Запропоновано метод портфельного інвестування, що дозволяє формувати оптимальну структуру портфеля з урахуванням ступенів задоволеності запитів груп зацікавлених сторін, ризиків і невизначеності зовнішнього і внутрішнього середовища. Розглянуто модель, що представляє собою задачу нечіткого нелінійного програмування. В якості цільової функції використовується зважене середнє корисностей проектів. Корисності проектів являють собою мультиплікативні функції типу Кобба-Дугласа, що використовують поряд з фінансовими показниками експертні вербальні оцінки якісних показників задоволеності запитів стейкхолдерів, перетворені в нечіткі числа. Показники ступенів в даній функції відображають важливість стейкхолдерів для організації з точки зору існуючого ресурсного обміну між компанією та стейкхолдером і ступеня взаємного впливу. Кількісний облік ризиків здійснюється на основі підходу Г. Марковіца і методу сценаріїв. Невизначеність і недолік інформації для показника економічної ефективності проектів моделюється за допомогою використання нечітко-множинного підходу. Обмеження в моделі також нечіткі. Перехід від нечіткої задачі оптимізації до чіткої проводиться шляхом завдання рівнів достовірності для цільової функції і обмежень. Вибір певного рівня достовірності також дозволяє в деякій мірі враховувати невизначеність, що, в свою чергу, впливає на склад портфеля. Рішення моделі знаходиться чисельно з використанням запропонованого методу, що дозволяє на основі нечітких корисностей знаходити нечітку цільову функцію та обмеження, і переводити нечітку модель в чітке завдання квадратичного програмування при заданих рівнях достовірності. Розглянуто приклад формування оптимального портфеля інвестиційних проектів рибопромислового підприємства

Ключові слова: оптимізація портфеля проектів, облік запитів стейкхолдерів, функція корисності, нечітка модель

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DEVISING A FUZZY STAKEHOLDER MODEL FOR OPTIMIZING THE PORTFOLIO OF PROJECTS AT A FISHING INDUSTRIAL ENTERPRISE TAKING RISKS INTO ACCOUNT

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1. Introduction

The success of operation of most modern large organizations is determined by their ability to meet the requirements of multiple stakeholders. In this regard, organizations are faced with the need to take into account multiple and often conflicting interests of stakeholders during designing and implementation of development strategies. The main tool for the implementation of the strategy is the investment program, consisting of a particular set (portfolio) of projects competing for shared resources.

Traditional methods for project portfolio selection are based on the use of various financial indicators, which, however, do not always are key indicators both in terms of successful implementation of a project, and in terms of achieving the strategic objectives of an organization [1]. In this regard, when solving the problem of portfolio investment, it is necessary to take into account, along with financial indicators, qualitative indicators, reflecting the value (utility) of potential projects for stakeholders. This utility can be expressed in an increase in stakeholders' satisfaction with relationships with an organization as a result of the project implementation.

In this context, it is a relevant problem to develop the methods for portfolio investment, which could make it possible to:

– reach maximum integral advancement on satisfaction of basic needs of stakeholders of an organization when selecting a portfolio of projects;

– make the best use of the available resources;

– take into account the uncertainty of external and internal environment, affecting the achievement of results.

2. Literature review and problem statement

Modern studies on optimization of project management actively use the theory of stakeholders. In papers [2–4], both systematization in the theoretical aspects of the theory of stakeholders, and the application of the theory to practice in specific optimization models are offered. In particular, article [2] proposes the concept of "shadows of the context" to analyze stakeholders in project management. It is supposed that based on understanding the stakeholder views on the past, present and future, it is possible to enhance the quality of prediction of stakeholders' behavior and to implement effective control during the implementation of a particular project. We imply by stakeholders' behavior their actions against or in favor of a project and possible resource contribution to a project. In this case, however, there is a lack of tools to measure the "shadows of the context". The development of such tools would make it possible to coordinate better the behavior of stakeholders with the needs of a project. Paper [3] considered the priorities for management of a company by stakeholders in terms of attracting potential investors. The experimental study of how and based on what factors potential investors react to prioritizing the interests of owners and other stakeholders in company management. It was shown that there are at least two types of stakeholders, whose interests are mutually exclusive. It is clear, however, that the interests of stakeholders, belonging to the second group are not homogeneous and, in most cases, contradictory, if not mutually exclusive. In this regard, there arises a need to develop the tools that allow taking into account the conflicting interests of different groups of stakeholders in forming the project portfolio. Article [4] explores the involvement (inclusion) of stakeholders within a project. It was shown that increasing inclusiveness of stakeholders in project, on the one hand, increases the probability of more engaged and satisfied stakeholders. On the other hand, the risk of losing attention to those stakeholders who have the most important resources for survival and progress of a project increases. In addition, the risk of frustration of stakeholders due to escalating expectations and inability to accept conflicting demands and wishes increases. In this regard, we need the tools of formation of a projects' portfolio that not only take into account contradictory interests of different stakeholders, but also their expectations for an organization.

In article [5], the authors present the model for calculating the cost of a project from the perspective of each stakeholder. As a result, a project gets a set of estimates from each stakeholder. However, for a person making a decision on the inclusion of a project to the portfolio, this set of estimates may be inconvenient to perceive due to different understanding of the value of a project by different stakeholders. Value is differently interpreted and evaluated by various stakeholders, who can influence the decision-making processes [6]. Types of values, to which managers and stakeholders orient may vary, depending on organizational strategies and objectives [7]. In this respect, there appear special in-depth thematic studies focused on understanding how differently stakeholders perceive and express the value and how the value is identified in project portfolios [8]. However, in these works the value of projects is not related to established relationships of an organization and stockholders and their changes as a result of these projects' implementation.

The identification of stakeholders themselves is also an important issue when dealing with the optimization of the portfolio of actual projects. In article [9], the model of evaluating and selecting stakeholders in complex business networks during implementation of a large investment project was proposed. The choice of stakeholders is based on multi-criteria cooperation function. However, the proposed function evaluates only the resource contribution of the partners of an organization. The utility of a project for stakeholders is not taken into account. In practice, the company working with actual projects rarely faces the problem of the choice of stakeholders. In such companies, the combination of stakeholders is determined by the external environment and market conditions. In view of this, a company must be flexible in relation to conditions of external environment and take into consideration social criteria in selecting projects. The issues of corporative social responsibility are considered in papers [10, 11]. However, in [10], in the frameworks of a multi-criteria optimization problem of the portfolio formation, in addition to financial criteria and their risks, the interests of one more stakeholder – "society" – are taken into consideration and only in the aspect of jobs creation. The authors propose to consider in future taking into consideration the interests of this stakeholder in other aspects, such as "environmental friendliness" and "sustainable development". Article [11] applies the approach, taking into account the use of the principles of corporative social responsibility in developing strategic action plans implemented through strategic activities (projects). This allows considering the levels of goals attaining, achieved during the implementation of projects as utilities of these projects. Such approach makes it possible to take into consideration projects' utility for any number of stakeholders whose interests were taken into account during designing the strategy maps. However, the established relationships of an organization and stakeholders and their probable changes as a result of the project implementation is not taken into account in this paper.

Along with the theory of stakeholders, the application of fuzzy sets is actively promoted in portfolio investment. This is related to the nature of certain constraints when selecting projects (considerable difficulty of their quantitative estimation) and to the desire of experts and decision-makers to operate verbal estimates. Paper [12] examined the existing and proposed new approaches of using fuzzy logic in modeling. The fuzzy approach seems a promising direction, allowing modeling the uncertainty of verbal expert estimates of the model parameters, future results of projects implementation and possible risks based on representation of parameters and functional dependencies in the form of fuzzy numbers [13–15]. The obtained fuzzy optimization problems require special solutions. However, the lack of examples of approbation of the proposed methods and approaches in real projects and portfolios creates serious difficulties in their further use in optimization models.

Fuzzy optimization models with fuzzy objective functions and constraints allow varying the results when assigning different exogenously established satisfaction degrees [16]. It gives a decision-maker greater flexibility, which is particularly important when choosing and planning the integrated project portfolio [17]. On the other hand, such models allow taking into account not only the risks themselves, but also the inclination to risk of a decision maker, which is expressed in different approaches to choosing a portfolio [18].

The theory by H. Markowitz remains the most common theory of portfolio optimization. A lot of modern models and optimization methods were developed based on it. Thus, in article [19], the model of portfolio optimization by Markowitz was explored and, as an alternative, 3 kinds of optimization modeling, which take into account not only budget constraints, but also a constraint on resources and time, were proposed. However, only financial indicators of the project portfolio (*NPV*) were assessed in this article, and it was noted that it is appropriate to take into consideration non-financial indicators of projects' portfolio evaluation. Paper [20] proposed the model of minimizing the risk of significantly low incomes using the analytical hierarchical process. In the model, project risks are ranked both in terms of meeting strategic objectives of an organization, and in terms of the type of risk: technological, economic, and political. However, this approach, to representation the portfolio risk only indirectly takes into account the needs of stakeholders.

Thus, it is possible to state about the absence of fuzzy methods of formation of a portfolio of the projects that take into account the impact of potential projects on the relations of an organization with its all key stakeholders considering the importance of stakeholders for an organization, on the one hand, and the significance of conflicting requirements of stakeholders to an organization for stakeholders themselves, on the other hand.

In this regard, as a continuation of the research by the authors [21, 22], it is proposed to modify fuzzy models and the algorithms of solving them, taking into account the changes in parameters of a project significance to each stakeholder, depending on the scenario. Along with taking into account social and state significance of projects, the possibility to take into account the needs of other stakeholders was introduced to the model.

3. The aim and objectives of the study

The aim of this study is to develop the economic-mathematical method for the formation of an optimal enterprise projects portfolio, contributing to the satisfaction of the requirements of main stakeholders, taking into account their relevance to an organization.

To achieve the aim, the following tasks were set:

– to develop a fuzzy optimization model that allows the maximal achievement of integrated utility of the portfolio, which is characterized by a degree of satisfaction, estimation of expectations and degree of desire of changes of each stakeholder;

– to propose the method for finding a solution to the model, given that the objective function of the quadratic programming problem and its constraints are fuzzy;

– to explore the computational aspects of application of the fuzzy model under condition of actual operation of a fishing production enterprise.

4. Fuzzy portfolio optimization model taking into account the stakeholder requirement

The project portfolio optimization problem is considered in the stakeholder paradigm, which takes into consideration the relations with stakeholders groups, resource constraints (financial and non-financial) and risks. To take into account uncertainties and risks, we will use the scenario-based approach within the theory of portfolio investment by H. Markowitz [23].

We will consider a company, for which it is possible to separate K stakeholder groups. Stakeholders' relationships with the company line up around resource sharing between them and are characterized by a degree of satisfaction with obtained resources, assessment of mutual expectations, the degree of desire of changes, and degree of mutual influence [24]. To formalize the process of formation of an optimal portfolio of investment projects, we will characterize each project P_1, $P_{2,}$..., P_N by utility function, which includes the significance of a project for each of the stakeholders. Significance of a project for a separate stakeholder is associated with the degree of satisfaction of his requirements to the company.

The uncertainty associated with possible changes of internal and external environment generates risks. These risks may relate to each separate project and the portfolio in general. We will use the scenario-based approach for quantitative description of such risks. We explore L scenarios of C_1, $C_{2,}$..., C_L, probabilities of implementation of which the likelihood of which are p_1, $p_{2,}$..., p_L. Scenarios characterize possible states of internal and external environment. Probabilities of scenarios express the degree of experts' confidence in certain changes in the external and internal conditions and are assigned in the form of fuzzy numbers. To do this, the verbal estimate, given by experts (in assigned linguistic scales), are converted into fuzzy numbers, which are first aggregated (taking into account the competence of experts) and then normalized [25].

The utility of the n-th project during implementation of the l-th scenario will be assigned as follows:

$$u_n^l = u(\Pi_n, C_l) = \left(S_{n1}^l\right)^{\alpha_1}\left(S_{n2}^l\right)^{\alpha_2}\ldots\left(S_{nK}^l\right)^{\alpha_K},$$

$$0 \le \alpha_i \le 1, \quad i = \overline{1, K}, \tag{1}$$

where S_{nk}^l is the significance of the n-th project for the k-th stakeholder during implementation of the l-th scenario. Power dependence by variables of significances models the effect of utility saturation by these variables.

Equation (1) shows that the project utility is determined by its significance to all major stakeholders. The more significant is a project to stakeholders (taking into account their significance for an organization), the greater its utility. In this case, the role of weight factors of stakeholders is played by exponents (α_i). Significance of a project for each stakeholder is determined by the consequences of the project implementation in terms of the impact on the interests of stakeholders. Because under different scenarios, these effects are different, the projects' utility for each scenario is different.

We will consider the following set of stakeholders of a company as the basic variant: "owners and investors", "state", "staff", "customers", "society", and "business community". To determine the significance of a project for a specific stakeholder, we will assign for each of them a set of parameters Z_k^m that describe the stakeholder requirements and their importance (from the stakeholder point of view) w_k^m. Then significances of projects are found as weighted average of the values for parameters

$$S_{nk}^l = \sum_{m=1}^{M_k} w_k^m \cdot Z_k^m(\Pi_n, C_l), \tag{2}$$

where k is the number of a stakeholder; n is the project number; l is the scenario number; w_k^m is the importance of the m-th parameter characterizing the significance of a project for the k-th stakeholder; $Z_k^m(\Pi_n, C_l)$ are the value of parameter Z_k^m for project P_n and scenario S_l.

Parameter values for each project and scenario are determined by the expert method. It is much easier for experts to state their subjective views and feelings about the values of the characteristics of projects for stakeholders in the form of verbal statements, rather than as a crisp number in a certain scale. For quantitative formalization of verbal estimates, we will apply the fuzzy-multiple approach and transform these terms into fuzzy trapezoidal numbers. To do this, consider the following term-set of the linguistic variable that describes the parameter values:

{Very low; Low; Average; High; Very high},

and corresponding trapezoidal membership functions:

$$\mu_1(x)=(0;0;1.5;2.5),$$

$$\mu_2(x)=(1.5;2.5;3.5;4.5),$$

$$\mu_3(x)=(3.5;4.5;5.5;6.5),$$

$$\mu_4(x)=(5.5;6.5;7.5;8.5),$$

$$\mu_5(x)=(7.5;8.5;10;10).$$

To determine the weights of parameters, their expert ranking in terms of significance for a stakeholder is carried out and weights of significance parameters are calculated from the Fishburn formula:

$$w_k^m=\frac{2(M_k-m+1)}{M_k(M_k+1)}, \qquad (3)$$

where m is the parameter number at descending ranking; M_k is the number of parameters of projects' significance of the k-th stakeholder.

To perform the operations with trapezoidal fuzzy numbers, the formulas based on the expansion principle are used [26].

The utility for each project can be considered as a random magnitude, depending on the scenario, that is, on external and internal factors and the time function. The measure of projects and portfolio risk will be considered as utility dispersion.

Next, we find fuzzy mathematical expectations of the utility of each project P_n:

$$m_n=E(u_n^l)=\sum_{l=1}^{L}u_n^l p_l, \qquad (4)$$

and fuzzy elements of covariation matrix of projects' utilities i and j:

$$v_{ij}=\sum_{l=1}^{L}(u_i^l-m_i)\cdot(u_j^l-m_j)\cdot p_l. \qquad (5)$$

Introduce binary variable x_n, which characterized the inclusion of a project into the portfolio:

– if x_n=0, a project is not included in the portfolio;

– if x_n=1, a project is included in the portfolio.

Portfolio utility:

$$m_{port}=\sum_{n=1}^{N}x_n m_n. \qquad (6)$$

Portfolio risk:

$$\sigma_{port}^2=\sum_{i,j=1}^{N}x_i x_j v_{ij}. \qquad (7)$$

Volume of required portfolio resources:

$$R_{port}=\sum_{n=1}^{N}x_n R_n, \qquad (8)$$

where R_n is the necessary resource volume for the n-the project, which is a fuzzy number.

The company's project portfolio is formed by the criterion of a maximum of expected utility at constraints for the magnitude of portfolio risk (σ_0^2) and the volume of resources required for its implementation (R_0):

$$\begin{cases}\sum_{n=1}^{N}x_n m_n \to \max;\\ \sum_{i,j=1}^{N}x_i x_j v_{ij}\le \sigma_0^2;\\ \sum_{n=1}^{N}x_n R_n \le R_0.\end{cases} \qquad (9)$$

Problem (9) is a quadratic programming problem with fuzzy objective function and fuzzy constraints. This model is stated not entirely (or fuzzily), because it is not indicated how one can compare fuzzy numbers between themselves while checking constraints of the model and how to establish the optimality of a project portfolio. The solution of such problem requires the use of special methods.

When developing the method enabling finding solutions to the proposed model, we will use the approach presented in paper [27]. The idea behind the approach is to convert a fuzzy optimization model into a crisp model through the conversion of fuzzy inequalities for the objective function, and constraints into crisp equalities at the assigned satisfaction degrees.

It should be noted, however, that in the specified work, the authors set and solved a fuzzy integer linear programming problem. In this case, it is necessary to convert a quadratic programming problem into a crisp optimization model, which requires a similar transformation for quadratic fuzzy inequality.

Assign the satisfaction degrees λ_{m_0}, $\lambda_{\sigma_0^2}$, λ_{R_0} for constraints for the objective function, risk and resources, accordingly. We have the following system of ratios:

$$\begin{cases}m_{port}\to \max;\\ N_{\sum x_i m_i}(m_{port},m_{port},\infty,\infty)\ge \lambda_{m_0};\\ N_{\sum x_i x_j v_{ij}}(\sigma_0^2)\ge \lambda_{\sigma_0^2};\\ N_{\sum x_i R_i}(R_0)\ge \lambda_{R_0};\\ x_i\in\{0,1\}.\end{cases} \qquad (10)$$

Here, $N_A(B)>\lambda$ means that number A meets constraint B with satisfaction degree λ.

This condition is equivalent to the following inequality:

$$\min_x \max(1-\mu_A(x),\mu_B(x))>\lambda,$$

where $\mu_Y(x)$ is the membership function of fuzzy number Y.

In particular, let us assume that the elements of fuzzy covariation matrix v_{ij} are trapezoidal fuzzy numbers $v_{ij}=\left(v_{ij}^1, v_{ij}^2, v_{ij}^3, v_{ij}^4\right)$ and the constraint from above for the portfolio risk has fuzzy representation $\sigma_0^2=\left(0,0,\sigma_3,\sigma_4\right)$. Then, fuzzy constraint $N_{\sum x_i x_j v_{ij}}\left(\sigma_0^2\right)\geq\lambda_{\sigma_0^2}$ is equivalent to:

$$\sum_{i,\,j=1}^{N}\left[\left(1-\lambda_{\sigma_0^2}\right)\cdot v_{ij}^3+\lambda_{\sigma_0^2}\cdot v_{ij}^4\right]\cdot x_i\cdot x_j\leq$$
$$\leq\lambda_{\sigma_0^2}\cdot\sigma_3+\left(1-\lambda_{\sigma_0^2}\right)\cdot\sigma_4.$$

Similarly, fuzzy inequalities in paper (10) are represented as crisp inequalities, and thus we come to a crisp Boolean quadratic programming problem, which is solved through applying the standard packages of numerical optimization, for example, the evolutionary algorithm in “Solution search” package λ_{m_0}, $\lambda_{\sigma_0^2}$, $\lambda_{\sigma_0^2}$, of MS Excel or the method of branches and boundaries.

5. The use of the model in the formation of an optimal portfolio of investment projects of a fishing production enterprise

The described above fuzzy-multiple model of formation of a projects’ portfolio can be applied under actual conditions. Consider the example of formation of a portfolio of projects of the fishery company, engaged in fishing, seafood processing and further wholesale both in the market in Russia and abroad. Select the main stakeholders of such company:

a) owners and investors;
b) company staff;
c) clients;
d) society;
e) public administration structures and bodies.

