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FORMALISING THE FORMATION OF PROJECT TEAMS CONSIDERING ALTERNATIVE COMPETENCE ASSESSMENTS UNDER UNCERTAINTY

*The **subject** of this paper is mathematical models and methods of project team formation under conditions of uncertainty regarding candidates' competences and requirements. The **aim** is to create an approach to formalising project team formation that considers multiple fuzzy assessments of specific candidate qualities. **Tasks** to be solved: to define a way of describing a set of fuzzy evaluations of specific qualities of candidates, to define a way of checking whether the candidate's qualities meet the fuzzy requirements, to propose a mathematical model of the problem, and to solve a test case. The **methods** used are: fuzzy set theory, multicriteria optimisation methods. The following **results** were obtained: it was proposed to use a trapezoidal fuzzy interval to describe the set of evaluations of specific candidate properties; to determine the compliance of candidate properties with fuzzy requirements, it was proposed to calculate the value of the requirements membership function at the point equal to the lower modal value of the fuzzy interval describing candidate properties; an example of applying the approach to solving the problem of forming a project team is considered. **Conclusions**. Because of the research conducted, it was proposed to describe multiple evaluations of a particular candidate property using trapezoidal fuzzy intervals. The novelty of the proposed approach lies in the method for evaluating the conformity of a set of assessments of a candidate's qualities with fuzzy requirements. It is proposed to form a project team by maximising the sum of dominant competencies and the weighted sum of competencies, subject to constraints on the workload of the work, on the fulfilment of competency requirements and on the cost of the team's work. The generalised function method was applied to solve the multi-criteria problem.*

Keywords: *project team; formation; uncertainty of candidates' competences; uncertainty of requirements; fuzzy sets; trapezoidal fuzzy interval; model; optimization; multi-criteria problem.*

1. Introduction

1.1. Motivation

Forming a project team is a complex task because the requirements for the project, its products, and the team are often imprecise, incomplete, and subjective. Moreover, under modern conditions, these requirements often change during the project life cycle. Assessments of candidates' technical competence through examinations, tests and interviews are rather subjective, contradictory and inaccurate. The situation is even more difficult when it comes to assessing behavioural competencies. This area is even more subjective, imprecise, contradictory, and far from perfect. The outcome of a project depends significantly on the team composition, which determines the importance of solving the problem. The application of mathematical methods to form a project team is a promising direction that may allow finding solutions in conditions of uncertainty and subjectivity.

1.2. State of the art

Quite an extensive literature is devoted to the formalisation of project team formation. The systematic literature review [1] initially considered 103 papers published between 2010 and 2020. Then, 30 papers that fulfilled the selection criteria were retained. Among the works published earlier, it is worth noting [2], the authors proposed a mathematical model for selecting a project team. The model includes two criteria. The first criterion maximizes the skills of the least qualified team members. The second criterion tries to maximize the size of the team. Both criteria are fuzzy. The model contains crisp restrictions, including the project budget, the allowable time for engaging a candidate, and the inadmissibility of combining candidates who do not want to work together in one team.

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The authors of [3] proposed a mathematical model for the problem of forming a project team. 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 an individual's workload from the desired workload in the organization.

In [4], a mathematical model of the problem of selecting project team candidates was proposed. The model contains two objective functions and constraints. The first objective function maximizes the team's competencies by considering the weighting factors for the criteria used. The second objective function maximizes collaboration. This considers the number of projects in which the candidates participated together as well as the number of communications between the candidates in the past.

The authors of the study [5] proposed a decision-making approach that includes global optimization based on a genetic algorithm. The authors maximize the average knowledge score values of the candidates.

The analysis of these and other publications showed that most of the papers focused on approaches to team building, considering the knowledge, skills, and experience of candidates. However, it should be remembered that the personal qualities of applicants play a crucial role in team work. The authors of [6] suggest that tools that allow the assessment of candidates' soft skills will improve the effectiveness of project team selection and hence the effectiveness of project execution.

Thus, the leadership style of a project manager may stimulate some participants and sharply repel others, and may give rise to the emergence of factions that act according to the type 'against whom we are friends'. Bright personalities with high qualifications may be very unfriendly in the team, demand more attention, and want to have a very high salary, which will put a heavy burden on the project. A good professional may be an individual player who is not comfortable with a team. The list of problems arising in a team due to the peculiarities of the behavioural qualities of its members can continue to evolve. The question arises. How can the behavioural qualities of applicants be considered when formalizing team formation? Extensive literature exists on team effectiveness.

The authors of [7] identified the factors that influence team effectiveness. They concluded that they included five internal factors: Thrust, Trust, Talent, Team Skills, Task Skills and two external factors: Team Leader Fit, Team Support.

As a result of processing surveys of more than 6000 project team members from different industries, the authors [8] proposed a model of an effective team, which comprises five areas Team Members, Team Relationships, Team Problem-Solving, The Team Leader, The Organizational Environment.

J. Richard Hackman in [9] described his model of an effective team based on 40 years of experience researching team work. In his opinion, for this to happen, a team must fulfil five conditions: Being a Real Team, Compelling Direction, Enabling Structure, Supportive Context, Expert Coaching.

The authors of [10] proposed a variant of the team effectiveness model. In their opinion, the following conditions must be met for successful team performance: Organizational context, Team design, Team synergy, Process effectiveness, Material resources, Group effectiveness.

The Team Effectiveness Model [11] suggests that a winning team has four components such as: Context, Composition, Work design, Process.

In a survey of more than 200 teams at Google, researchers concluded that who is on the team matters much less than how team members interact, structure their work, and value their contributions [12]. They identified five dynamic characteristics that distinguished high-performing teams from outsiders: Psychological safety, Dependability, Structure and Clarity, Meaning, Impact.

The community of Agile experts represented on LinkedIn was used by the authors of [13] to identify the characteristics and attributes required to create an effective team in software development. As a result, it was concluded that members of an effective project team should possess Knowledge, which include: Education background, Technical, Domain / Business, have Skill such as Interpersonal, Technical, Domain / Business, have Ability: Learnability, Adaptability, have Experience: Quantity of similar projects. Regarding personality traits such as Honesty-humility, Emotionality, Extraversion, Agreeableness, Conscientiousness, Openness to experience, respondents indicated that they should also be considered to a certain extent, which may vary from organization to organization and country to country.

A significant contribution to the development of methods for forming project teams was made by R. Meredith Belbin. His book [14] is widely known around the world. Because of extensive research conducted by many teams, R. Meredith Belbin identified 9 roles that team members fulfil. Each team member can fulfil not necessarily one role, but several roles at once. Each role in the team is described by him, and the strengths and weaknesses of the roles are given.

The roles identified include Resource Investigator, Teamworker, and Coordinator (the Social roles); Plant, Monitor Evaluator, and Specialist (the Thinking roles); and Shaper, Implementer, and Completer Finisher (the Action or Task roles). He developed a questionnaire to assess a candidate's readiness to fulfil a role. The questionnaire consists of 8 sections. Each section contains 10 answers. The questionnaire taker must allocate 10 points between the possible answers that best characterize him/her. In some cases, all 10 points can be allocated to one answer. The scores related to a single role are totaled. The highest cumulative score achieved by a candidate indicates how well they can perform the role for which they are most prepared. R. Meredith Belbin developed a table showing the sum of the scores for each of the roles, which can be used to establish how much a person's abilities are more pronounced than the 'standard'. This table shows the ranges of scores for each role: low, medium, high, very high.

In addition to self-assessment, R. Meredith Belbin suggested that an individual should be evaluated by at least four people who have worked with the person for at least 3 months. As a result, everyone can obtain percentile scores for each team role based on self-assessment and Observers' aggregate perceptions at https://www.belbin.com.

In [15], the authors proposed balancing the number of team members capable of fulfilling certain roles according to Belbin based on the solution of a linear programming problem. Alternative assessments of a candidate by observers were not considered. The professional competences of the team members were not considered.

The authors of [6] proposed a mathematical model for solving the problem of determining a cohesive team for an IT project, considering personality types and roles in the project. The problem contains fuzzy target functions and fuzzy constraints.

The authors of [16] proposed the use of an Intuitionistic Fuzzy Soft Set (IFSS) apparatus to select team members. They looked at an example of selecting candidates for a team based on their communication, technical, problem-solving, and decision-making skills.

In [17], a fuzzy multi-agent model was presented for creating a group based on nine roles defined by the Belbin typology.

Because of reviewing popular models of team effectiveness, we concluded that the approach of R. Meredith Belbin is most suitable for integration with the mathematical model of project team formation [18, 19]. However, the use of triangular fuzzy numbers to describe candidate competences does not allow considering simultaneously several assessments for the same parameter (competence). This may be of importance not only when taking into account several assessments, how ready a candidate is to fulfil a particular role. Different assessments can also be considered when assessing knowledge, skills and experience. For example, the results of passing a test, examination, and subjective assessments by colleagues, etc. The author [20] highlighted the fact that when selecting a project manager, when there are several alternative candidates, there is a possibility of disagreement between the members of the board charged with the selection. In other words, there will be more than one assessment of a candidate's specific qualities.

1.3. Objective and Approach

The goal of this article is to create an approach to formalizing the formation of a project team, which will allow considering multiple fuzzy assessments of specific qualities of candidates.

