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Table of Contents

Fuzzy Set Model of Project Portfolio Optimization Inclusive for Requirements of Stakeholders

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Abstract:

The paper suggests a fuzzy model for the formation of an optimal portfolio of investment projects of the company, which adheres to stakeholder management as a discrete institutional alternative. It considers companies whose main stakeholders are company personnel, founders and investors; society; structures and bodies of state administration. Each of the stakeholders has its own requests in relation to the company. Optimization of the portfolio is based on the proposed multiplicative utility function, which reflects the stakeholder importance of projects and includes, along with the indicator of economic efficiency, qualitative indicators characterizing social and state significance. Risk management is carried out within the framework of the portfolio investment theory of H. Markowitz using the scenario approach. To model the uncertainty of input parameters and the results of project implementation, a fuzzy set approach is used, in which verbal expert estimates of input parameters and results of projects are transformed into fuzzy sets with subsequent formulation and solution of fuzzy optimization problems. A fuzzy model is transformed into a clear quadratic programming problem, which is solved using standard numerical methods. An example of the formation of a portfolio of real projects of a construction company, a developer, operating in the market of the Primorsk Territory of the Russian Federation, is considered.

Keywords: project portfolio optimization; stakeholder approach; social significance; utility function; fuzzy model

JEL Classification: C61; O21

Introduction

This paper is a continuation of works of the authors devoted to the problem of formation of a portfolio of investment projects of the company on the basis of the project utility function, which allows to compare projects and programs and find the optimal solution using a certain principle of domination.

A stakeholder theory has become widespread in the works on project management optimization. In particular, articles Vayyavur (2015), Eskerod, Hamann and Ringhofer (2016) provide an overview of the principles of application of the stakeholder theory in the project activity. Various areas of application of the stakeholder theory can be met in the works on portfolio investment. For example, articles of Rojas and Liu (2015), Ang, Killen, and Sankaran (2015) note that the core goal of the project portfolio management is to maximize the strategic significance of tangible and intangible value of the portfolio for all stakeholders. Integrated decision-making models can help project practitioners in the design, planning, and achievement of objectives of many stakeholders in the

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framework of project portfolio management. Due to this, these articles also indicate the need for further research on the impact of choosing the most appropriate environment for relations with stakeholders to maximize the project value. Article of Rajablu, Marthandan, Wan Fadzilah and Wan Yusoff (2015) is devoted to the analysis of six key indicators of the stakeholder theory that impact the success of the project. However, the data are processed using statistical methods and procedures, which are considered insufficiently efficient due to the presence of ambiguous and fuzzy estimates of project efficiency indicators for various stakeholders.

Analysis of the impact of accounting for corporate social responsibility on investment efficiency has become widespread in recent years (Benlemlih and Bitar 2016). In their previous works, the authors considered an approach under which the company's corporate social responsibility is expressed during goal-setting, inclusive of the interests of all stakeholders (Mazelis and Solodukhin 2013, Mazelis, and Solodukhin 2015, Mazelis, