UDC 519.863:331.108.37:004.4 **doi: 10.32620/reks.2021.3.12**

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MATHEMATICAL MODEL OF SOFTWARE DEVELOPMENT PROJECT TEAM COMPOSITION OPTIMIZATION WITH FUZZY INITIAL DATA

Increasingly frequent changes in demand for products, reducing product life cycles, changes in the business environment during a crisis, the innovative nature of projects, the complexity of forecasting external and internal conditions, the impact of the human factor lead to increased uncertainty and inability to plan team activities with a given degree of accuracy. In this regard, ***the subject matter*** *of the article is the task of creating an adaptive project team that can work effectively in the mentioned above conditions. This task is especially relevant for the sphere of software development. The sphere is dynamic and characterized by frequent changes in product requirements, technologies, working conditions, and restrictions on project implementation. Agile approaches are used to manage such projects, which can help the team respond to uncertainties and frequent changes. To date, there are many agile approaches to project management, but the issue of selecting team members in such approaches is insufficiently covered. Therefore,* ***this work formalizes*** *the task of deciding on the selection of software development team members, considering the uncertainty and subjectivity of the information that affects the selection of candidates for the team.* ***The task*** *of the work is to create a decision-making model based on the use of the mathematical apparatus of fuzzy sets and* ***methods*** *of operations research. Such a model should allow considering the uncertainty of estimates of project requirements and the level of competence of team candidates.* ***The result*** *is a mathematical model of a two-criterion constrained optimization problem. The first objective function is aimed at finding a team composition that maximizes the maximum competencies of its members. The second criterion is aimed at forming a team with the maximum sum of competencies for all indicators, considering the weight of each indicator. The first constraint assumes that at least one team member meets the competency requirements expressed by a specific indicator. Additionally, it is required that the available time fund of the team members allows the project to be completed on time. It considers the limitation on the salary of the team.* ***Conclusions****. Solving the problem in accordance with the proposed mathematical model will allow making a team as readily as possible to meet the existing and new requirements for the project staff. The last circumstance is especially important when implementing a software development projects.*

Keywords: *software; development; team creation; model; fuzzy sets; Agile; Scrum; maximization of competencies.*

Introduction

Software development companies often face problems related to running out of implementing time, following cost plans, user requirements, or the necessary quality of the product. Possible causes of these problems can be caused by poor project management and inadequate execution of work. In turn, for these reasons, there is one common thing – insufficiently qualified staff. Software project staffing is one of the most vulnerable elements in the software development project management process. In software development projects, people are the main resource. To deliver the software product in an agreed scope and budget, the development team must have the necessary qualification. It is known from practice that even a team consisting of the best specialists can fail when there is a lack of communication, the ability to cooperate and compromise as well as coherence within the team. All these factors lead to the need to pay more attention to the process of selecting team members. Cross-functionality and self-organization of the team require mature social behavior from team members, in particular in the field of communication, decision-making, motivation, and commitment to joint action. The necessary qualities of the team members can be described by the appropriate competencies.

Taking into account the above factors, the problem of project team creation can be defined as the selection of project team members by comparing the competencies of the candidates and the required competencies in the context of the project to improve the potential quality of the created team. **The aim of this paper** is the formalization of the task of deciding on the composition of the software development team, taking into account the uncertainty and subjectivity of information that affects the selection of candidates for the team.

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

1. Literature Review

Modern research confirms that the human factor significantly affects the successful implementation of the project, so the development of a method for the creation of an effective team is an urgent task. As the analysis of current research shows, new methods of forming requirements for candidates for an effective project team can use a fuzzy approach.

In the works [1, 2] a model for determining the cohesion of the IT team, which is based on the so-called "role patterns" and the paradigm of fuzzy logic. Also in [1], a model of team member selection based on decision-making in a fuzzy environment is proposed. The authors formulate the task as the selection of the best candidate for a certain role in the team, which is a limitation for team creation in the context of agile project management methodologies. In [3], a model of personnel selection for a multi-stage project was developed, which takes into account the correspondence between the skills possessed by each person, the skills required for each development stage, and quite flexible budget requirements. An algorithm is proposed which uses a fuzzy compatibility design to measure the compliance of a set of individual skills with the goal set for each phase of the project. The authors of [3] tried to determine the team that has the best team skills and considers budget constraints and quality requirements, but the main focus is on meeting the requirements of potential customers and the necessary skills.

The authors of the study [4] propose a modified fuzzy approach to the selection of project teams, which combines models of decision-making on several criteria with dynamic weight for each parameter. The main design parameters in this model are the conversion of input data into a fuzzy form, the calculation of the degree of membership, and the calculation of nondeterministic values based on estimates of membership and lack of membership, with a fuzzy conclusion is converted into a clear set known as defuzzification. The authors assert that this method helps to determine the most qualified candidates in the order of their abilities from the group of applicants. In this case, the overall assessment of the created team is not carried out, which limits the practical application of the proposed approach. Using the fuzzy method and expert assessments are typical for the process of decision-making in project team management. Thus, the authors of [5] proposed the method of information support for the project monitoring and control method, which will provide information on resource and risk load requirements of the project and can allow making informed decisions on strategies of interaction with the team.

In the work [6], an approach is considered to provide an alternative solution to the problem of team building based on clustering of arrays, which allows forming groups of candidates based on the similarity of tasks they can perform. The authors [6] pay attention to the importance of taking into account the competencies of candidates in creating a team and emphasize three levels of evaluation of candidates: static, functional, and dynamic. A fuzzy relationship approach is proposed to determine a candidate's suitability for the team. However, this approach has some limitations when the set of all tasks is not yet defined or may change.

In [7], the authors built a system that mimics the Scrum framework with management processes and roles in the project. To implement the Scrum processes, the ontology is proposed, and for the team-member role competencies, the project team members – a fuzzy-logical representation. As a result, the authors present a hybrid fuzzy-ontological system. The work [8] is devoted to the creation of a fuzzy genetic analytical model for the problem of creating a project team. The authors note that the requirements of the project and the competence of the candidates are usually presented verbally, which causes unclear assessments. In [8] it is proposed to use fuzzy logic and genetic algorithm to find the optimal solution for the composition of the team, the proposed approach requires prior data preparation and significant computational resources.

In the work [9 the authors present a method and tools for modeling competencies for project knowledge management. Based on the use of a fuzzy competency model, they propose an algorithm for expanding group competencies, which takes into account the costs of expanding the competencies of the project team.

In [10, 11] the assessment of the project team is also determined in the context of competence development. The Agile approach model is used to assess the competency patterns of the IT project management team and the entrepreneurial potential of the IT project team. These two models are used as templates to analyze the success of the team.

When creating a project team, decision-makers often face the problem of having several criteria that make the selection task more difficult. In [12], an approach to decision-making is proposed, which includes global optimization based on a genetic algorithm. To solve the problem of team creation, a multicriteria problem is solved, the authors present the results of numerical experiments that show the effectiveness of the proposed algorithm. The authors of [13] describe an experiment in which team performance is evaluated by intelligent agents using fuzzy logic. The results show that intelligent agents can perceive and critically evaluate the work of the team. [14] also presents a fuzzy multi-agent model for creating a group based on nine roles defined by the Belbin typology, using strengths and ideal responsibilities for each role of a team member. Researchers use a fuzzy logic approach to balance different working groups based on existing roles. It is also necessary to add, that the managing team includes human resources risk management. The authors of [15] assume that using psychophysiological techniques it's possible to avoid such risks and as a result improve the efficiency of the project team.

To identify qualified teams for software development, it is necessary to compare the technical experience of the development teams with the specific technical requirements, which are caused by the different objectives of the project. In this context, the work [16] proposes a fuzzy approach to support the selection processes of distributed groups of developers who have the technical skills to implement software modules in distributed software development projects. The proposed approach formalizes the extremely complex problem of team creation following the technical requirements of the project and can be useful in the process of creating distributed development teams.

Thus, the analysis of the state of research on the creation of the software development team shows that this task is complex, poorly structured, and multi-criteria. To formalize the task, it is necessary to determine the competencies and technical skills of candidates, compare them with the requirements of the project, as well as assess the competencies of the team as a whole. Typically, researchers use approaches based on fuzzy logic and fuzzy sets to solve this class of problems.

2. Problem statement

The project team must be flexible and adaptable. According to the Scrum framework, an important factor influencing the creation of an effective team is to ensure the ability to self-organize and cross-functionality of the team. Members of the software development team have specialized competencies in certain areas, but the overall team is responsible for the work. This leads to the need to solve the problem of team creation as a process of selecting candidates who have all the professional competencies at a certain level and are able as a team to meet the requirements of the project. The method of team creation is considered in detail in [17, 18, 19], where are such stages as:

– creation of a set of candidates based on assessments of their competencies and compliance of candidates with the requirements of the project;

– determination of team options under the requirements of the project, taking into account the time constraints of the project and budget constraints;

– determining the optimal composition of the software development team based on certain tasks.

Given the inaccuracy of estimates and some uncertainty of the requirements for candidates for the project team, it is proposed to formalize the problem of creating a project team based on the mathematical apparatus of fuzzy sets.