To achieve the set goal, it is necessary to solve the following tasks:

- to define a way of describing a set of fuzzy evaluations of the specific qualities of candidates;
- to determine the method for checking the conformity of candidates' qualities to the given requirements,
- to propose a mathematical model of the problem,
- and solve the test case.

Section 2 describes the solution to the first three problems. Section 3 presents an example of application of the proposed approach. Section 4 discusses the results. Section 5 presents conclusions on the results of the paper.

2. Mathematical model of project team formation

We assume that the competence requirements of the project team candidates are defined. All competence areas are considered according to [21], i.e., prospective, practical and human competences.

A set of indicators has been introduced to assess candidates in relation to project requirements $K = \{1, 2, ..., m\}$ the values of which together characterize all candidates and allow evaluating them in relation to all project requirements. First, for each indicator $k \in K$ it is necessary to define the value, which meets the project requirements. Given the subjective nature of the formation of such an assessment, we use a fuzzy assessment that corresponds to the expression 'the indicator k should be approximately on the same level with $\bar{q}_k$ or higher'. Mathematically the fuzzy set $\bar{Q}_k$ is defined as a set of ordered pairs like: $<q, \mu_{Q_k}(q)>$, where $q \in Q$, is an element of the accepted scale on the project, and $\mu_{Q_k}(q)$ – is a membership function that matches each of the elements $q \in Q$, some real number from the interval [0,1]. We define the membership function

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$\mu_{Q_k}(q)$ as follows

$$\mu_{Q_k}(q) = \begin{cases} 0, & q \le \bar{q}_k - \Delta\bar{q}_k \\ \left(\dfrac{q - \bar{q}_k + \Delta\bar{q}_k}{\Delta\bar{q}_k}\right), & \bar{q}_k - \Delta\bar{q}_k \le q \le \bar{q}_k \\ 1, & \bar{q}_k \le q \end{cases}, \quad (1)$$

where $\bar{q}_k \in Q$ – the desired clear level of the k-th indicator, $k \in K$;

$\Delta\bar{q}_k$ – permissible from the point of view of the project deviation from the level $\bar{q}_k$;

Q – assessment scale.

Newer and more innovative projects tend to have a higher level of uncertainty and, accordingly, a higher value of $\Delta\bar{q}_k$.

We assume that n candidates for roles in the team are being considered. In this case we have a set of numbers of candidates for the project team $N = \{1,2,\dots,n\}$.

Suppose that we have *n* assessments of the competences of the j-th candidate for indicator k, i.e. $\bar{C}_{jki} \in Q,\ k \in K,\ j \in N,\ i = \overline{1,n}$. Given the uncertainty and subjectivity of competence assessments, we assume that for each indicator, each candidate is characterized by a fuzzy closed interval (segment), which can be interpreted using the following expression: "the assessment of the competences of the j-th candidate for the k-th indicator is approximately in the interval $[\bar{C}_{jkmin}, \bar{C}_{jkmax}]$, where $\bar{C}_{jkmin}, \bar{C}_{jkmax}$ are the minimum and maximum values among the n assessments of the competences of the j-th candidate for the k-th indicator."

In this case, the fuzzy set that determines the fuzzy assessment of the competencies of the j-th candidate by indicator k, $j \in N,\ k \in K$ is equal to

$$\tilde{C}_{jk} = \left\{< C, \mu_{\tilde{C}_{jk}}(C)) >, C \in Q\right\}.$$

The membership function is expressed as follows (Fig. 1)

$$\mu_{\tilde{C}_{jk}}(C) = \begin{cases} 0, & C \le C_{jk}^{(\alpha)}; \\ \dfrac{C - C_{jk}^{(\alpha)}}{\bar{C}_{jk\min} - C_{jk}^{(\alpha)}}, & C_{jk}^{(\alpha)} \le C \le \bar{C}_{jk\min}; \\ 1, & \bar{C}_{jk\min} \le C \le \bar{C}_{jk\max}; \\ \dfrac{C_{jk}^{(\beta)} - C}{C_{jk}^{(\beta)} - \bar{C}_{jk\max}}, & \bar{C}_{jk\max} \le C \le C_{jk}^{(\beta)}; \\ 0, & C \ge C_{jk}^{(\beta)}; \end{cases} \quad (2)$$

where $C \in Q,\ C_{jk}^{(\alpha)}, \bar{C}_{jkmin}, \bar{C}_{jkmax}, C_{jk}^{(\beta)} \in Q,\ k \in K,\ j \in N,\ \mu_{\bar{C}_{jk}}(C) \in [0,1]$, $C_{jk}^{(\alpha)}, C_{jk}^{(\beta)}$ are the parameters of the membership function, $C_{jk}^{(\alpha)} \le \bar{C}_{jkmin} \le \bar{C}_{jkmax} \le C_{jk}^{(\beta)},\ k \in K,\ j \in N$.

