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RESEARCH ARTICLE

Evaluation of the project based on the theory of fuzzy sets and the concept of fuzzy logic. Method and methodology

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Abstract

Objectives. The work sets out to develop a method and methodology for evaluating project activities, including research and development work. The development of this method and its associated methodology is relevant due to the need to provide an analytical assessment of a project based on its main performance indicators, such as the uniqueness of the results and the resources required to produce them. This assessment must take into account both the requirements of the customer and the capabilities of the prospective performers to make an informed decision on its formulation. Currently, the best-known methods for evaluating a planned project are based on economic efficiency. However, the approaches taken by customers and contractors are often different and sometimes contradictory. For example, a customer may minimize the risk of failing to achieve the project goal by setting appropriate requirements and resource costs, while a contractor minimizes the same risks by increasing the requested time and material resources, as well as by adjusting the requirement criteria for the project results, which are based on their ability to fulfill them. The concept of fuzzy sets allows various assessment approaches to be combined to provide informed and coordinated decision-making regarding the feasibility and expediency of setting up and executing a project.

Methods. The developed method and methodology for project evaluation are based on the theory of fuzzy sets and the concept of fuzzy logic, using membership functions to model project parameter estimates.

Results. The project assessment method and implementation methodology were developed, taking into account customer requirements and the capabilities of the potential contractor, to enable rational decision-making regarding its formulation.

Conclusions. The method may be applied to establish the optimal requirements and conditions for project implementation in a balanced manner. In contrast to expert methods, the presented analytical method and methodology provide a higher objectivity of the generalized assessment, validity, and effectiveness in making and implementing managerial decisions. The methodology's universal criteria and procedures make it suitable for application to various kinds of assessment and in various areas of project activity, including research and development work.

Keywords: project, theory of fuzzy sets, linguistic variables, membership functions, fuzzification, defuzzification

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НАУЧНАЯ СТАТЬЯ

Оценка проекта на основе теории нечетких множеств и концепции нечеткой логики. Метод и методика

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Резюме
Цели. Цель работы – разработка метода и методики оценки проектной деятельности, включая научно-исследовательские и опытно-конструкторские работы. Актуальность разработки обусловлена потребностью в аналитической оценке проекта по его основным показателям (уникальности результатов и требуемым ресурсам), учитывающей как требования заказчика, так и возможности предполагаемых исполнителей для принятия согласованного решения по его постановке. В настоящее время основой известных методов оценки планируемого проекта является экономическая эффективность. При этом подходы к оценке проекта заказчика и исполнителя различны и противоречивы. Заказчик в своих требованиях к проекту и затратам ресурсов минимизирует риски недостижения цели проекта. Исполнитель те же риски минимизирует увеличением запрашиваемых временных и материальных ресурсов, а также своими требованиями к результатам проекта, в основе которых – его возможности их выполнить. Объединить различные подходы к оценке для обоснованного и согласованного принятия решений относительно возможности и целесообразности постановки и выполнения проекта позволяет концепция нечетких множеств.
Методы. В основе разработанных метода и методики оценки проектов – теория нечетких множеств и концепция нечеткой логики с моделированием оценок параметров проекта с помощью функций принадлежности.
Результаты. Разработаны метод и реализующая его методика оценки проекта, учитывающие требования заказчика и возможности предполагаемого исполнителя для обоснованного принятия решений в отношении его постановки.
Выводы. Применение метода позволяет сбалансированно установить оптимальные требования и условия для осуществления проекта. В отличие от экспертных методов представленные аналитический метод и методика обеспечивают более высокую объективность обобщенной оценки, обоснованность и эффективность в принятии и реализации управленческих решений. Универсальность критериев и процедур методики содержит в себе возможность ее применения в оценках различных видов и по различным направлениям проектной деятельности, включая научно-исследовательские и опытно-конструкторские работы.

Ключевые слова: проект, теория нечетких множеств, лингвистические переменные, функции принадлежности, фаззификация, дефаззификация

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INTRODUCTION

A project differs from operational activities in three main ways: its goal is to produce a unique result that has never been created before; it has a limited time frame; and it has limited resources. Risk factors that may prevent the project from achieving its goal included a lack of prior information or experience of performing similar work or creating a similar product. It is important to note that these risks apply to both the project contractor and the customer [1–3]. The repercussions of a contractor's erroneous evaluation of their competencies are twofold: firstly, in failing to attain the stipulated objective, and secondly, in being unable to conclude the project. In order to mitigate risk, contractors often overestimate the resources and deadlines required for project work and underestimate the level of resources necessary for the development stage [4–6]. Customers, who are willing to expend their own resources, generally seek to achieve the required result with fewer resources and in a shorter timeframe than contractors would like. Thus, an objective evaluation of the project that takes into account both the customer's requirements and the contractor's capabilities could foster a more harmonious relationship between the two parties.

One possible resolution to this issue consists in an assessment method that incorporates assessments of the same object by both parties to resolve the conflict of interests between them. This possibility is realized through an approach based on fuzzy logic and fuzzy set theory. This approach is based on the use and processing of large amounts of information using digital information technology methods and tools to obtain a variety of solutions for different evaluation criteria.

The need to use fuzzy logic methodology is based on the requirement to achieve more reliable assessment outcomes by using analytical methods that are sensitive to changes in the project activity being evaluated. These include individual projects, programs and project portfolios, as well as research and development work and preliminary designs. The results of assessments employing such analytical methods to evaluate proposed project activities according to their three attributes (criteria and characteristic features) have the potential to serve as the basis for joint decisions on setting and implementing project activities by interacting parties (customers and contractors).

The reliability of assessments is pivotal in determining the adequacy of decisions taken and the effectiveness of project management. To achieve this, assessment results must demonstrate sensitivity to changes in project parameters that lead to deviations from the set objectives. This establishes the requirements for the qualitative and quantitative indicators used to assess the project. Here it is important to note that methods based on measured data or expert opinion do not always allow for such an assessment [7–11].

1. MODEL FOR FORECASTING PROJECT PARAMETERS BASED ON THEIR FUZZY MODELING FOR MANAGEMENT DECISION-MAKING

The purpose of the method is to determine the feasibility of project activities based on a forecast assessment of three parameters comprising the novelty and originality of the planned results, the adequacy of the allocated resources and deadlines, and the optimal use and planning of these resources. These assessments, which are common to all interacting parties (customers and contractors), are characterized by ambiguity, the possibility of multiple responses, and different perceptions of their significance. This leads to decisions being made that vary in their effectiveness. The concept of fuzzy sets enables different assessments to be combined for informed and coordinated decision-making regarding the feasibility and advisability of setting up and implementing a project. The presented method involves modelling the customer's and contractor's project assessments using membership functions within a specific fuzzy set, thereby generating a generalized assessment.

The result of applying this method should be an assessment of the project in terms of its compliance with the customer's requirements and the contractor's capabilities. This should be followed by a decision on the feasibility of implementation that satisfies both parties. Focusing on using artificial intelligence technologies to manage the project at all stages—from establishing feasibility to selecting optimal scientific, technical, and organizational solutions—requires mathematical models to be developed for each stage of project activity [12–14].

Fuzzy set theory enables the structuring of project criteria, parameters, and characteristics that cannot be assessed using a single scale and that can be perceived differently by the two interacting parties: contractors and project customers. The need to evaluate these parameters, which do not have a single, unambiguous rating scale, can be met by using the provisions of fuzzy set theory to determine whether they meet the criteria of the category "Meets requirements and satisfies participants." This can be achieved by modelling the project evaluation as a fuzzy system that links the impact of project assessments in terms of novelty, originality, sufficiency of resources, and deadlines for work completion according to customer requirements and contractor capabilities. This modelling process involves three stages: first, creating a mental model of the project; second, creating a verbal model of the project; and third, developing a fuzzy linguistic model of the project. Input parameters for such a fuzzy model can be obtained in three ways: through expert assessment of the parameters of the modelled project; by constructing self-tuning fuzzy models based on system input and output measurements; and by constructing self-organizing and self-tuning fuzzy models based on system input and output measurements[1] [15, 16].

The mental model of a project is a vision of the activities involved in creating a new, unique product within a limited timeframe and with limited resources. The verbal model, which describes the project's main properties and distinctive features in clear terms, is then transformed into a fuzzy linguistic model to facilitate informational interaction between project participants.

The consistency of two factors should be ensured by the fuzzy linguistic system and its model: the customer's requirements and the contractor's capabilities. The assessment is based on a joint assessment model that uses fuzzy logic methods, in which the customer and the prospective contractor evaluate the predicted project results.

The customer and contractor comprising the two interacting parties are considered as a fuzzy system [17–19]. The inputs for analysis in the fuzzy model are the project parameters predicted by each of the interacting parties. These inputs include the degree of originality of the scientific, technical, or other planned results of the project, the level of adequacy of resource support for the project work, and the adequacy of time for the project work. The analysis provides a general assessment of the project's alignment with the customer's needs and the contractor's capabilities. This requires a solution to the problem of combining the two independent assessments from each party. Based on this assessment, a decision is made on whether to implement the project.

The structure and substance of the project predictive assessment method, which is based on fuzzy set theory, fuzzy logic, and fuzzy modelling of its characteristics, is used to make decisions on project initiation and management. The method comprises the following stages (Fig. 1):

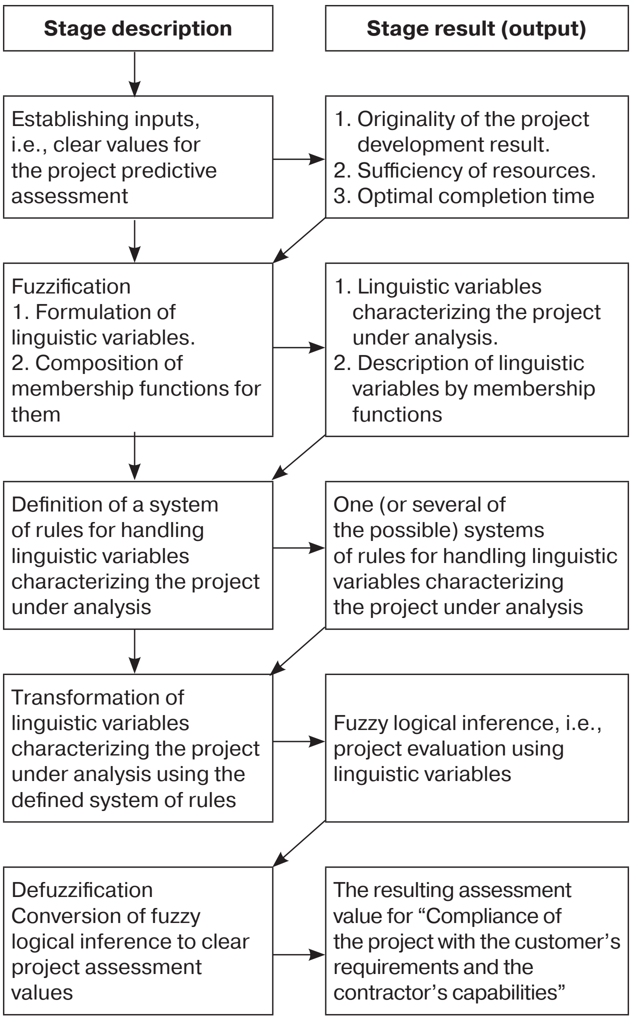

Fig. 1. Stages of the method for assessing the compliance of the proposed project with the customer's requirements and the contractor's capabilities

1. Problem statement: assessment of the project's feasibility and obtaining original scientific, technical or other results that satisfy the customer. Definition and establishment of inputs: clear values that characterize the contractor's activities and are necessary for their assessment using fuzzy logic.

1 Dadone P. *Design Optimization of Fuzzy Logic Systems*: Ph. Dissertation. Blacksburg, Virginia; 2001. 197 p.

2. Fuzzification: the conversion of clear input values to fuzzy linguistic variables representing the predicted degree of originality of the project result, the level of resource sufficiency and the optimality of work planning in terms of project stage deadlines. Formulation of linguistic variables and composition of membership function(s) for them. Description of linguistic variables by membership functions.
3. Selection of a system of rules for handling linguistic variables in order to formulate a fuzzy logical conclusion.
4. Transformation of linguistic variables using a system of rules to obtain a fuzzy logical conclusion.
5. Defuzzification, which is the reverse transition from fuzzy logical inference to an output parameter, i.e., a generalized assessment of the planned project.
6. Obtaining the output, which is the degree to which the project complies with the customer's requirements and the contractor's capabilities, thereby satisfying both parties.