3. Formalization of the task

To formalize the problem, let us introduce the following notation (Table 1).

To assess the candidate, we need to create a set of indicators, the values of which together characterize the properties of the candidate and allow us to assess it in relation to the requirements of the project. At the first stage, the set of candidates is determined on the basis of assessments of their compliance with the project requirements. At the second stage, we form options for a potential team. If there is more than one option, we move on to the third stage, i.e. to the creation of the optimal team. Given the uncertainty of the requirements for candidates, which are usually expressed in text form, as well as the impossibility of measuring the characteristics of candidates, which leads to the use of a subjective evaluation scale, it is proposed to formalize the task of creating a project team based on fuzzy sets.

Table 1

Notations and definitions

Notation	Definition
$K = \{1,2,..., m\}$	A set of indicator numbers, the values of which together characterize all candidates and allow to evaluate them in regards to all project requirements
$Q = \{q_i : i = 1,..., \zeta\}$	The common scale for assessing candidates' requirements
$\bar{q}_k \in Q, k \in K$	Clear assessment of requirements by indicator $k \in K$, which is expressed on the scale Q and expresses the desired level of k-th indicator from the project requirements point of view
$\bar{Q}_k = \left\{ \begin{array}{l} \langle q, \mu_{Q_k}(q) \rangle, \\ q \in Q \end{array} \right\}$	Fuzzy set, which defines fuzzy assessment for the project requirements k-th indicator, $k \in K$; $\mu_{Q_k}(q) \in [0,1]$ – membership function defined on a fuzzy set carrier $q \in Q$.
$N = \{1,2,..., n\}$	A set of candidates for the project team

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

Continuation of the Table 1

Notation	Definition
$\overline{C}_{jk} \in Q,\ k \in K,\ j \in N$	Clear assessment of the competencies of j-th candidate by indicator k
$\tilde{C}_{jk} = \left\{ \left\langle C, \mu_{\tilde{C}_{jk}}(C) \right\rangle, C \in Q \right\}$	Fuzzy set, which defines fuzzy assessment of the competencies of the j-th candidate by indicator k, $j \in N, k \in K$
$\tilde{X}_{jk} = \left\{ \left\langle x, \mu_{\tilde{X}_{jk}}(x) \right\rangle, x \in Q \right\}$	Fuzzy set, which defines fuzzy assessment of the compliance of the j-th candidate with project requirements by the indicator k, $j \in N, k \in K$
$Conf = \left(\mu_{\tilde{X}_{jk}}(x)\right)_{j=\overline{1,n},\ k=\overline{1,m}}$	The matrix of compliance of candidates with the requirements of the project, where $\mu_{\tilde{X}_{jk}}(x) = \min_{x \in Q}\left\{\mu_{Qk}(x)\mu_{\tilde{C}_{jk}}(x)\right\}$ – membership function, which determines the compliance of competencies of the j-th candidate in regards to the k-th requirements of the project
$X_g = \left(x_{ip}\right)_{i=\overline{1,n},\ p=\overline{1,n}}$	Assignment matrix – diagonal matrix, elements of the main diagonal $x_{jj} \in \{0,1\},\ j = \overline{1,n}$ determine whether the candidate selected to the g-th team option
$time_j$, $j = \{1,2,..., n\}$	Available time of the j-th candidate for the project work, hours per week
$rate_j$, $j \in \{1,2,..., n\}$	Cost of a working hour of the j – the candidate (salary rate)
Cost	Labor costs of the team (budget), conventional units
Laboriousness	The laboriousness of the project, which was estimated at the stage of formation of requirements for team competencies, person-hours
ρ	Time of the project implementation, weeks

Let us consider the technology of forming criteria. 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 to evaluate them in relation to all project requirements [19]. First, for each indicator, $k \in K$ it is necessary to define the value, which meets the project requirements. Let us consider $\overline{q}_k$ – is a numerical assessment of the requirements expressed by the indicator $k \in K$, i.e. $\overline{q}_k$ express the desired level of the k-th characteristic of the contractor in the context of 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 $\overline{q}_k$ or higher. To formalize such assessments, let us denote a fuzzy set $\overline{Q}_k$ as a group of values $\overline{q}_k \in Q$, in respect of which it is not possible to state with complete certainty whether this or that element belongs to a given group or not. Mathematically the fuzzy set $\overline{Q}_k$ 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]. The membership function $\mu_{Q_k}(q)$ defines the certainty, with what the values of assessments q on the scale Q belong to the fuzzy set $\overline{Q}_k$. The set Q is the carrier of a fuzzy set $\overline{Q}_k$. So, the fuzzy set $\overline{Q}_k$ defines the desired project assessment of the candidates’ characteristics for the team by k–th indicator. Given the semantic significance of the requirements for candidates, we define the membership function $\mu_{Q_k}(q)$ at the following way:

$$\mu_{Q_k}(q) = \left\{ \begin{array}{c} 0,\ q \le \overline{q}_k - \Delta\overline{q}_k \\ \left(\dfrac{q - \overline{q}_k + \Delta\overline{q}_k}{\Delta\overline{q}_k}\right),\ \overline{q}_k - \Delta\overline{q}_k \le q \le \overline{q}_k \\ 1,\ q_k \le q \end{array} \right\}, \quad (1)$$

where $\overline{q}_k \in Q$ – the desired clear level of the k-th indicator, $k \in K$, $\Delta\overline{q}_k$ – permissible from the point of view of the project deviation from the level $\overline{q}_k$, Q – assessment scale, α – parameter.

The geometric interpretation of the membership function (1) is shown on the Fig. 1. The view of the function (1) on the interval $(\overline{q}_k - \Delta\overline{q}_k, \overline{q}_k)$ is defined by the parameter $\alpha \in R$, (in a case $\alpha = 1$ it is linear dependence). Next, to simplify the presentation, we assume that $\alpha = 1$. Then, the membership function (1) has a partially linear view and is characterized by 3 intervals:

1) $q \le \bar{q}_k - \Delta\bar{q}_k$, where $\mu_{Q_k}(q) = 0$;

2) $\bar{q}_k - \Delta\bar{q}_k \le q \le \bar{q}_k$, where $\mu_{Q_k}(q) = \dfrac{q - \bar{q}_k + \Delta\bar{q}_k}{\Delta\bar{q}_k}$ is strictly monotonously growing;

3) $\Delta\bar{q}_k \le q$, $\Delta\bar{q}_k \le q$, where $\mu_{Q_k}(q) = 1$, i.e. it takes its maximum value.

The interval $\Delta\bar{q}_k \le q$, is the nucleus of the fuzzy set $\bar{Q}_k$. According to the definition given in [19], the membership function $\mu_{Q_k}(q)$ is unimodal, and the corresponding fuzzy set $\bar{Q}_k$ project requirements by k-th indicator is unimodal. In this case, the value $\bar{q}_k$ is modal value or mode of the fuzzy set $\bar{Q}_k$.

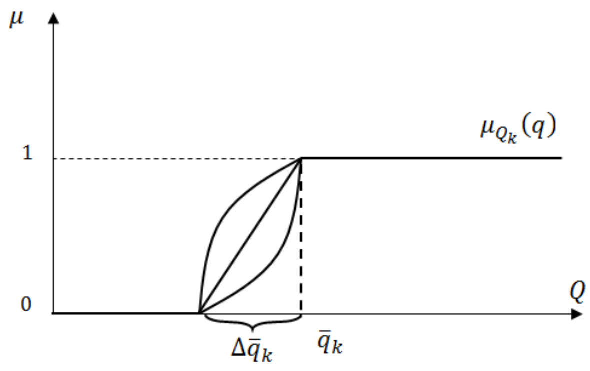

Fig. 1. Geometric interpretation of the membership function $\mu_{\tilde{C}_{jk}}(C)$

At the next step, after interviews with candidates, for each candidate, it is necessary to form assessments of their competencies for each $k \in K$ indicator. Let us denote $\bar{C}_{jk} \in Q$ – is a clear assessment of the competencies of j-th candidate by indicator k, $k \in K$ [19]. Given the subjectivity of the assessment of competencies, we will assume that for each indicator, each candidate is characterized by a fuzzy number, which can be interpreted using the following statement: 'assessments of candidate's competencies by k-th indicator approximately corresponds the level of $\bar{C}_{jk}$. To formalize the assessment of candidates' competencies, we denote a fuzzy set $\tilde{C}_{jk}$ with carrier $C \in Q$ and membership function $\mu_{\tilde{C}jk}(C) \in [0,1]$

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

So, the fuzzy set $\tilde{C}_{jk}$ defines real (received as results of interviews) assessments of candidates' characteristics by k-th indicator. Given the semantic significance of the obtained assessments of competencies, we define the membership function $\mu_{\tilde{C}_{jk}}(C)$ in the following way:

$$\mu_{\tilde{C}jk}(C) = \left\{ \begin{array}{c} 0, \ C \le C_{jk}^{(\alpha)}; \\ \dfrac{C - C_{jk}^{(\alpha)}}{\bar{C}_{jk} - C_{jk}^{(\alpha)}}, \ C_{jk}^{(\alpha)} \le C \le \bar{C}_{jk}; \\ \dfrac{C_{jk}^{(\beta)} - C}{C_{jk}^{(\beta)} - \bar{C}_{jk}}, \ \bar{C}_{jk} \le C \le C_{jk}^{(\beta)}; \\ 0, \ C \ge C_{jk}^{(\beta)} \end{array} \right\}, \quad (2)$$

where $j \in N$, $k \in K$, $C \in Q$, $\bar{C}_{jk} \in Q$ – clear assessment of the competencies of the j–th candidate by indicator k, Q – a scale of the assessment, $\mu_{\tilde{C}jk}(C) \in [0,1]$, $C_{jk}^{(\alpha)}, C_{jk}^{(\beta)}$ – membership function parameters, $C_{jk}^{(\alpha)} \le \bar{C}_{jk} \le C_{jk}^{(\beta)}$.

Graphical interpretation of the membership function $\mu_{\tilde{C}_{jk}}(C)$ is shown on the Figure 2.

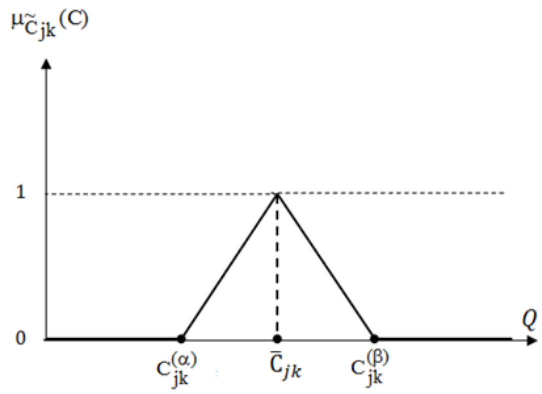

Fig. 2. Graphical interpretation of the membership function $\mu_{\tilde{C}_{jk}}(C)$

The proposed membership function $\mu_{\tilde{C}_{jk}}(C)$ is a special case of membership functions $(R-L)$- type – triangular function.

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 re-

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

quirements for the candidate and the assessment of the candidate's competencies.

Definition 1. The intersection of two fuzzy sets $\tilde{A}$ and $\tilde{B}$, defined on the universe X is called $\tilde{C} = \tilde{A} \cap \tilde{B}$, the membership function of which is found in the following way [20]:

$$\mu_{\tilde{C}}(x) = \min_{x \in U} \{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\}$$

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 $\overline{Q}_k$ and candidate's competencies $\tilde{C}_{jk}$. Then, according to the mentioned above definition 1, 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 $x \in Q$, a $\mu_{\tilde{X}_{jk}}(x)$ – the membership function, which can be found as follows:

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

The graphic interpretation of the 'compliance' of the j-th candidacy with the project requirements is shown on the Figure 3.

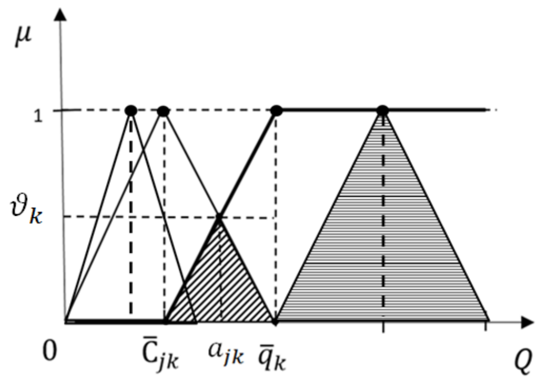

Fig. 3. Graphic interpretation of the membership function $\mu_{\tilde{C}_{jk}}(C)$

The expert will be considered as a candidate if at least one criterion meets the requirements of the project, so for the j-th candidate among the sets of compliance assessments $\tilde{X}_{jk}$ there is at least one set, which has a value of $\mu_{\tilde{X}_{jk}}(\alpha_{jk})$ is not less than υ_k (where υ_k is a threshold, for example, $\upsilon_k = 0{,}5$). The threshold defines the minimum value of the membership function that allows meeting the requirements of the project.