The proposed fuzzy set

$$\tilde{C}_{jk} = \left\{< C, \mu_{\tilde{C}_{jk}}(C)) >, C \in Q\right\}$$

is a fuzzy interval of the $(R - L)$ – type, $\bar{C}_{jkmin}, \bar{C}_{jkmax}$ are the lower and upper modal values of the fuzzy interval.

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

On the set of candidates, it is possible to define an evaluation of compliance of each candidate concerning each requirement of the project as a crossing of two fuzzy sets: project requirements $\bar{Q}_k$ and candidate's competencies $\tilde{C}_{jk}$. Then fuzzy set $\tilde{X}_{jk}$, which is the assessment of compliance of the j-th candidate to the requirements by the indicator k, $k \in K$, is formed as a set of ordered pairs

$$< x,\ \mu_{\tilde{X}jk}(x) >,$$

where $x \in Q$, and $\mu_{\tilde{X}jk}(x)$ – the membership function, which can be found as following:

$$\mu_{\tilde{X}_{jk}}(x) = \min_{x \in Q}\left\{\mu_{Q_k}(x), \mu_{\tilde{C}_{jk}}(x)\right\},$$
$$k = \overline{1,m},\ j = \overline{1,n}. \quad (3)$$

A specialist is considered a candidate if he or she meets the project requirements by at least one criterion. In other words, for the j-th candidate, among the sets of eligibility assessment $\tilde{X}_{jk}$, there is at least one set in which $\mu_{\tilde{X}_{jk}}(\bar{C}_{jkmin})$ has a value of at least v_k (Fig. 2)

$$\mu_{\tilde{X}_{jk}}(\bar{C}_{jkmin}) = \begin{cases} 0, & \bar{C}_{jkmin} \le \bar{q}_k - \Delta\bar{q}_k; \\ \dfrac{\bar{C}_{jkmin} - \bar{q}_k + \Delta\bar{q}_k}{\Delta\bar{q}_k}, & \bar{q}_k - \Delta\bar{q}_k \le \bar{C}_{jkmin} \le \bar{q}_k; \\ 1, & \bar{C}_{jkmin} \ge \bar{q}_k. \end{cases}$$

Here v_k is the threshold, for example, it can be $v_k = 0.8$. The threshold determines the minimum value of the membership function of the intersection of the sets of requirements and competencies that allows the candidate to meet the project requirements.

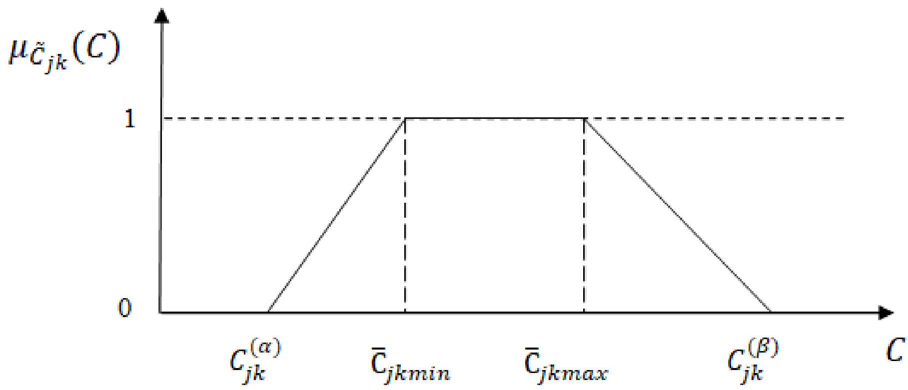

Fig. 1. Graphical interpretation of membership function $\mu_{\tilde{C}_{jk}}(C)$

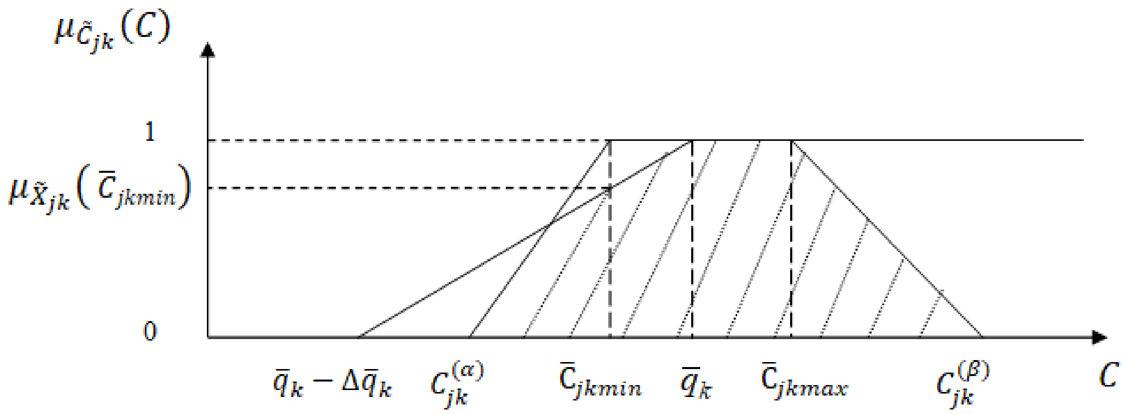

Fig. 2. Graphical interpretation of the intersection of membership functions of competence and the requirements for competence

The competence value of the j-th candidate, considering compliance with the k-th requirement, can be determined as follows

$$\alpha_{jk}(\tilde{X}_{jk}) = \begin{cases} 0, \ \bar{C}_{jkmin} \le \bar{q}_k - \Delta\bar{q}_k; \\ 0, \ \frac{\bar{C}_{jkmin} - \bar{q}_k + \Delta\bar{q}_k}{\Delta\bar{q}_k} < v_k, \\ \quad \bar{q}_k - \Delta\bar{q}_k < \bar{C}_{jkmin} < \bar{q}_k; \\ \bar{C}_{jkmin}, \ \frac{\bar{C}_{jkmin} - \bar{q}_k + \Delta\bar{q}_k}{\Delta\bar{q}_k} \ge v_k, \\ \quad \bar{q}_k - \Delta\bar{q}_k < \bar{C}_{jkmin} < \bar{q}_k; \\ \bar{C}_{jkmin}, \ \bar{C}_{jkmin} \ge \bar{q}_k - \Delta\bar{q}_k. \end{cases} \quad (4)$$

Then we can construct the matrix $A = \left(\alpha_{jk}(\tilde{X}_{jk})\right)_{j=\overline{1,n},\ k=\overline{1,m}}$, whose elements are $\alpha_{jk}(\tilde{X}_{jk})$ (4).

Next, as additional conditions for the team creation we will consider: the resource of the available time of each candidate per week $time_j$ and cost of working hour for each candidate $rate_j$. In addition, requirements are set for the total cost of labor of team members Cost, for the Laboriousness of the project, and the time of the project implementation in ρ weeks.

Denote $g = \overline{1,G}$ – is a number of a team option. Let us build an assignment matrix $X_g = (x_{ip})_{i=\overline{1,n},\ p=\overline{1,n}}$ as diagonal matrix, where the elements $x_{jj} \in \{0,1\}$, $j = \overline{1,n}$ on the main diagonal define whether the j-th candidate was selected to the g-th team option (x_{jj}=1) or not (x_{jj}=0). Then we can build a matrix $A_g = X_g \times A$, that defines compliance of the g-th team with project requirements.

We use two criteria as objective functions for the team composition optimization problem.

The first criterion requires that for each indicator, the team has a member with the highest possible competence value. This will allow us to form a team with the best specialist for each indicator. Such a team will have the maximum possible knowledge, skills, and abilities and will be able to cope with tasks in time if the re-

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quirements for the product or project change. This criterion appears as follows

$$X_g^{opt} = \arg\max_{x_{jj}} \sum_{k=1}^{m} \max_{j\in N}\{\alpha_{jk}(\tilde{X}_{jk})\}, \quad (5)$$

where $\alpha_{jk}(\tilde{X}_{jk}) \epsilon A_g$, $A_g = X_g \times A$.

The second criterion aims at forming a team with the maximum sum of competencies across all indicators, considering the weight of each indicator. This will allow you to select the best team in all competencies.

$$X_g^{opt} = \arg\max_{x_{jj}} \sum_{k=1}^{m} \lambda_k \sum_{j=1}^{n} \alpha_{jk}(\tilde{X}_{jk}), \quad (6)$$

where λ_k is the weight of the k–th indicator.

The application of these two criteria will allow you to form a team that, on the one hand, includes 'stars' and, on the other hand, has a high level of competence among team members.

The limitations of the task are as follows:

1) the team's competencies meet all project requirements:

$$\forall k \epsilon K \quad \mu_{\tilde{X}_{jk}}(\max_{j\in N}\{\alpha_{jk}(\tilde{X}_{jk})\}) \geq \nu_k; \quad (7)$$

2) the team's time spent on the project meets the requirements for project labour intensity:

$$\sum_{\forall j\in N} x_{jj} \cdot \rho \cdot time_j \geq Laboriousness, \quad (8)$$

where $time_j$ is the working time of the j–th candidate per week;

ρ is the number of weeks in which the project is planned;

3) the team's labour costs should not exceed the allocated budget

$$\sum_{\forall j\in N} \rho \cdot x_{jj} \cdot time_j \cdot rate_j \leq Cost. \quad (9)$$

Thus, the solution to the problem is the option of a team whose maximum competence in all indicators $k \in K$ is the highest among the possible, and the sum of competence in all indicators, taking into account the weight of each indicator, is also the highest, the maximum competence in each indicator is not less than the specified one, and the team will be able to complete the project within the budget.