Each of the stakeholders has his own requirements in relation to the company and their relationship with it can be characterized by a degree of satisfaction, expectations and degree of desire of changes. A group of experts was formed to determine the parameters of significance of each project for stakeholders from representatives of all stakeholders. The experts identified a set of parameters of evaluation of projects’ significance for each of the selected stakeholder. The set of parameters is shown in Table 1. It should be noted that for each company, sets of parameters of evaluation of significances may be different due to the nature and specific features of a company under consideration.

The company is considering six projects to realization.

P_1 – buying quota for fishery for expansion of fishing at auction 1.

P_2 – buying quota for fishery for expansion of fishing at auction 2.

P_3 – buying an operating fishing vessel and its further introduction into fishery.

P_4 – installation of new equipment onto an operating fishing vessel.

P_5 – construction of a new fishing vessel at a shipyard of Russia.

P_6 – construction of warehouse cooling terminal in Primorsky Krai.

The average fuzzy amount of necessary resources in the project was determined in an expert way, like average fuzzy payback period of the project. These indicators are shown in Table 2.

Table 1

Parameters of evaluation of projects’ significance for groups of stakeholders

Group of stakeholders	Parameter	Designation
Owners and investors	Financial indicator of *NPV* of a project	Z_1^1
Staff	Change in average salary	Z_2^1
Staff	Change in working conditions	Z_2^2
Staff	Change in the opportunity of qualification upgrading	Z_2^3
Staff	Change in social support	Z_2^4
Clients	Change in average level of fish food prices	Z_3^1
Clients	Change in quality of fish products	Z_3^2
Clients	Change in assortment of fish products on sale	Z_3^3
Society	Change in the number of working places	Z_4^1
Society	Change in magnitude of taxes	Z_4^2
Society	Change in average level of fish food prices	Z_4^3
State	Change in magnitude of taxes	Z_5^1
State	Change in volume of production output	Z_5^2
State	Change of the number of workplaces	Z_5^3
State	Change of magnitude of added value	Z_5^4

Table 2

Volume of required resources and payback period of the project

Project	Fuzzy value of volume of resources in the project, USD thousand	Fuzzy payback period of the project, years
P_1	(1,201; 1,211; 1,216; 1,221)	(7.67; 7.76; 7.80; 7.84)
P_2	(1,450; 1,470; 1,495; 1,510)	(5.32; 5.41; 5.53; 5.59)
P_3	(12,470; 12,500; 12,535; 12,565)	(5.23; 5.25; 5.26; 5.28)
P_4	(246; 251; 251; 256)	(2.13; 2.18; 2.18; 2.22)
P_5	(36,900; 37,000; 37,100; 37,250)	(8.97; 9.00; 9.03; 9.07)
P_6	(13,250; 13,300; 13,335; 13,365)	(7.69; 7.71; 7.73; 7.75)

Constraints for the level of admissible risk and the volume of available resources (R_0=54,850 USD thousand) does not allow including to the portfolio and implementing all the projects. The proposed model allows generating the optimal portfolio at existing constraints.

Examine three scenarios of development of external environment: C_1 – pessimistic, C_2 – realistic and C_3 – optimistic. Under the pessimistic scenario for development of external environment, experts forecast both deteriorating financial indicators of projects regarding the level of the realistic scenario, and possible decrease in the estimates of significances by other parameters (Table 1). The pessimistic scenario describes the situation of stagnation or even recession in the market of the enterprise operation and the economy of the country in general. Thus, for example, experts consider that upon the occurrence of a pessimistic scenario, basic parameters (execution time, cost) of project P_5 – construction of a new fishing vessel at the shipyard of the country – can deteriorate. In this case, the attractiveness of this project in terms of personnel can be decreased due to complexities with the creation of more comfortable working conditions, insufficient salary increase at transition to a new vessel, impossibility of upgrading professional skill of personnel, and, as an alternative, attraction of new, qualified professionals, with a view to implementation of production plans. All of these potential consequences of scenario development make us decrease the project grade. Due to the deterioration of the basic parameters of the project upon the occurrence of a pessimistic scenario, the estimate by public authorities may also be reduced, in view of the possible failure of the plan to provide new jobs or the production output, which leads to a decrease in tax deductions to the budget. Thus, the stagnation of the market leads to a decrease in many indicators of projects. The stimulation of the fishing industry market – the optimistic scenario – leads to opposite effects. It is worth noting that at the change of the scenario of development of external environment, not only the estimates of parameters can change, but also the weight of these parameters.

To estimate the probability of occurrence of each scenario, the following term-set of linguistic variables was accepted:

{Virtually improbable; Hardly probable; Probable; Very probable; Extremely probable}

Fig. 1 shows the corresponding trapezoidal membership functions.

Subsequently, the experts determined the probabilities of each scenario by the appropriate linguistic scale. Normalization of the obtained expert fuzzy probabilities is carried out according to the following formula:

$$p_l = \left(\frac{p_{l1}}{\sum_{l=1}^{L} p_{l4}}, \frac{p_{l2}}{\sum_{l=1}^{L} p_{l3}}, \frac{p_{l3}}{\sum_{l=1}^{L} p_{l2}}, \frac{p_{l4}}{\sum_{l=1}^{L} p_{l1}} \right).$$

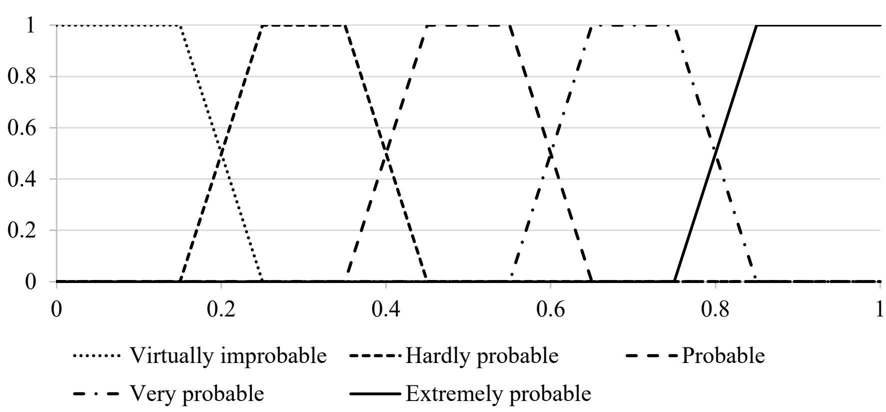

Fig. 1. System of trapezoidal membership functions on carrier [0; 1]

Expert fuzzy probabilities of scenarios and calculated normalized fuzzy scenarios probabilities are shown in Table 3.

