методу формалізації задачі багатокритеріального ранжування

кандидатів у склад команди з урахуванням невизначеності вихідної інформації. **Завдання:** провести аналіз актуальності завдання створення моделей та методів ранжування кандидатів у команду ІТ-проекту в умовах невизначеності; створити метод багатокритеріального ранжування кандидатів у команду ІТ-проекту у нечіткій постановці; розв'язати приклад задачі багатокритеріального ранжування претендентів для подальшого формування команди ІТ-проекту. Використовуваними **методами** є: метод аналізу ієрархій, метод «лінія», методи нечіткої арифметики. Отримані такі **результати**. Розроблено метод багатокритеріального ранжування кандидатів у команду ІТ-проекту, який відрізняється від існуючих використанням нечітких чисел для завдання переваг кандидатів та оцінювання узагальненої компетентності кожного кандидата на основі порівнянь з еталонною компетентністю, що дозволяє покращити можливості для оцінювання кандидатів. Даний метод може бути використаний на першому етапі створення команди ІТ-проекту, коли відбувається ранжування можливих кандидатів до команди. Розв'язано задачу відбору претендентів для подальшого формування команди ІТ-проекту. **Висновки.** Наукова новизна методу багатокритеріального ранжування кандидатів у команду проекту полягає в тому, що на відміну від існуючих в ньому використовуються нечіткі уявлення про переваги кандидатів при оцінюванні узагальненої компетентності кожного кандидата на основі порівнянь з еталонною компетентністю, що дозволяє покращити можливості для оцінювання кандидатів. У статті розглянуто приклад використання запропонованого методу для розв'язання задачі відбору претендентів для подальшого розв'язання задачі формування команди ІТ-проекту при нечіткому оцінюванні.

Ключові слова: команда проекту; кандидати; компетентності; вимоги; невизначеність; модель; метод; ранжування; нечіткі числа.

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