Then it is possible to form a matrix of compliance of candidates with the project requirements. The compliance matrix is built from the membership functions obtained as the intersection of the membership function for j-th candidate by k-th indicator and the membership function of k-th requirement to the candidates, $j = \overline{1,n}$, $k = \overline{1,m}$. The formed compliance matrix of all candidates can be defined as follows:

$$\text{Conf} = \left(\mu_{\tilde{X}jk}(x)\right)_{\substack{j=\overline{1,n} \\ k=\overline{1,m}}} =$$

$$= \begin{pmatrix} \mu_{\tilde{X}11}(x) & \mu_{\tilde{X}12}(x) & \ldots & \mu_{\tilde{X}1m}(x) \\ \mu_{\tilde{X}21}(x) & \mu_{\tilde{X}22}(x) & \ldots & \mu_{\tilde{X}2m}(x) \\ \ldots & \ldots & \ldots & \ldots \\ \mu_{\tilde{X}n1}(x) & \mu_{\tilde{X}n2}(x) & \ldots & \mu_{\tilde{X}nm}(x) \end{pmatrix}.$$

For each element of the matrix Conf it's necessary to calculate the coordinate value of the membership function mode of the fuzzy set for compliance of the j-th candidate with k-th requirement, i.e. $\alpha_{jk}(\tilde{X}_{jk})$

$$\alpha_{jk}(\tilde{X}_{jk}) = \begin{cases} 0, \text{ if } \ C_{jk}^{(\beta)} \le \overline{q}_k - \Delta\overline{q}_k; \\ \dfrac{q_k C_{jk}^{(\beta)} - q_k \overline{C}_{jk} + \Delta\overline{q}_k \overline{C}_{jk}}{C_{jk}^{(\beta)} - \overline{C}_{jk} + \Delta\overline{q}_k}, \text{ if } \ \begin{matrix} \overline{C}_{jk} < \overline{q}_k \text{ and} \\ C_{jk}^{(\beta)} > \overline{q}_k - \Delta\overline{q}_k; \end{matrix} \\ \overline{C}_{jk}, \text{ if } \ \overline{q}_k \le \overline{C}_{jk} \end{cases} \quad (3)$$

Then, we can build a matrix $A = \left(\alpha_{jk}(\tilde{X}_{jk})\right)_{\substack{j=\overline{1,n} \\ k=\overline{1,m}}}$, the elements of which correspond the coordinate values of the 'compliance' membership function mode (3) of the candidates with project requirements.

To create a team we need to specify additional conditions. Next, as additional conditions for the team creation we will consider: the resource of the available time of each candidate time_j and the 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 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 $X_g = \left(x_{ip}\right)_{\substack{i=\overline{1,n} \\ p=\overline{1,n}}}$ as the 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.

The criteria for selecting a team can be written as follows:

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

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

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

where λ_k is a weight of k-th indicator,

$$0 \le \lambda_k \le 1, \quad \sum_{k=1}^{m} \lambda_k = 1.$$

One criterion requires that for each indicator the team has a member with the highest possible competence value. This will create a team that will have the best possible specialist for each indicator. Such a team will have the maximum possible knowledge, skills, and abilities and will be able to cope with the assigned tasks in time if the requirements for a product or project change.

The second criterion is aimed to form a team with the maximum sum of competencies for all indicators, taking into account the weight of each indicator. This will allow choosing the composition of the team, which in total is better than others in all competencies.

The application of these two criteria will make it possible to form a team that, on the one hand, includes "stars", and on the other hand, has a high general level of competence of the team members.

The restrictions are the following:

1) the competencies of the team meet all the requirements of the project:

$$\forall k \in K \ \ \mu_{\tilde{X}_{jk}}\left(\max_{j \in N}\{\alpha_{jk}(\tilde{X}_{jk})\}\right) \ge \upsilon_k;$$

2) teamwork time in the project meets the requirements for the laboriousness of the project:

$$\sum_{\forall j \in N} x_{jj} \cdot \rho \cdot time_j \ge \text{Laboriousness},$$

where $time_j$ – working time of the j-th candidate per week, ρ – number of weeks, planned for implementing the project,

3) team costs should not exceed the allocated budget:

$$\sum_{\forall j \in N} \rho \cdot x_{jj} \cdot time_j \cdot rate_j \le Cost.$$

Thus, the solution of the problem is an option of the team, the maximum competence of which for all $k \in K$ is the largest among the possible, and the sum of competencies for all indicators, taking into account the weight of each indicator, is also the highest, the maximum competence for each indicator is not less than the specified υ_k, the team will have enough time to complete the project within the budget.

4. Case study

To illustrate the case study of the proposed target functions, let us consider a simple example, which we present in a clear statement without taking into account any restrictions.

Let us say the competence of candidates is assessed by two indicators "Design patterns" and "Data types" on a five-point scale. A total of 6 candidates are being considered. Among the possible options for the teams' composition, as an example, we will consider only two (Table 2 and Table 3).

Table 2

Team №1

Candidate	"Design patterns" assessment	"Datatypes" assessment
1	5	2
2	4	3
3	4,5	1
4	3	4
	Max value 5	Max value 4

The sum of the max values: 9.