One of the parameters of a project is the uniqueness of the result obtained, its novelty, and exceptional originality (it has no analogues or surpasses existing solutions by offering fundamentally new ways of meeting the customer's requirements). The method uses the ratio of the number of original technical, scientific or other solutions to their total number in the project as a unit of measurement of project uniqueness. This value is represented by the letter α and lies within a set of possible values A: $\alpha \in A$. The corresponding linguistic variable is "Project uniqueness."

The second project parameter, β, represents the planned time interval for project implementation and its distribution across project stages. The input data is the ratio of the deadlines requested by the potential project contractor and those set by the project customer. The gradations for assessing compliance with the linguistic variable requirements are different degrees of sufficiency or insufficiency of time for project completion. The linguistic parameter "Sufficiency of time for project completion" is assessed using a scale with values from 0.0 to 1.0, where 0.0 represents a complete lack of compliance with the established deadlines and 1.0 represents full compliance with the contractors' and customer's needs.

The third clear input value, γ, is the ratio of the resources (in terms of volume and type) requested by the prospective project contractor and allocated by the project customer. The linguistic parameter "Resource sufficiency" establishes a scale for the fuzzy assessment of project resource provision and the optimal distribution of resources across project stages. The unit of measurement used to assess compliance with requirements is the level of resource sufficiency for project implementation, which is assessed on a scale from 0.0 to 1.0. Here, 0.0 represents complete insufficiency, while 1.0 represents full compliance with requirements.

The fuzzy logic method is employed to reconcile the assessments of the first and second parties during their interaction, thereby facilitating the attainment of a more objective and mutually acceptable assessment. The method requires three input parameters, which are clear values assessed by the customer and the prospective project contractor. This task is solved by fuzzification, i.e., converting the clear input values into linguistic variables. These variables combine the parameters into a set of fuzzy sets whose boundaries do not have clear, unambiguous values that are perceived and accepted by the interacting parties.

Thus, the uniqueness, originality, and novelty of a project may correspond to varying degrees with the requirements and assessments of the customer and contractor. This is because each party has different requirements for assessing the same parameters, project characteristics, and measures to ensure uniform measurements of the project's main characteristics. In an effort to win the contract, the prospective contractor often overestimates their capabilities and the level of the proposed project development, relying on previous experience of performing work that does not fully meet the requirements of the new project. Conversely, the customer, in an effort to minimize the risk of failing to achieve the project goals, is generally more demanding in terms of the planned project results and its key performance indicators. Therefore, in the fuzzy logic approach, there are two subsets: "high compliance" and "low compliance" with the requirements for the main project parameters. These reflect the positions of both the customer and the potential contractor.

There are no clear and unambiguous parameters or limits for indicators such as resource adequacy and the time interval for project implementation. The approach of assessing in terms of "fast/slow," "much/little," "expensive/cheap," and etc. does not bring the positions of the customer and the contractor any closer together when it comes to making decisions on the project.

The problem of combining estimates in the method under consideration can be solved by assigning the linguistic variables to the clear parameter "Uniqueness, originality, and novelty of project results," where α is "Proportion of original solutions in the project out of their total number," β is "Sufficiency of time for project implementation," and γ is "Level of sufficiency of resources for project implementation."

The result of combining the estimates should be the linguistic variable δ, which is defined as "compliance of the project with the customer's requirements and the contractor's capabilities."

The range of possible values in the assessment of project uniqueness corresponds to the fuzzy set A, which is a set of pairs of the form $<\alpha, \varphi_\alpha>$. The grade of membership of each element α of the fuzzy set in set A ($\alpha \in A$) is described by the membership function $\varphi_\alpha(A)$. This function maps each value α to a number within its possible value range. For the "Project uniqueness" parameter, this range is [0.0; 1.0], i.e., $\varphi_\alpha(A)$: A → [0.0; 1.0], where each α belongs to set A: $\forall\alpha \to \in A$. Here, ∀ is the quantifier of universality of properties for all α belonging to set A.

The linguistic variable "Project uniqueness" corresponds to the two extreme values in the range: "high," with a value of "1.0," and "low," with a value of "0.0," from the entire range of possible values of the fuzzy set A. Between these two extremes, there are many other values of the fuzzy set for this project parameter. The membership function $\varphi_\alpha(A)$ shows the extent to which parameter α, i.e., the project uniqueness assessment, has certain properties of subset A, with functions such that when α = 1.0, the degree of uniqueness, novelty and originality of the project is maximal, while α = 0.0 means that it is minimal. The assessment using fuzzy sets involves assigning a fuzzy value to one of the two subsets, α_{high} and α_{low}, and their respective membership functions, $\varphi_{\alpha high}(A)$ and $\varphi_{\alpha low}(A)$, These functions complement each other, together making up the full range of values of parameter α belonging to the fuzzy set A, as follows:

$$\varphi_{\alpha high}(A) + \varphi_{\alpha low}(A) = 1; \forall\alpha \to \in A. \quad (1)$$

The innovative nature of project activities consists, among other things, in the fact that the uniqueness, novelty and originality of the development are usually formed at the early stages of the project. Therefore, the membership functions of the "Project uniqueness" parameter in subsets α_h and α_l are best represented by the power function:

$$\varphi_{\alpha high}(A) = \alpha^n \text{ and } \varphi_{\alpha low}(A) = 1 - \alpha^n, \quad (2)$$

where *n* [0.0; 1.0] is the project innovation index, taking values from 0.0 to 1.0. The value of *n* indicates the degree of novelty, originality, and patentability of the scientific and technical solutions usually set out in project developments at the early stages, as well as in marketing, the search for and selection of new promising areas of research, and the development of innovative approach.

The membership function graphs for subsets α_h and α_l at the selected range of their possible values, A → [0.0; 1.0], for exponents $n = 0.7$, $n = 0.5$, and $n = 0.3$, are shown in Fig. 2.

The area on the graph bounded by the coordinate axes and the membership function line $\varphi_{\alpha high}(A)$ represents the subset of uniqueness with high levels of project novelty ratings, while the membership function line $\varphi_{\alpha low}(A)$ represents the subset with low levels of development originality ratings for which the project is rated as "not unique." The intersection of these subsets represents the subset with a mean estimate for this parameter.

The second project parameter, β, is the planned time interval for project implementation and its division into stages. The membership function of the linguistic variable "Sufficiency of time for project implementation" for the clear parameter "Time interval for project implementation" has the following gradations: "sufficient" and "insufficient." These correspond to the two fuzzy subsets of the total number of fuzzy sets, $\beta \in B$, corresponding to the planned deadlines for implementing project B:

$$\Psi_{\beta high}(B) = \beta^m, \quad \Psi_{\beta low}(B) = 1 - \beta^m. \quad (3)$$

The fuzzy subset $\beta_{low}(B)$ corresponds to insufficient time being planned for project completion. The subset $\beta_{high}(B)$ corresponds to a time interval that is sufficient for project completion, as well as an optimal distribution of this time across the project's stages. The maximum value of the membership function "Sufficiency of time for project implementation" is 1.0. The ratio of the membership functions $\Psi_{\beta low}(B)$ and $\Psi_{\beta high}(B)$ for the subsets $\beta_{low}(B)$ and $\beta_{high}(B)$ respectively, is given by:

$$\Psi_{\beta low}(B) + \Psi_{\beta high}(B) = 1; \forall\beta \to \in B. \quad (4)$$

Given the unevenness and considerable uncertainty in the accuracy of the time distribution across project stages, confidence in the assessment of the parameter "Sufficiency of time for project implementation" belonging to the "sufficient" subset increases nonlinearly as the time interval for project implementation approaches its highest values. Conversely, the grade of membership in the "insufficient" subset also decreases nonlinearly. This type of dependence (Fig. 3) for the subsets $\Psi_{\beta low}(B)$ and $\Psi_{\beta high}(B)$ corresponds to power functions with exponents $m > 1$.

The degree indicator *m*, being the "fuzziness indicator," represents the level of requirements for assigning a linguistic parameter to the "sufficient" or "insufficient" subsets. The higher its value, the more the linguistic parameter belongs to a particular subset at higher values of the project completion time β, and, accordingly, the higher the level of certainty and rigor in the assessment of the linguistic parameter. When $m = 0$, i.e., for the linear membership function, the fuzzy set of values of the parameter "Sufficiency of time for project implementation" is divided into two equal fuzzy subsets. As m increases, the fuzzy and crisp estimates tend to converge and become equal at $\beta = 1$.

In the graph (Fig. 3), the area bounded by the coordinate axes and the lines $\Psi_{\beta high}(B)$ and $\Psi_{\beta low}(B)$ is a subset for which the time interval for project completion is estimated to be sufficient or insufficient, respectively.

The intersection of these two areas represents the mean estimate of the sufficiency of time for project implementation.

The third clear input value, γ, is the ratio of the volume and types of resources requested by the prospective project contractor and allocated by the project customer. The membership function of the linguistic variable "sufficiency of resources" according to the "Ratio of resources" parameter (volume and types) requested by the prospective project contractor and allocated by the project customer has two gradations: "sufficient" and "insufficient."

These correspond to two fuzzy subsets of the total number of fuzzy sets $\gamma \in \Gamma$, which corresponds to the ratio of resources Γ requested by the prospective project contractor and allocated by the customer. Assessments of resource provision as "insufficient" for the performance of project work are represented by the fuzzy subset $\chi_{\gamma low}(\Gamma)$; on the other hand, assessments of the sufficiency of resources for the performance of project work are represented by the subset $\chi_{\gamma high}(\Gamma)$, as follows:

$$\chi_{\gamma low}(\Gamma) + \chi_{\gamma high}(\Gamma) = 1; \ \forall\gamma \rightarrow \in \Gamma. \qquad (5)$$

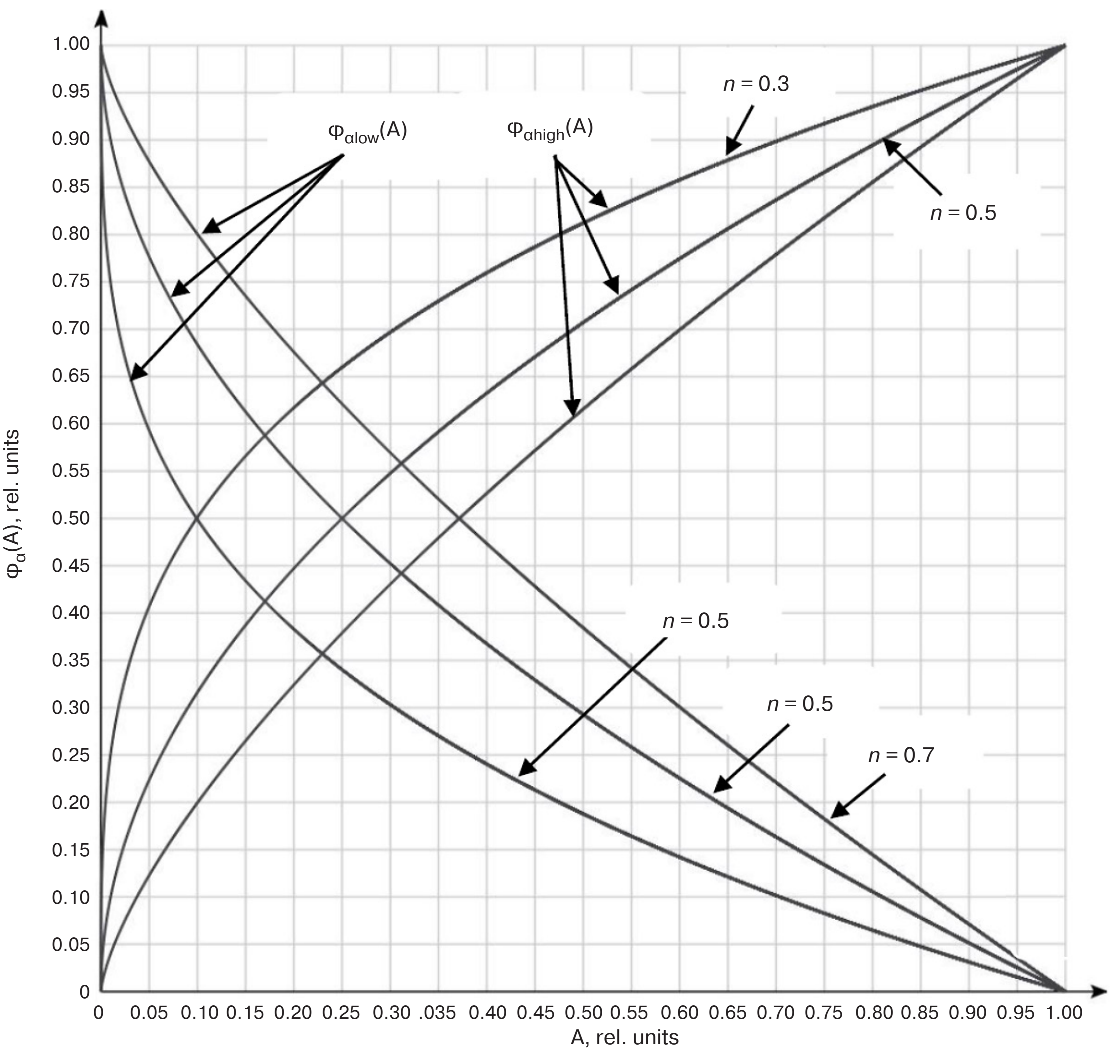

Fig. 2. Membership functions $\varphi_\alpha(A)$ of the linguistic variable "Project uniqueness" in subsets $\varphi_{\alpha high}(A)$ being "unique" and $\varphi_{\alpha low}(A)$ being "not unique" for various indicators of project innovativeness n

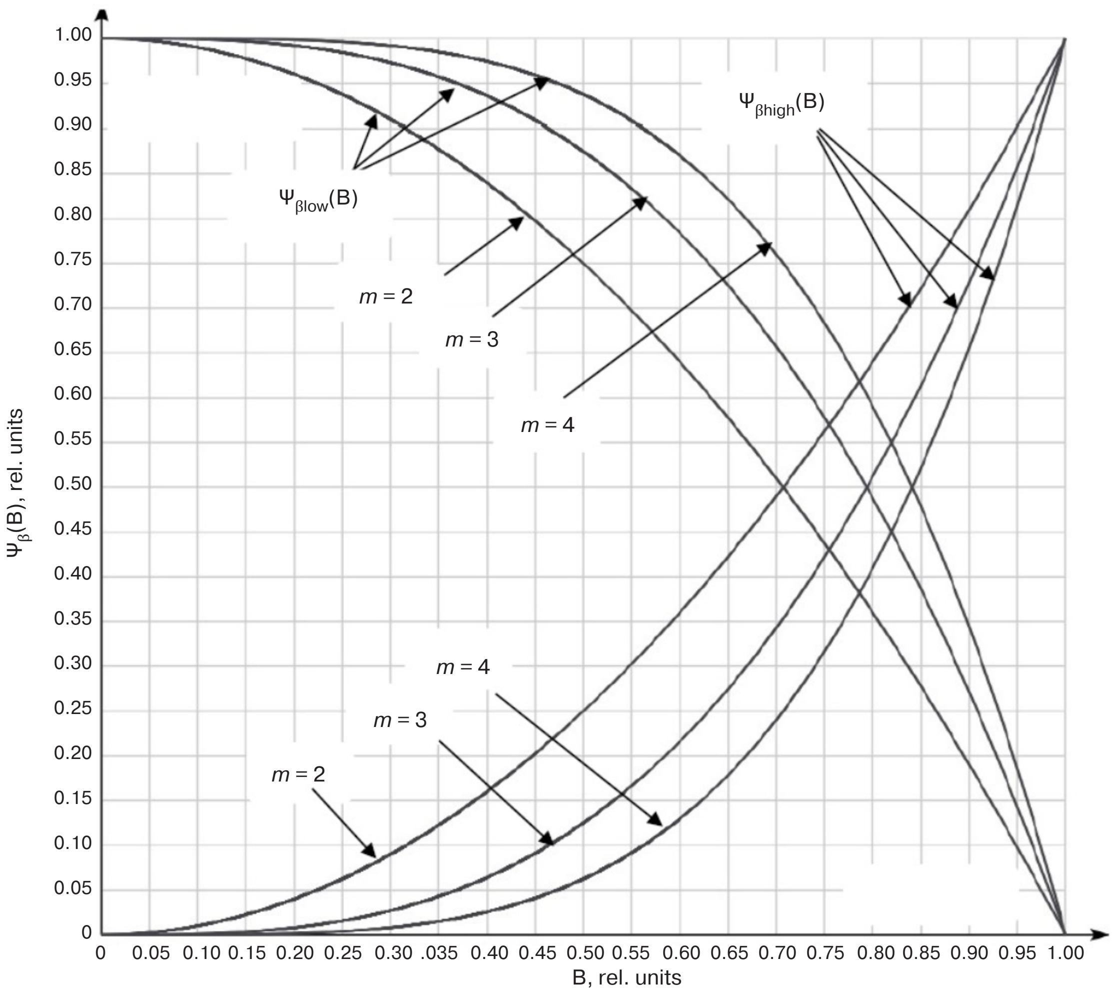

Fig. 3. Membership functions $\Psi_l(B)$ of the linguistic variable "Sufficiency of time for project implementation" in subsets $\Psi_{\beta high}(B)$ being "sufficient" and $\Psi_{\beta low}(B)$ being "insufficient" for various indicators of the degree of certainty of estimates *m*

A distinctive feature of providing material resources for a project is the uneven distribution of these resources across the stages of the project. The creative potential and intellectual resources of contractors are used at the initial stages of project activity, while the main consumption of material resources is concentrated at the stages of development and research, modelling, prototyping, measurements, and testing of prototypes and other results of project activity. At the final stages, which involve documentation and acceptance, the project is supported by information along with organizational and management resources. The distribution of material and intellectual resources across the project stages is best described by the membership function of the linguistic variable "Sufficiency of resources" in sigmoid form (Fig. 4), as follows:

$$\chi_{\gamma high}(\Gamma) = 1 - e^{-2k\gamma}; \chi_{\gamma low}(\Gamma) = e^{-2k\gamma}, \qquad (6)$$

where k is the indicator of the increase in the need for material resources at different stages of the project.

The linguistic parameter δ, "Compliance of the project with the customer's requirements and the contractor's capabilities," is evaluated on a three-point scale: "does not comply," "partially complies," and "complies." This parameter is a combination of the assessments of the three linguistic variables discussed above: "Originality of the project," "Sufficiency of resources," and "Sufficiency of time for project implementation."