The level of satisfaction of the requirements of owners and investors is usually closely linked to the economic efficiency of a project. The net reduced cost of project NPV is usually taken as a corresponding indicator; in this case, it can be calculated from the following formula:

$$NPV_n^l = \sum_{t=1}^{T_n} \frac{CF_{nt}^l}{(1+r)^t} - \sum_{t=1}^{T_{inv}} \frac{I_t}{(1+r)^t}, \qquad (11)$$

where n is the project number; l is the scenario number; t is the period number; T_n is the project implementation term; T_{inv} is the investment term; r is the market interest rate, corresponding to project term T_n; CF_{nt}^l is the net profit of the project at moment t for scenario l, I_t is the volume of investment at moment t. Net profit of the project, investment volume are fuzzy trapezoidal numbers. Table 4 givess calculation results..

Table 3

Fuzzy values of scenarios probability

Scenario	Expert mean fuzzy value of scenario probability	Normalized fuzzy value of scenario probability
S_1	(0.08; 0.17; 0.25; 0.33)	(0.068; 0.167; 0.305; 0.524)
S_2	(0.50; 0.55; 0.63; 0.67)	(0.424; 0.539; 0.768; 1.063)
S_3	(0.05; 0.10; 0.14; 0.18)	(0.042; 0.098; 0.171; 0.286)

Table 4

Fuzzy values of NPV of projects considering a scenario

Project	Scenario		
	S_1	S_2	S_3
	Fuzzy value of NPV of a project considering scenario, USD thousand		
P_1	(192; 195; 203; 211)	(226; 231; 236; 246)	(266; 271; 274; 282)
P_2	(769; 787; 814; 836)	(810; 825; 850; 870)	(845; 857; 880; 905)
P_3	(7,222; 7,247; 7,287; 7,322)	(8,124; 8,154; 8,189; 8,219)	(8,820; 8,843; 8,875; 8,900)
P_4	(663; 669; 669; 675)	(690; 695; 695; 700)	(713; 717; 717; 724)
P_5	(2,585; 2,740; 2,838; 2,933)	(3,234; 3,384; 3,484; 3,584)	(3,940; 4,093; 4,185; 4,287)
P_6	(3,820; 3,843; 3,878; 3,927)	(4,294; 4,324; 4,359; 4,409)	(5,008; 5,037; 5,068; 5,120)

To calculate the significance of projects with regard to requirements of other stakeholders, the parameters shown in Table 1 are ranked in an expert way separately for each stakeholder. Then, the weights of parameters are determined from formula (3). The parameter weight indicates its importance for a stakeholder when evaluating a project under conditions of a scenario.

Then, the parameter values for each project taking into consideration the scenario are estimated in the expert way by the linguistic scale presented in the model. Table 5 shows as an example the verbal estimates of parameter of significance and their weight for project P_5. For simplicity, the parameter weights in the example are taken as crisp.

The value of membership function of the estimation scale is put in compliance with the verbal estimation of an expert. Table 6 shows fuzzy estimates of parameters significance of project P_5, corresponding to verbal estimates.

Resulting fuzzy significances S_{nk}^l of projects are found from formula (2). Table 7 shows significances of project P_5.

Table 5

Verbal estimate of parameters of significance of project P_5 taking scenario in account

Parameter designation	Scenarios					
	S_1		S_2		S_3	
	Verbal estimation of parameter	Parameter weight	Verbal estimation of parameter	Parameter weight	Verbal estimation of parameter	Parameter weight
Z_2^1	Medium	0.400	Medium	0.400	High	0.400
Z_2^2	Medium	0.300	Medium	0.300	Medium	0.300
Z_2^3	High	0.200	High	0.200	Very high	0.200
Z_2^4	Medium	0.100	High	0.100	High	0.100
Z_3^1	Medium	0.167	High	0.167	High	0.333
Z_3^2	High	0.333	High	0.333	Very high	0.167
Z_3^3	High	0.500	High	0.500	Very high	0.500
Z_4^1	High	0.333	Very high	0.333	Very high	0.500
Z_4^2	High	0.167	High	0.167	Very high	0.167
Z_4^3	Medium	0.500	High	0.500	High	0.333
Z_5^1	High	0.400	Very high	0.400	Very high	0.400
Z_5^2	High	0.300	High	0.300	Very high	0.300
Z_5^3	High	0.100	Very high	0.200	Very high	0.200
Z_5^4	High	0.200	Very high	0.100	Very high	0.100

Significances for other projects are calculated similarly.

Utilities of projects within various scenarios are calculated from formula (1). For example, utility of project P_5 under scenario S_2 can be calculated as follows:

$$u_5^2 = u(\Pi_5, C_2) = NPV_5^2 \cdot \left(S_{52}^2 \cdot S_{53}^2 \cdot S_{54}^2 \cdot S_{55}^2\right)^{1/4} =$$
$$= (3{,}234;\ 3{,}384;\ 3{,}484;\ 3{,}584) \times$$
$$\times \left(\begin{matrix} (4.10;\ 5.10;\ 6.10;\ 7.10) \times (5.50;\ 6.50;\ 7.50;\ 8.50) \times \\ \times (6.17;\ 7.17;\ 8.33;\ 9.00) \times (6.90;\ 7.90;\ 9.25;\ 9.55) \end{matrix} \right)^{1/4} =$$
$$= (18{,}000;\ 22{,}275;\ 26{,}850;\ 30{,}418).$$

Fuzzy values of utility for other scenarios and projects are calculated similarly. Fuzzy mathematical expectations of projects are found from formula (4):

$$m_1 = (447;\ 867;\ 1{,}680;\ 3{,}036),$$

$$m_2 = (1{,}721;\ 3{,}242;\ 6{,}266;\ 11{,}102),$$

$$m_3 = (11{,}300;\ 22{,}388;\ 45{,}813;\ 84{,}297),$$

$$m_4 = (1{,}527;\ 2{,}826;\ 5{,}264;\ 9{,}139),$$

$$m_5 = (9{,}551;\ 17{,}668;\ 32{,}805;\ 55{,}606),$$

$$m_6 = (10{,}154;\ 18{,}904;\ 34{,}971;\ 61{,}072).$$

Fuzzy values of the covariance matrix are calculated according to formula (5).