To solve the problem (5) - (9), we can use existing methods of multicriteria optimization. One such method is the generalized function method. When using it, we normalize the objective functions. Here, we denote objective functions (5) and (6) by $Z(X_g)$ and $Y(X_g)$, respectively. For normalization, we use monotonic functions of the following form:

$$Z^{norm}(X_g) = \frac{Z^{max} - Z(X_g)}{Z^{max} - Z^{min}};$$

$$Y^{norm}(X_g) = \frac{Y^{max} - Y(X_g)}{Y^{max} - Y^{min}};$$

where Z^{max} is the maximum value of criterion (5);

Z^{min} is the minimum value of criterion (5) for the set of acceptable alternatives;

Y^{max} is the maximum value of criterion (6);

Y^{min} is the minimum value of criterion (6) for the set of acceptable alternatives. The optimal solution to problems (5) - (9) is the following

$$X_g^{opt} = \arg\min_{x_{jj}} (\rho_1 Z^{norm}(X_g) + \rho_2 Y^{norm}(X_g))$$

taking into account constraints (7) - (9), where ρ_1 and ρ_2 are the weights of the relevant criterion determined by the decision maker, $\rho_1, \rho_2 \geq 0$, $\sum_{l=1}^{2} \rho_l = 1$. This method allows us to obtain an effective solution to the problem.

3. Solving the problem of forming an IT project team with fuzzy initial data

Now, we consider the problem of forming an IT project team with fuzzy data on the competencies and requirements of candidates. To solve this problem, we will use the mathematical model (5) - (9) [11]. We chose a continuous scale for the indicators of the requirements for candidates' competencies from 0 to 4 (where 4 is the best possible score).

The fuzzy indicators of the requirements for candidates' competencies are presented in Table 1.

Table 1
Indicators of requirements for candidates' competences

Name of the indicator	Project requirements	
	$\bar{q}_k$	$\Delta\bar{q}_k$
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

At the same time, $\mu_{\tilde{X}_{jk}}(\bar{C}_{jkmin})$ must be at least $v_k = 0.9$, $j=\overline{1,n}$, $k=\overline{1,m}$, $m=5, n=3$. The weights of the indicators λ_k are assumed to be the same for all $k=\overline{1,m}$.

The project execution time is ρ=5 weeks, the project labour intensity is Laboriousness = 250 man-hours, and the allowable cost of the team's labour is Cost=5000 conventional units.

At the stage of candidate selection, we obtained assessments of competencies in the form of trapezoidal fuzzy intervals for all indicators. The competence scores are presented in Table 2.

The available time per week for each candidate to work on the project and their pay rate were determined, as shown in Table 3.

The set of team options has G options, where $G = 2^3 - 1 = 7$. This set is formed as follows:

$$g = 1: [0, 0, 1],$$
$$g = 2: [\, 0, 1, 0],$$
$$g = 3: [0, 1, 1],$$
$$g = 4: [1, 0, 0],$$
$$g = 5: [1, 0, 1],$$
$$g = 6: [1, 1, 0],$$
$$g = 7: [1, 1, 1].$$

Table 2

Assessment of candidates' competences

j	Indicators, k											
	1				2				3			
	$C_{j2}^{(\alpha)}$	$\bar{C}_{j2min}$	$\bar{C}_{j2max}$	$C_{j2}^{(\beta)}$	$C_{j2}^{(\alpha)}$	$\bar{C}_{j2min}$	$\bar{C}_{j2max}$	$C_{j2}^{(\beta)}$	$C_{j3}^{(\alpha)}$	$\bar{C}_{j3min}$	$\bar{C}_{j3max}$	$C_{j3}^{(\beta)}$
1	1	1	1	1	1	1	1	1	2	2	2	2
2	2	3	3	4	0.5	1	1.5	2	1.5	2	2.5	3
3	2.5	3	3.5	3.5	0.5	1	1.5	1.5	1	1.5	2	2.5

End of Table 2

j	Indicators, k							
	4				5			
	$C_{j4}^{(\alpha)}$	$\bar{C}_{j4min}$	$\bar{C}_{j4max}$	$C_{j4}^{(\beta)}$	$C_{j5}^{(\alpha)}$	$\bar{C}_{j5min}$	$\bar{C}_{j5max}$	$C_{j5}^{(\beta)}$
1	2	2	2	2	4	4	4	4
2	1	1.5	2	3	3	3.5	4	4
3	1	1.5	2	2.5	2.6	3	3	3.4

Table 3

Available time and rate of remuneration of candidates

j	$time_j$, hours	$rate_j$, conventional units per hour
1	30	10
2	20	15
3	30	8

Let's form the matrix $A = \left(\alpha_{jk}(\tilde{X}_{jk})\right)_{\substack{j=\overline{1,n},\\ k=\overline{1,m}}}$, whose elements correspond to (4). The elements of matrix A are presented in Table 4.