The parameter "Compliance of the project with the customer's requirements and the contractor's capabilities" incorporates two assessments from each of the parties involved: the project customer organization and the contractor organization. The incorporation of these assessments increases the objectivity of the final assessment.

In order to analyze the linguistic variable "Compliance of the project with the customer's requirements and the contractor's capabilities" in the presented fuzzy evaluation model, the following system of rules, incorporating the logical operators "AND" and "OR," is selected from the possible options [15].

The logical operator “AND” denotes the intersection of three fuzzy sets with the intersection membership function:

$$\delta_{A\cap B\cap \Gamma} = \min(\varphi_\alpha(A); \psi_\beta(B); \chi_\gamma(\Gamma)). \qquad (7)$$

The logical operator “OR” represents the union of three fuzzy sets. The membership function in this union is as follows:

$$\delta_{A\cap B\cap \Gamma} = \max(\varphi_\alpha(A); \psi_\beta(B); \chi_\gamma(\Gamma)). \qquad (8)$$

A system of three rules is applied to defuzzify the fuzzy assessment based on these three linguistic variables and obtain an evaluation of the generalized indicator “Compliance of the project with the customer’s requirements and the contractor’s capabilities.” The first rule is:

R_1: if $(\alpha \in \alpha_{high})$ AND $(\beta \in \beta_{high})$ AND $(\gamma \in \gamma_{high})$, then $\Delta \in \delta_{high}$.

This means that if the assessments of all three linguistic parameters (“Project uniqueness,” “Sufficiency of time,” and “Sufficiency of material resources”) belong to subsets with a “high” compliance, then the assessment of the “Compliance of the project with the customer’s requirements and the contractor’s capabilities” indicator, Δ, belongs to the “high” subset.

The second rule is:

R_2: if $(\alpha \in \alpha_{low})$ AND $(\beta \in \beta_{low})$ AND $(\gamma \in \gamma_{low})$, then $\Delta \in \delta_{low}$.

This means that if all three assessments of the project parameters in terms of uniqueness, sufficiency of time and resources for project implementation, and compliance with requirements belong to the “low” subsets, then the compliance assessment of the “Compliance of the project with the customer’s requirements and the contractor’s capabilities” indicator Δ belongs to the “low” subset.

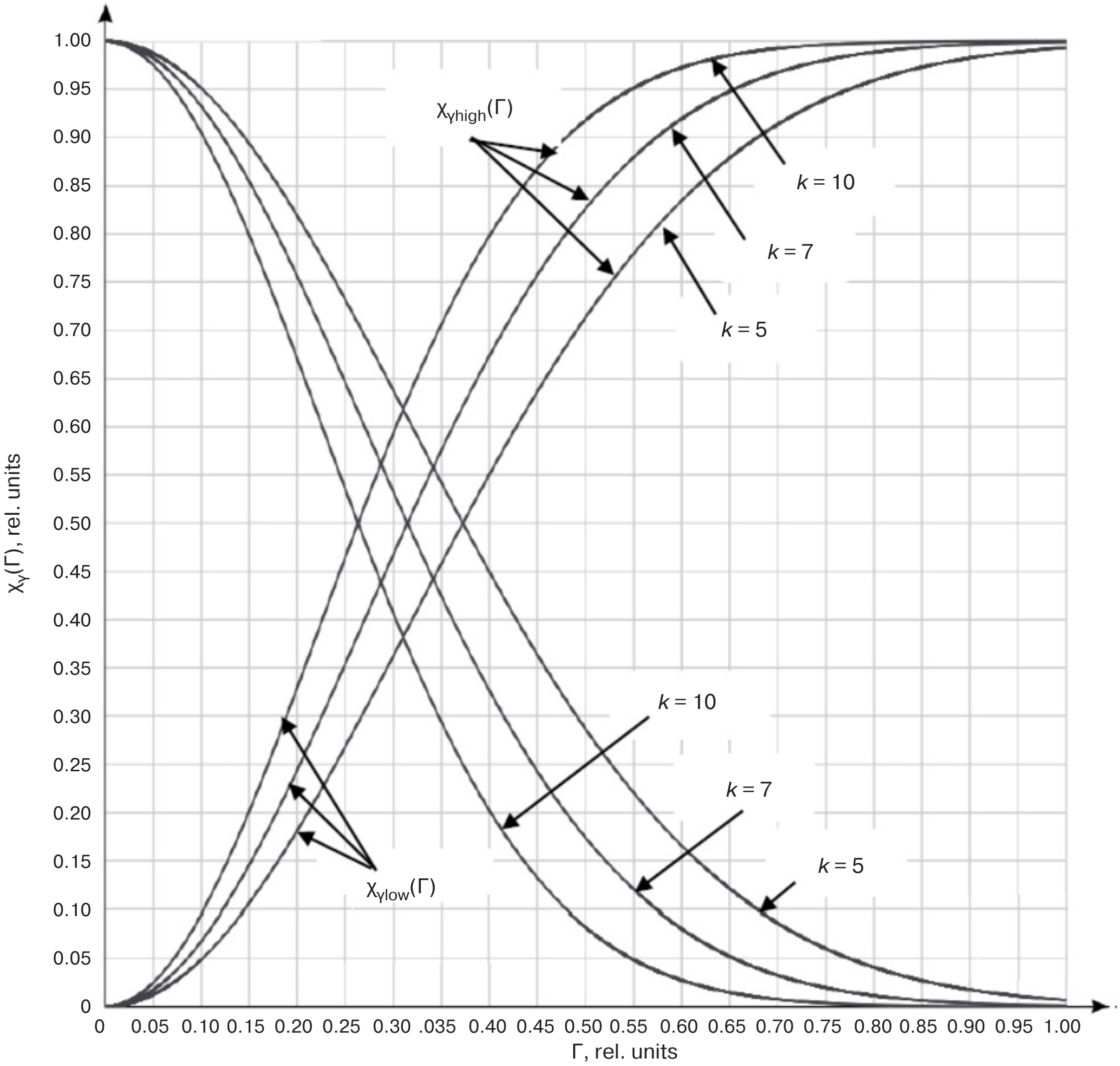

Fig. 4. Membership functions of the linguistic variable “Sufficiency of resources” for different values of the indicator *k* of increased demand for material resources at project stages

It follows from rule R_3 that:

if $(\alpha \in \alpha_{high})$ AND $(\beta \in \beta_{high})$ AND $(\gamma \in \gamma_{low})$ OR
OR $(\alpha \in \alpha_{low})$ AND $(\beta \in \beta_{high})$ AND $(\gamma \in \gamma_{high})$ OR
OR $(\alpha \in \alpha_{high})$ AND $(\beta \in \beta_{low})$ AND $(\gamma \in \gamma_{high})$,
then: $\Delta \in \delta_{m}$.