Table 6

Fuzzy estimate of parameter of significance of project P_5 taking into account the scenario

Parameter designation	Scenarios					
	S_1		S_2		S_3	
	Fuzzy estimate of parameter	Parameter weight	Fuzzy estimate of parameter	Parameter weight	Fuzzy estimate of parameter	Parameter weight
Z_2^1	(3.5; 4.5; 5.5; 6.5)	0.400	(3.5; 4.5; 5.5; 6.5)	0.400	(5.5; 6.5; 7.5; 8.5)	0.400
Z_2^2	(3.5; 4.5; 5.5; 6.5)	0.300	(3.5; 4.5; 5.5; 6.5)	0.300	(3.5; 4.5; 5.5; 6.5)	0.300
Z_2^3	(5.5; 6.5; 7.5; 8.5)	0.200	(5.5; 6.5; 7.5; 8.5)	0.200	(7.5; 8.5; 10; 10)	0.200
Z_2^4	(3.5; 4.5; 5.5; 6.5)	0.100	(5.5; 6.5; 7.5; 8.5)	0.100	(5.5; 6.5; 7.5; 8.5)	0.100
Z_3^1	(3.5; 4.5; 5.5; 6.5)	0.167	(5.5; 6.5; 7.5; 8.5)	0.167	(5.5; 6.5; 7.5; 8.5)	0.333
Z_3^2	(5.5; 6.5; 7.5; 8.5)	0.333	(5.5; 6.5; 7.5; 8.5)	0.333	(7.5; 8.5; 10; 10)	0.167
Z_3^3	(5.5; 6.5; 7.5; 8.5)	0.500	(5.5; 6.5; 7.5; 8.5)	0.500	(7.5; 8.5; 10; 10)	0.500
Z_4^1	(5.5; 6.5; 7.5; 8.5)	0.333	(7.5; 8.5; 10; 10)	0.333	(7.5; 8.5; 10; 10)	0.500
Z_4^2	(5.5; 6.5; 7.5; 8.5)	0.167	(5.5; 6.5; 7.5; 8.5)	0.167	(7.5; 8.5; 10; 10)	0.167
Z_4^3	(3.5; 4.5; 5.5; 6.5)	0.500	(5.5; 6.5; 7.5; 8.5)	0.500	(5.5; 6.5; 7.5; 8.5)	0.333
Z_5^1	(5.5; 6.5; 7.5; 8.5)	0.400	(7.5; 8.5; 10; 10)	0.400	(7.5; 8.5; 10; 10)	0.400
Z_5^2	(5.5; 6.5; 7.5; 8.5)	0.300	(5.5; 6.5; 7.5; 8.5)	0.300	(7.5; 8.5; 10; 10)	0.300
Z_5^3	(5.5; 6.5; 7.5; 8.5)	0.100	(7.5; 8.5; 10; 10)	0.200	(7.5; 8.5; 10; 10)	0.200
Z_5^4	(5.5; 6.5; 7.5; 8.5)	0.200	(7.5; 8.5; 10; 10)	0.100	(7.5; 8.5; 10; 10)	0.100

Utility and risk of the portfolio are found from formulas (6), (7). For a company seeking to maximize utility with a certain risk level boundary and assigned resource constraints, the model, according to formula (9), takes the form:

$$\begin{cases} \sum_{i=1}^{6} x_i m_i \to \max; \\ \sum_{i,j=1}^{6} x_i x_j v_{ij} \le \sigma_0^2; \\ \sum_{i=1}^{6} x_i R_i \le 54{,}850. \end{cases}$$

To convert a fuzzy optimization problem into a crisp one, it is necessary to assign the satisfaction degrees for the objective function and for each constraint. In general case, these satisfaction degrees may vary. In the studied example, we assign the same satisfaction degrees of constraints for objective function $\lambda_m = 0.95$, risk $\lambda_{\sigma^2} = 0.95$ and resources $\lambda_R = 0.95$. It is proposed to carry out the defuzzification of fuzzy utility of projects' portfolio, fuzzy risk and non-fuzzy budget by th e mean maximum method [22].

Table 7

Fuzzy significances of project P_5 taking into account scenario

Significance designation	Scenario		
	C_1	C_2	C_3
	Fuzzy significances of project Π_5		
S^l_{51} (NPV)	(2,585; 2,740; 2,838; 2,933)	(3,234; 3,384; 3,484; 3,584)	(3,940; 4,093; 4,185; 4,287)
S^l_{52}	(3.90; 4.90; 5.90; 6.90)	(4.10; 5.10; 6.10; 7.10)	(5.30; 6.30; 7.40; 8.20)
S^l_{53}	(5.17; 6.17; 7.17; 8.17)	(5.50; 6.50; 7.50; 8.50)	(6.83; 7.83; 9.17; 9.50)
S^l_{54}	(4.50; 5.50; 6.50; 7.50)	(6.17; 7.17; 8.33; 9.00)	(6.83; 7.83; 9.17; 9.50)
S^l_{55}	(5.50; 6.50; 7.50; 8.50)	(6.90; 7.90; 9.25; 9.55)	(7.50; 8.50; 10.00; 10.00)

The transition from fuzzy coefficients of objective function $m_i = \left(m_i^1; m_i^2; m_i^3; m_i^4\right)$ into crisp analogue of coefficients of objective function $\tilde{m}_i$ due to the use of utility function in maximizing model occurs by formula of constraint from below, in which abscissas of two left vertices of the trapezoid take part:

$$\tilde{m}_i = \lambda_m \cdot m_i^1 + \left(1-\lambda_m\right)\cdot m_i^2.$$

As a result of calculations, we obtain the following crisp analogues of fuzzy coefficients of objective function:

$$\tilde{m}_1 = 468,\ \ \tilde{m}_2 = 1{,}797,\ \ \tilde{m}_3 = 11{,}854,$$

$$\tilde{m}_4 = 1{,}591,\ \ \tilde{m}_5 = 995,\ \ \tilde{m}_6 = 10{,}592.$$

To transfer from fuzzy risk constraint from above into the crisp one, it is necessary to carry out the transition from fuzzy values of the elements of covariance matrix $v_{ij} = \left(v_{ij}^1; v_{ij}^2; v_{ij}^3; v_{ij}^4\right)$, into their crisp analogues $\tilde{v}_{ij}$ according to formula:

$$\tilde{v}_{ij} = \left(1-\lambda_{\sigma^2}\right)\cdot v_{ij}^3 + \lambda_{\sigma^2}\cdot b_{ij}^4.$$

Table 8 gives crisp analogues of fuzzy values of the elements of covariance matrix calculated according to this formula.

Transition from fuzzy volume of resources required in the project $R_i = \left(R_i^1; R_i^2; R_i^3; R_i^4\right)$ into their crisp analog occurs in the similar way:

$$\tilde{R}_i = \left(1-\lambda_R\right)\cdot R_i^3 + \lambda_R \cdot R_i^4.$$

As a result of calculations, we obtain the following crisp analogues of fuzzy values of required resources in a project:

$$\tilde{R}_1 = 1{,}221,\ \ \tilde{R}_2 = 1{,}509,\ \ \tilde{R}_3 = 12{,}564,$$

$$\tilde{R}_4 = 256,\ \ \tilde{R}_5 = 37{,}243,\ \ \tilde{R}_6 = 13{,}364.$$

To determine the portfolio composition, we use the toolset "Solution search" of the package of MS Excel add-in (evolutionary method). Table 9 shows the results of application of two models for the example under consideration:

a) the one proposed in this research;

b) the model taking into account only financial indicator of projects NPV_n^l.