Then we can build the matrix $A_g = X_g \times A$ of the *g*-th team's compliance with the project's competence requirements. The results are presented in Table 5.

We check the fulfilment of the task constraints of different team options.

The competencies of team options 1, 2, 3, and 4 do not meet all the requirements of the project, so constraint (7) is not met for them.

Constraint (8) on the team's time in the project, which must meet the requirements for project complexity, was met by teams 3, 5, 6, and 7.

Constraint (9) on team labour costs is met by all teams. The results of calculating the constraints' values are presented in Table 6.

Let's calculate the values of the objective functions of problem (5) and (6). The results are presented in Table 7.

As a result, we find that the optimal solution to problems (5) - (9) is the seventh option for building a project team that includes all candidates.

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Table 4

Elements of the matrix A

Candidates, j	Indicators, k				
	1	2	3	4	5
1	0	1	2	2	4
2	3	1	2	0	3.5
3	3	1	0	0	3

Table 5

Matrix $A_g = X_g \times A$

Team option	Candidates, j	Indicators, k				
		1	2	3	4	5
$X_1 = \begin{pmatrix} 0\ 0\ 0 \\ 0\ 0\ 0 \\ 0\ 0\ 1 \end{pmatrix}$	1	0	0	0	0	0
	2	0	0	0	0	0
	3	3	1	0	0	3
$X_2 = \begin{pmatrix} 0\ 0\ 0 \\ 0\ 1\ 0 \\ 0\ 0\ 0 \end{pmatrix}$	1	0	0	0	0	0
	2	3	1	2	0	3.5
	3	0	0	0	0	0
$X_3 = \begin{pmatrix} 0\ 0\ 0 \\ 0\ 1\ 0 \\ 0\ 0\ 1 \end{pmatrix}$	1	0	0	0	0	0
	2	3	1	2	0	3.5
	3	3	1	0	0	3
$X_4 = \begin{pmatrix} 1\ 0\ 0 \\ 0\ 0\ 0 \\ 0\ 0\ 0 \end{pmatrix}$	1	0	1	2	2	4
	2	0	0	0	0	0
	3	0	0	0	0	0
$X_5 = \begin{pmatrix} 1\ 0\ 0 \\ 0\ 0\ 0 \\ 0\ 0\ 1 \end{pmatrix}$	1	0	1	2	2	4
	2	0	0	0	0	0
	3	3	1	0	0	3
$X_6 = \begin{pmatrix} 1\ 0\ 0 \\ 0\ 1\ 0 \\ 0\ 0\ 0 \end{pmatrix}$	1	0	1	2	2	4
	2	3	1	2	0	3.5
	3	0	0	0	0	0
$X_7 = \begin{pmatrix} 1\ 0\ 0 \\ 0\ 1\ 0 \\ 0\ 0\ 1 \end{pmatrix}$	1	0	1	2	2	4
	2	3	1	2	0	3.5
	3	3	1	0	0	3

Table 6

Results of calculating the values of constraints (7) - (9)

Team option	Does it meet the competency requirements?	Team's working time	Labour costs
1	Does not meet requirement	150	1200
2	Does not meet requirement	100	1500
3	Does not meet requirement	250	2700
4	Does not meet requirement	150	1500
5	Relevant	300	2700
6	Relevant	250	3000
7	Relevant	400	4200

Table 7

Results of calculating values of objective functions (5) and (6)

Team option	Candidates, j	Indicators, k					Values of the objective functions
		1	2	3	4	5	
5	1	0	1	2	2	4	-
	2	0	0	0	0	0	-
	3	3	1	0	0	3	-
	Maximum	3	1	2	2	4	12
	Sum	3	2	2	2	7	-
	Weighted sum	0.6	0.4	0.4	0.4	1.4	2.8
6	1	0	1	2	2	4	-
	2	3	1	2	0	3.5	-
	3	0	0	0	0	0	-
	Maximum	3	1	2	2	4	12
	Sum	3	2	4	2	7.5	-
	Weighted sum	0.6	0.4	0.8	0.4	1.5	3.7
7	1	0	1	2	2	4	-
	2	3	1	2	0	3.5	-
	3	3	1	0	0	3	-
	Maximum	3	1	2	2	4	12
	Sum	6	3	4	2	10.5	-
	Weighted sum	1.2	0.6	0.8	0.4	2.1	5.1