The sum of points: 26,5.

Table 3

Team №2

Candidate	"Design patterns" assessment	"Datatypes" assessment
3	4,5	1
4	3	4
5	3	5
6	3	3,5
	Max value 4,5	Max value 5

The sum of the max values: 9,5.

The sum of points: 27.

In this case, among the two team options, the second one (Team №2) should be preferred. It turned out to be more appropriate according to both criteria. In this case study we did not take into account indicator

ISSN 1814-4225 (print)
ISSN 2663-2012 (online)

weights and limitations. A more complete example of the application of the proposed mathematical model, taking into account the fuzziness of the initial data and limitations, will be presented in a separate paper.

5. Discussion

Project teams are important working structures for successful project implementation. Many researchers define the choice of a project team as the choice of the right team members who together implement a certain project within a given period [2, 4, 10]. As the analysis showed, many researchers are involved in the taking decision on the selection of members for the development team. The use of mathematical tools of fuzzy sets is a fairly common technique for deciding to support problems resolving in determining the project team [6, 8, 12]. In typical ways to the application of agile project management approaches, many factors are not taken into account, including as developers' experience, the accuracy of competence assessment, etc. These factors are usually presented using only verbal description and are evaluated subjectively, which makes it difficult to take them into account. Therefore, researchers use the concepts of fuzzy mathematics to build models to improve decision-making results. The team creation model developed in this paper is also based on the application of the basic principles of fuzzy set theory and is fully consistent with the results of other researchers in this area. In contrast to the approach proposed in [6], the developed model allows creating a team following the requirements of the project in conditions when a certain list of tasks has not yet been defined. In comparison with the results obtained in [16], the developed approach provides opportunities to use a more flexible scale for assessing candidates, requirements, and the team as a whole, as well as assessing the overall competence of the created team, which allows not only to determine compliance but also to create a team with maximum competencies and take into account the prospects of project development.

Thus, the approach proposed in this paper allows setting the problem of creating an adaptive project team as a task of optimizing team competencies taking into account the requirements of budget, time, and technical characteristics of the project under uncertainty based on the application of mathematical apparatus of fuzzy set theory.

Conclusion

The formation of requirements for the competence of the project team is carried out by specialists. As a result, these requirements always contain some level of uncertainty. Likewise, there is considerable uncertainty in assessing the competencies of candidates for inclusion into a team. When creating a team, it is necessary to take into account the uncertainties of both the requirements for candidates and the assessments of their competencies.

A mathematical model for solving the problem of creating a project team is proposed. The first objective function of the task is aimed to find a team composition that maximizes the maximum competencies of its members. The second objective function is aimed to form a team with the maximum sum of competencies for all indicators, taking into account the weight of each indicator. This takes into account the restriction on the cost of the team. In addition, it is required that the available time fund of the team members allows the project to be completed on time. The third constraint assumes that the maximum value of the membership function for the compliance of at least one team member with the project requirements is not less than the specified one. The proposed model takes into account the assessments of the competencies of candidates and the requirements for them, given in the form of fuzzy sets.

Solving the problem following the proposed mathematical model will make it possible to create a team as ready as possible to fulfill the existing requirements for personnel. In addition, having the highest possible competencies among team members will best cope with new requirements that may arise during the implementation of the project. The last circumstance is especially important when implementing projects in the software development field.

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Надійшла до редакції 19.07.2021, розглянута на редколегії 23.09.2021

МАТЕМАТИЧНА МОДЕЛЬ ОПТИМІЗАЦІЇ СКЛАДУ КОМАНДИ ПРОЄКТУ З РОЗРОБКИ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ З НЕЧІТКИМИ ВХІДНИМИ ДАНИМИ