Table 9

Modeling of projects' portfolio formation (maximization of expected NPV projects' portfolio, $\gamma = 0{,}95$)

Form of function "project utility"	Constraint for shared resources, USD thousand	Numbers of projects included in portfolio	Numbers of projects not included in portfolio	Expected utility of projects' portfolio	Shared resources of projects' portfolio, USD thousand
From formula (1)	54,850	P_1, P_2, P_4, P_5, P_6	P_3	24,406	53,604
NPV_n^l	54,850	P_1, P_3, P_6	P_2, P_4, P_5	6,887	27,160

It is easy to see that formation of projects' portfolio based on maximization of expected utility of the portfolio for all major stakeholders and based on maximization of the expected value of financial indicator NPV lead to essentially different results. Thus, project P_3 (purchase of the operating fishing vessel and its further implementation in fishing) is replaced with projects P_4 (installation of new equipment on the operating fishing vessel) and P_5 (construction of a new fishing vessel at the shipyard of Russia), which are more significant for stakeholders "state" and "society". These projects give greater utility for the economy of the region and the country in general due to loading of Russian enterprises with orders, which leads to an increase in gross added value, tax deductions and jobs creation.

Table 8

Crisp analogues of fuzzy values of elements of covariance matrix

Project	Project					
	P_1	P_2	P_3	P_4	P_5	P_6
	Crisp analog of fuzzy values of covariance matrix					
P_1	9,011,752	31,820,266	256,232,549	25,359,283	153,803,132	169,186,281
P_2	31,820,266	114,775,272	915,515,557	91,512,828	547,912,086	604,688,695
P_3	256,232,549	915,515,557	7,306,408,630	729,785,244	4,373,873,019	4,826,062,061
P_4	25,359,283	91,512,828	729,785,244	72,974,538	436,726,066	482,037,135
P_5	153,803,132	547,912,086	4,373,873,019	436,726,066	2,625,337,708	2,888,320,080
P_6	169,186,281	604,688,695	4,826,062,061	482,037,135	2,888,320,080	3,188,780,120

6. Discussion of research results: formation of optimal investment strategy of a company taking into account requirements of major stakeholders

The proposed model makes it possible to form the investment portfolio of a company, taking into account the interests of other significant stakeholders along with the requirements of major stakeholders (owners and investors). It was shown that in case of taking into consideration the interests of many relevant stakeholders, the portfolio composition will be different from the one that was selected when focusing only on financial indicators, reflecting the interests of owners and investors (at the same satisfaction degree). This is the main advantage of the developed model, since if it is applied, the projects with the greatest cumulative significance to all the major stakeholders, taking into account their real importance to an organization, get into the portfolio. When using the models oriented to financial indicators, the projects, which are significant only for owners and investors, would get into the portfolio. The implementation of such a portfolio might lead to deterioration of resource exchange with other relevant stakeholders, even to breaking resource relations with them.

Each factor of multiplicative function of project utility corresponds to a separate stakeholder and reflects its importance to a stakeholder from the perspective of satisfaction of his requirements for an organization, taking into account their significance to a stakeholder. On the other hand, exponents in this function reflect the significances of stakeholders for an organization in terms of existing resource sharing between a company and a stakeholder and the degree of mutual influence. This "bilateral" approach determines the merits of the proposed method for the formation of projects' portfolio in comparison with other methods of portfolio investment, taking account the interests of stakeholders.

This allows, on the one hand, forming the investment strategies focused on more important stakeholders, whose requirements are crucial to the existence of an organization. On the other hand, it enables taking account the requirements significant for less important stakeholders in greater degree.

The main advantage of the proposed method for finding a solution to the fuzzy model is the ability to establish different satisfaction degrees for objective function and constraints. This makes it possible to a greater or lesser extent to take account of uncertainty in each case for each of the parameters characterizing the utilities of projects, risks and necessary resources. Selection of satisfaction degrees is up to a decision maker, and, above all, can characterize his inclination to risk.

It should be noted that despite the fact that while requirements of stakeholders to an organization are taken into account in the model explicitly, the values of characteristics of relations of an organization and stakeholders at decision making moment are taken into account implicitly. These characteristics are ultimately reflected in expert estimates of weight coefficients of significance of stakeholders and their requirements. In this case, possible changes of these characteristics are not taken into consideration due to the change of internal and external conditions, including the changes in relations between stakeholders themselves, leading to subsequent changes in their relationships with an organization. Possible changes in the characteristics of the relationships as a result of the implementation of long-term projects (as they are implemented) are not taken into account either. All this limits the possibilities of using the proposed model and is the direction for further research in this area. Specifically, it can be appropriate to develop the fuzzy multi-period portfolio model of selection of projects' portfolio and their calendar scheduling taking into account the changes in the characteristics of the relationships between stakeholders and an organization. However, it is possible to face difficulty finding a numerical solution to this model. In this regard, it may be required to develop the corresponding method for finding a solution.

7. Conclusions

1. We developed the fuzzy optimization model of portfolio investment based on multiplicative function of projects' utility that uses expert estimates of quality indicators of satisfaction of stakeholders' requirements represented in verbal form, along with financial indicators, The project utility is a multiplicative Cobb-Douglas type function, the factors of which describe the degree of satisfaction of requirements of a separate stakeholder to an organization. In the model, projects' utilities are considered as fuzzy random magnitudes, and the scenario-based method and a H. Markowitz approach are used for quantitative accounting for risk. The constraints in the model that is associated with a deficiency of necessary resources to implement projects and assigned magnitude of the possible risk of the portfolio are also fuzzy. Fuzzy optimization problem using the approach of the theory of possibilities, for the assigned satisfaction degrees is converted into a crisp problem, which is solved by numerical methods. The degree of taking into account the existing uncertainty is regulated by assigning the satisfaction degrees both for the objective function, and for constraints.

2. The method for finding a solution to the fuzzy model was proposed. Fuzzy utilities of projects for each scenario, fuzzy math expectations of projects, a portfolio as a whole and fuzzy portfolio risk based on the fuzzy covariance matrix are found at the first stage. Then, for the assigned satisfaction degrees of objective function and for each constraint, the fuzzy problem is converted into the crisp problem by calculating the parameters of the crisp objective function and crisp constraints. The quadratic programming problem is solved numerically at the second stage.