4. Discussion

An analysis of existing work in the area of formalizing team formation has shown that there are no solutions aimed at simultaneously considering several alternative fuzzy assessments of a candidate’s particular competence. The application of the arithmetic mean or median for alternative assessments does not reflect the scatter. The consideration of the range of variation in scores is essential. The use of trapezoidal fuzzy intervals to describe multiple grades is one fruitful technique. The consideration of multiple scores is important when considering the possible roles that a candidate is capable of fulfilling in a project team. When testing the suitability for possible roles, the interviewee receives scores based on self-assessment and on the combined perceptions of observers, i.e., at least two scores. The simultaneous application of test results, examinations, and subjective assessments of a competency also leads to a situation in which parallel assessments must be considered.

In order for a team to have a stock of competencies that can help to fulfil the project as the requirements for the product, the project, and therefore the team change, it is useful to have redundant competencies. One way to obtain a stock of competencies is to select team members with the maximum dominant competencies and maximum sum of competencies. In determining these competencies, one must consider the uncertainty of the estimates. For the team formation task to be realistic, some constraints must be considered.

5. Conclusions

The aim of this article was to create an approach to formalizing the formation of a project team, which would allow us to consider multiple fuzzy evaluations of specific candidate properties. Because of the research conducted, it was proposed to describe multiple evaluations of a particular candidate property using trapezoidal fuzzy intervals. The application of such a representation required determining a way for estimating how much the candidate properties correspond to the fuzzy requirements. It was proposed to find the intersection of the belonging functions of fuzzy competence requirements and fuzzy competence evaluations. The threshold for the values of the intersection of belonging functions of fuzzy requirements to competences and fuzzy competence evaluations is set, when reaching which the candidate's competences can be considered as satisfying the requirements. It is proposed to form a project team by maximizing the sum of dominant competencies and the weighted sum of competencies, subject to constraints on the workload of the work, on the fulfilment of competency requirements and on the cost of the team’s work. The generalized function method was applied to solve the multi-criteria problem.

An example of the application of this approach to optimizing the composition of the project team using trapezoidal fuzzy intervals to assess the competencies of candidates is considered.

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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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ФОРМАЛІЗАЦІЯ ФОРМУВАННЯ ПРОЄКТНИХ КОМАНД З УРАХУВАННЯМ АЛЬТЕРНАТИВНИХ ОЦІНОК КОМПЕТЕНТНОСТІ В УМОВАХ НЕВИЗНАЧЕНОСТІ

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Предметом дослідження в статті є математичні моделі та методи формування проєктних команд в умовах невизначеності компетентностей кандидатів та вимог до них. **Метою** роботи є створення підходу до формалізації формування проєктної команди, що враховує множину нечітких оцінок конкретних якостей кандидатів. **Завдання**, які необхідно вирішити: визначити спосіб опису множини нечітких оцінок конкретних якостей кандидатів, визначити спосіб перевірки відповідності якостей кандидата нечітким вимогам, запропонувати математичну модель задачі, розв'язати тестовий приклад задачі. Використані **методи**: теорія нечітких множин, методи багатокритеріальної оптимізації. Отримані наступні **результати**: запропоновано використовувати трапецієподібний нечіткий інтервал для опису множини оцінок конкретних властивостей кандидата; для визначення відповідності властивостей кандидата нечітким вимогам запропоновано обчислювати значення функції належності вимог в точці, що дорівнює нижньому модальному значенню нечіткого інтервалу, що описує властивості кандидата; розглянуто приклад застосування підходу до розв'язання задачі формування проєктної команди. **Висновки.** В результаті проведеного дослідження запропоновано описувати множину оцінок певної властивості кандидата за допомогою трапецієподібних нечітких інтервалів. Новизна запропонованого підходу полягає в методі оцінки відповідності множини оцінок якостей кандидата нечітким вимогам до них. Запропоновано формувати проєктну команду шляхом максимізації суми домінуючих компетентностей та зваженої суми компетентностей за умови дотримання обмежень на трудомісткість робіт, на виконання вимог до компетентностей та на вартість роботи команди. Для розв'язання багатокритеріальної задачі застосовано метод узагальнених функцій.

Ключові слова: проєктна команда; формування; невизначеність компетентностей кандидатів; невизначеність вимог; нечіткі множини; трапецієподібний нечіткий інтервал; модель; оптимізація; багатокритеріальна задача.

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