This means that, if the assessment of at least one of the three linguistic parameters of the project belongs to the "low" subset and the other two belong to the "high" subset, the "Compliance of the project with the customer's requirements and the contractor's capabilities" parameter, Δ, belongs to the "mean" subset.

The fourth rule considers another possible combination of the project's fuzzy linguistic parameter values:

R_4: if $(\alpha \in \alpha_{high})$ AND $(\beta \in \beta_{low})$ AND $(\gamma \in \gamma_{low})$ OR
OR $(\alpha \in \alpha_{low})$ AND $(\beta \in \beta_{low})$ AND $(\gamma \in \gamma_{high})$ OR
OR $(\alpha \in \alpha_{low})$ AND $(\beta \in \beta_{high})$ AND $(\gamma \in \gamma_{low})$,
then: $\Delta \in \delta_{low}$.

This means that if one of the three linguistic parameters of the project belongs to the subset with a high compliance, and the other two belong to subsets with a low compliance, then the "Compliance of the project with the customer's requirements and the contractor's capabilities" parameter, Δ, belongs to the subset with a low compliance, or "does not comply."

The conversion of fuzzy logical conclusions according to established rules to clear values corresponding to the management system assessment (defuzzification) provides an assessment of the parameter "Compliance of the project with customer requirements and contractor capabilities," taking into account the assessments of both parties involved in the project.

For example, let us consider the assessment of this parameter based on input data, i.e., the expert assessment of three parameters of the planned project based on the contractor's and customer's previous experience.

Thus, if the input data is an expert (i.e., clear) assessment of the uniqueness of the project with a value of 0.75, then the membership function value for project uniqueness in the "high" compliance subset, as calculated by formula (2) for a borrowing level of $n = 0.7$, is 0.817. For $n = 0.5$, the value is 0.866, while for $n = 0.3$, the corresponding value is 0.903. Similarly, for the same expert assessment of the possibility of achieving project uniqueness with an index of 0.75, the value of the membership function in the "low" subset is 0.183 for $n = 0.7$, 0.134 for $n = 0.5$, and 0.083 for $n = 0.3$.

For an expert assessment of the input parameter (i.e., the ratio of the time interval requested by the contractor and allocated by the customer for project implementation), $\beta = 0.80$, the value of the "Sufficiency of time for project implementation" membership function in the "sufficient" subset calculated using formula (3) is 0.64 for the "fuzziness index," $m = 2$, 0.51 for $m = 3$, and 0.4 for $m = 4$. For the same input parameter value, $\gamma = 0.80$, the membership function value in the "insufficient" subset is 0.36 for $m = 2$, 0.49 for $m = 3$, and 0.59 for $m = 4$.

The values of the membership function of the linguistic variable "Sufficiency of resources" in the subset "sufficient" for the parameter $\gamma = 0.65$, calculated using formula (4) with different indicators of increased need for material resources at project stage k, are as follows: 0.88 for $k = 5$; 0.93 for $k = 7$; and 0.98 for $k = 10$.

Accordingly, the membership grade of the linguistic variable "Sufficiency of material resources" in the "low" subset is estimated as 0.12 for $k = 5$; 0.07 for $k = 7$; and 0.02 for $k = 10$.

The resulting membership function values for each project parameter show that they all belong to subsets indicating high compliance with the project uniqueness requirements, as well as sufficient time and material resources. The defuzzification and evaluation of the membership of the parameter "Compliance of the project with the customer's requirements and the contractor's capabilities" in the "high" subset is determined by rule R_1 with the logical operator "AND," as follows:

$$\text{for } n = 0.7, m = 2, k = 5: \ \delta_{A\cap B\cap \Gamma} = \min(\varphi_{high}(A); \psi_{high}(B); \gamma_{high}(\Gamma)) = \min(0.82; 0.64; 0.88) = 0.64;$$

$$\text{for } n = 0.5, m = 3, k = 7: \ \delta_{A\cap B\cap \Gamma} = \min(\varphi_{high}(A); \psi_{high}(B); \gamma_{high}(\Gamma)) = \min(0.87; 0.51; 0.93) = 0.51;$$

$$\text{for } n = 0.3, m = 4, k = 10: \ \delta_{A\cap B\cap \Gamma} = \min(\varphi_{high}(A); \psi_{high}(B); \gamma_{high}(\Gamma)) = \min(0.90; 0.41; 0.98) = 0.41.$$

According to rule R_2, the assessment of the membership grade of the linguistic variable "Compliance of the project with the customer's requirements and the contractor's capabilities" in the fuzzy subset "low" yields the following results:

$$\text{for } n = 0.7, m = 2, k = 5: \ \delta_{A\cap B\cap \Gamma} = \min(\varphi_{low}(A); \psi_{low}(B); \gamma_{low}(\Gamma)) = \min(0.18; 0.46; 0.12) = 0.12;$$

for $n = 0.5$, $m = 3$, $k = 7$: $\delta_{A\cap B\cap \Gamma} = \min(\varphi_{low}(A); \psi_{low}(B); \gamma_{low}(\Gamma)) = \min(0.13; 0.49; 0.07) = 0.07;$

for $n = 0.3$, $m = 4$, $k = 10$: $\delta_{A\cap B\cap \Gamma} = \min(\varphi_{low}(A); \psi_{low}(B); \gamma_{low}(\Gamma)) = \min(0.10; 0.59; 0.02) = 0.02.$

This means that the membership grade of the parameter "Compliance of the project with the customer's requirements and the contractor's capabilities" is higher in the "high" subset than in the "low" subset. For the "high" subset, the estimated grades of membership for various factors affecting project implementation are 0.64, 0.51, and 0.41 points, while for the "low" subset they are 0.12, 0.07, and 0.02 points under the same conditions.

The membership of the indicator "Compliance of the project with the customer's requirements and the contractor's capabilities" in the subset "mean" is determined by rule R_3 using the following ratios:

for $n = 0.7$, $m = 2$, $k = 5$:

$$\delta_{A\cap B\cap \Gamma} = \max(\min(\varphi_{low}(0.75); \psi_{high}(0.80); \gamma_{high}(0.65)); \min(\varphi_{high}(0.75); \psi_{low}(0.80); \gamma_{high}(0.65));$$
$$\min(\varphi_{high}(0.75); \psi_{high}(0.80); \gamma_{low}(0.65))) = \max(\min(0.18; 0.64; 0.88);$$
$$\min(0.87; 0.64; 0.93); \min(0.82; 0.46; 0.12)) = \max(0.18; 0.46; 0.12) = \mathbf{0.46};$$

for $n = 0.5$, $m = 3$, $k = 7$:

$$\delta_{A\cap B\cap \Gamma} = \max(\min(\varphi_{low}(0.75); \psi_{high}(0.80); \gamma_{high}(0.65)); \min(\varphi_{high}(0.75); \psi_{low}(0.80); \gamma_{high}(0.65));$$
$$\min(\varphi_{high}(0.75); \psi_{high}(0.80); \gamma_{low}(0.65))) = \max(\min(0.13; 0.51; 0.93);$$
$$\min(0.82; 0.49; 0.88); \min(0.87; 0.51; 0.07)) = \max(0.13; 0.49; 0.07) = \mathbf{0.49};$$

for $n = 0.3$, $m = 4$, $k = 10$:

$$\delta_{A\cap B\cap \Gamma} = \max(\min(\varphi_{low}(0.75); \psi_{high}(0.80); \gamma_{high}(0.65)); \min(\varphi_{high}(0.75); \psi_{low}(0.80); \gamma_{high}(0.65));$$
$$\min(\varphi_{high}(0.75); \psi_{high}(0.80); \gamma_{low}(0.65))) = \max(\min(0.10; 0.41; 0.98);$$
$$\min(0.90; 0.59; 0.98); \min(0.90; 0.41; 0.02)) = \max(0.10; 0.59; 0.02) = \mathbf{0.59}.$$

The estimated values of the membership functions of the parameter "Compliance of the project with the customer's requirements and the contractor's capabilities" in the "high," "mean," and "low" subsets, when calculated according to rules R_1, R_2, and R_3, yield the following results:

for $n = 0.7$, $m = 4$, $k = 10$: 0.64; **0.46**; 0.12;
for $n = 0.5$, $m = 3$, $k = 7$: 0.51; **0.49**; 0.07;
for $n = 0.3$, $m = 4$, $k = 10$: 0.41; **0.59**; 0.02.

By comparing the values obtained for the degree of agreement between the customer and contractor's assessments of the planned project the following output is achieved:

- the customer decides on the prospects and feasibility of setting up work on the project, taking various influencing factors into account, and to review and change the project requirements, the allocated resources, and the deadlines;
- the contractor identifies additional opportunities to implement the project under the conditions proposed by the customer.

2. METHODOLOGY FOR ASSESSING THE COMPLIANCE OF THE PROJECT WITH THE CUSTOMER'S REQUIREMENTS AND CONTRACTOR'S CAPABILITIES USING AN APPROACH BASED ON FUZZY SET THEORY

The application of the above method for assessing the compliance of the project with the customer's requirements and the contractor's capabilities, while taking into account the perceptions of both interacting parties, consists of a sequence of stages which are presented in Fig. 1[2] [15, 16] that comprises:

- identifying the project, its goals and purpose, and the planned results, as well as describing the project's most significant and essential properties, parameters and characteristics (in particular, its uniqueness, scope and types of resources, and time frame);

[2] Dadone P. *Design Optimization of Fuzzy Logic Systems*: Ph. Dissertation. Blacksburg, Virginia; 2001. 197 p.

- formulating the task of obtaining a joint assessment of the project's compliance with the customer's requirements and the contractor's capabilities, which will serve as the basis for decisions regarding the project's feasibility and advisability;
- determining the values of the input parameters of the modelled project using calculations and/or expert assessment, and establishing them for further fuzzification;
- fuzzification, i.e., the transition to fuzziness and the conversion of clear input values (the predicted degree of originality of the project result, the level of resource sufficiency, and the project completion dates) into fuzzy linguistic variables;
- formulating linguistic variables and defining their membership functions; describing linguistic variables using membership functions;
- selecting a system of rules for handling linguistic variables in order to formulate fuzzy logical conclusions.
- transforming linguistic variables using a system of rules to obtain fuzzy logical conclusions;
- defuzzification – reverse transition from a fuzzy logical conclusion to a clear value (the output parameter), i.e., a generalized assessment of whether the planned project complies with the customer's requirements and the contractor's capabilities;
- obtaining an output, i.e., a quantitative value of the project's compliance with the customer's requirements and the contractor's capabilities, with acceptance by both parties.

When supplemented with requirements for contractor competence, the documented methodology can serve as a tool for making and implementing decisions regarding the management of project activities, including research and development work [12–14].

CONCLUSIONS

The presented method and technique allow projects to be evaluated, whether they are planned for implementation or have already been completed, based on the results obtained. The evaluation of project management's individual stages using the presented method will also improve its effectiveness, as will further detailing, breaking down, and evaluating individual types of work if necessary.

Along with the corresponding methodology for its application in adopting and implementing decisions based on the generalized assessment obtained, the application of this analytical method, which represents an alternative to expert methods, will ensure greater validity, objectivity and effectiveness.

The documented evaluation procedure ensures reproducible results based on the identity and repeatability of actions by different contractors. This reduces dependence on subjective qualities and increases the objectivity of the evaluation, as well as ensuring comparability with previous evaluation results for similar projects. The use of consistent criteria and procedures also permits a comparison of the results of project activity assessments by different contractors.

A promising development for the method and its associated methodology would be to apply membership functions to the analysis of fuzzy systems. This would take into account a greater number of characteristics of projects and their components, as well as determining the potential of contractors and customer requirements. The increasing volume of data and the resulting complexity of computational processes will require new resources to process information for both assessment and solution development. One effective solution to this problem could be to apply digital and artificial intelligence technologies to the processes of assessment and development of management decisions.

Due to the invariance of the project activity attributes criteria, the presented method and techniques recommend themselves as a universal tool for managing various types of projects and activities, including research and development work.

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