І. В. Кононенко, Г. В. Сушко

Все частіші зміни попиту на продукцію, короткі життєві цикли продукції, зміна бізнес-оточення в період кризи, інноваційний характер проєктів, складність прогнозування зовнішніх і внутрішніх умов, вплив людського фактору призводять до збільшення невизначеності і неможливості планування діяльності команд із заданим ступенем точності. У зв'язку з цим, **предметом вивчення в статті** є задача формування адаптивної команди проєкту, що може ефективно працювати в вищезазначених умовах. Така задача особливо актуальна для сфери розробки програмного забезпечення. Дана сфера являється динамічною та характеризується частою зміною вимог до продукту, технологій, умов роботи та обмежень щодо виконання проєкту. Для управління такими проєктами доволі часто використовують гнучкі підходи, що можуть допомогти команді реагувати на невизначеності та часті зміни. На сьогоднішній день існує ряд гнучких підходів до управління проєктами, але питання відбору членів команди в таких підходах, на думку авторів, висвітлено недостатньо. Саме тому, **метою даної роботи** є формалізація задачі прийняття рішення щодо відбору членів команди з розробки програмного забезпечення з врахуванням невизначеності та суб'єктивності інформації, що впливає на вибір кандидатів в команду. **Завданням** роботи є створення моделі прийняття рішень на основі застосування математичного апарату нечітких множин та **методів** дослідження операцій. Така модель повинна дозволяти врахувати невизначеність оцінок вимог до проєкту та рівня компетентностей кандидатів в команду. **Отриманим результатом** є математична модель двокритеріальної задачі оптимізації з обмеженнями. Перша цільова функція спрямована на пошук складу команди, який максимізує максимальні компетентності її членів. Другий критерій спрямований на формування команди з максимальною сумою компетентностей за всіма індикаторами з урахуванням ваги кожного індикатора. Перше обмеження передбачає, що вимогам до компетентності, вираженим конкретним індикатором, задовольняє хоча б один член команди. Крім того необхідно, щоб наявний фонд робочого часу членів команди дозволяв виконати проєкт вчасно. При цьому враховується обмеження на оплату праці колективу. **Висновки.** Розв'язання завдання відповідно до запропонованої математичної моделі дозволить скласти команду, що максимально відповідає виконанню наявних вимог до персоналу. Крім того, наявність максимально можливих компетентностей у членів команди дозволить найкращим чином впоратися з новими вимогами, які можуть з'явитися в процесі виконання проєкту. Остання обставина особливо важливо при виконанні проєктів в області розробки програмного забезпечення.

Ключові слова: програмне забезпечення; розробка; формування команди; модель; нечіткі множини; Agile; Scrum; максимізація компетентностей.

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ОПТИМИЗАЦИИ СОСТАВА КОМАНДЫ ПРОЕКТА ПО РАЗРАБОТКЕ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ С НЕЧЕТКИМИ НАЧАЛЬНЫМИ ДАННЫМИ

И. В. Кононенко, Г. В. Сушко

Все более частые изменения спроса на продукцию, сокращающиеся жизненные циклы продукции, изменение бизнес-окружения в период кризиса, инновационный характер проектов, сложность прогнозирования внешних и внутренних условий, влияние человеческого фактора приводят к увеличению неопределенности и невозможности планирования деятельности команд с заданной степенью точности. В связи с этим, **предметом изучения** в данной статье является задача создания адаптивной команды проекта, которая может эффективно работать в вышеупомянутых условиях. Такая задача особенно актуальна для сферы разработки программного обеспечения. Данная сфера является динамичной и характеризуется частой сменой требований к продукту, технологий, условий работы и ограничений по выполнению проекта. Для управления такими проектами довольно часто используют гибкие подходы, которые могут помочь команде реагировать на неопределенности и частые изменения. На сегодняшний день существует ряд гибких подходов к управлению проектами, но вопрос отбора членов команды в таких подходах, по мнению авторов, освещен недостаточно. Именно поэтому, **цель данной работы** – формализация задачи принятия решения по отбору членов команды по разработке программного обеспечения с учетом неопределенности и субъективности информации, что влияет на выбор кандидатов в команду. **Задачей** работы является создание модели принятия решений на основе применения математического аппарата нечетких множеств и **методов** исследования операций. Такая модель должна позволять учесть неопределенность оценок требований к проекту и уровня компетентностей кандидатов в команду. **Полученным результатом** является математическая модель двухкритериальной задачи оптимизации с ограничениями. Первая целевая функция направлена на поиск состава команды, который максимизирует максимальные компетентности ее членов. Второй критерий направлен на формирование команды с максимальной суммой компетентностей по всем индикаторам с учетом веса каждого индикатора. Первое ограничение предполагает, что требованиям к компетентности, выраженным конкретным индикатором, удовлетворяет хотя бы один член команды. Кроме того, требуется чтобы доступный фонд рабочего времени членов команды позволял выполнить проект вовремя. При этом учитывается ограничение на оплату труда коллектива. **Выводы.** Решение задачи в соответствии с предложенной математической моделью позволит составить команду в максимальной степени готовую к выполнению имеющихся требований к персоналу. Кроме того, наличие максимально возможных компетентностей у членов команды позволит наилучшим образом справиться с новыми требованиями, которые могут появиться в процессе выполнения проекта. Последнее обстоятельство особенно важно при выполнении проектов в области разработки программного обеспечения.

Ключевые слова: программное обеспечение; разработка; формирование команды; модель; нечеткие множества; Agile; Scrum; максимизация компетентностей.

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