3. Computational aspects of the proposed method are considered during the formation of the optimal portfolio of investment projects of a fishing industrial enterprise. The projects' portfolio that is optimal by the criterion of the maximum of expected utility at an assigned satisfaction degrees was formed based on the performed computations. The considered example shows that the composition of the portfolio can change compared to the problem, in which only the financial indicator NVP is the utility, that is when only the requirements of owners and investors are taken into consideration.

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References

1. Gergert, D. V., Pronyushkin, D. V. (2013). Metody i modeli formirovaniya portfelya proektov. V sbornike: Sovershenstvovanie strategicheskogo upravleniya korporatsiyami i regional'naya innovatsionnaya politika. Materialy VI Rossiyskoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem. Perm': Izd-vo Permskogo gosudarstvennogo natsional'nogo issledovatel'skogo universiteta, 50–55.
2. Eskerod, P., Larsen, T. (2018). Advancing project stakeholder analysis by the concept "shadows of the context." International Journal of Project Management, 36 (1), 161–169. doi: https://doi.org/10.1016/j.ijproman.2017.05.003
3. Schwarzmüller, T., Brosi, P., Stelkens, V., Spörrle, M., Welpe, I. M. (2016). Investors' reactions to companies' stakeholder management: the crucial role of assumed costs and perceived sustainability. Business Research, 10 (1), 79–96. doi: https://doi.org/10.1007/s40685-016-0040-9
4. Eskerod, P., Huemann, M., Ringhofer, C. (2015). Stakeholder Inclusiveness: Enriching Project Management with General Stakeholder Theory1. Project Management Journal, 46 (6), 42–53. doi: https://doi.org/10.1002/pmj.21546
5. Voropaev, V. I., Gel'rud, Ya. D. (2012). Matematicheskie modeli proektnogo upravleniya dlya zainteresovannyh storon. Upravlenie proektami i programmami, 4, 258–269.
6. Brunsson, N. (2007). The consequences of decision-making. Oxford University Press, 174.
7. Winter, M., Szczepanek, T. (2008). Projects and programmes as value creation processes: A new perspective and some practical implications. International Journal of Project Management, 26 (1), 95–103. doi: https://doi.org/10.1016/j.ijproman.2007.08.015
8. Ang, K. C. S., Killen, C. P. (2016). Multi-Stakeholder Perspectives of Value in Project Portfolios. In Proc. of EURAM, the 16th Annual conference of the European Academy of Management.
9. Tamošiūnas, A. (2016). Managing stakeholders in complex investments projects. 9th International Scientific Conference "Business and Management 2016." doi: https://doi.org/10.3846/bm.2016.41
10. Khalilzadeh, M., Salehi, K. (2017). A multi-objective fuzzy project selection problem considering social responsibility and risk. Procedia Computer Science, 121, 646–655. doi: https://doi.org/10.1016/j.procs.2017.11.085
11. Mazelis, L. S., Solodukhin, K. S. (2013). Multi-period models for optimizing an institution's project portfolio inclusive of risks and corporate social responsibility. Middle-East Journal of Scientific Research, 17 (10), 1457–1461.
12. Aras, A. C., Kaynak, O., Batyrshin, I. (2008). A comparison of fuzzy methods for modeling. 2008 34th Annual Conference of IEEE Industrial Electronics. doi: https://doi.org/10.1109/iecon.2008.4757927
13. Carlsson, C., Fullér, R., Heikkilä, M., Majlender, P. (2007). A fuzzy approach to R&D project portfolio selection. International Journal of Approximate Reasoning, 44 (2), 93–105. doi: https://doi.org/10.1016/j.ijar.2006.07.003
14. Novak, V., Perfilieva, I., Dvorak, A. (2016). Insight into Fuzzy Modeling. Wiley. doi: https://doi.org/10.1002/9781119193210
15. Emrouznejad, A., Ho, W. (2017). Fuzzy analytic hierarchy process. New York: Chapman and Halll/CRC, 430. doi: https://doi.org/10.1201/9781315369884
16. Anshin, V. (2015). Methodological aspects of measuring mutual effect of project portfolio and company's goals. Scientific Research and Development. Russian Journal of Project Management, 4 (3), 3–8.
17. Zhang, X., Hipel, K. W., Tan, Y. (2019). Project portfolio selection and scheduling under a fuzzy environment. Memetic Computing. doi: https://doi.org/10.1007/s12293-019-00282-5
18. Zhou, X., Wang, J., Yang, X., Lev, B., Tu, Y., Wang, S. (2018). Portfolio selection under different attitudes in fuzzy environment. Information Sciences, 462, 278–289. doi: https://doi.org/10.1016/j.ins.2018.06.013
19. Better, M., Glover, F. (2006). Selecting Project Portfolios by Optimizing Simulations. The Engineering Economist, 51 (2), 81–97. doi: https://doi.org/10.1080/00137910600695593
20. Dixit, V., Tiwari, M. K. (2019). Project portfolio selection and scheduling optimization based on risk measure: a conditional value at risk approach. Annals of Operations Research. doi: https://doi.org/10.1007/s10479-019-03214-1
21. Likhosherst, E. N., Mazelis, L. S., Chen, A. Ya. (2015). Selection of the optimal portfolio construction company taking into account the requests of stakeholdersin the formulation of multi-fuzzy. Vestnik Vladivostokskogo gosudarstvennogo universiteta ehkonomiki i servisa, 4, 27–40.
22. Likhosherst, E., Mazelis, L., Gresko, A., Lavrenyuk, K. (2017). Fuzzy set model of project portfolio optimization inclusive for requirements of stakeholders. Journal of Applied Economic Sciences, 12 (5), 1263–1273.
23. Markowitz, H. (1952). Portfolio Selection. The Journal of Finance, 7 (1), 77–91. doi: https://doi.org/10.1111/j.1540-6261.1952.tb01525.x
24. Soloduhin, K. S. (2009). Strategicheskoe upravlenie vuzom kak steykholder-kompaniey. Sankt-Peterburg: Izd-vo Politehn. un-ta, 290.
25. Ptuskin, A. S. (2003). Investment projects ranking by risk level with the use of linguistic approach. Economics of Contemporary Russia, 3, 94–101.
26. Zadeh, L. A. (1978). Fuzzy sets as a basis for a theory of possibility. Fuzzy Sets and Systems, 1 (1), 3–28. doi: https://doi.org/10.1016/0165-0114(78)90029-5
27. Demkin, I. V., Tsar'kov, I. N., Nikonov, I. M., An'shin, V. M. (2008). Primenenie teorii nechetkih mnozhestv k zadache formirovaniya portfelya proektov. Nauchnye issledovaniya i razrabotki. Problemy analiza riska, 5 (3), 8–21.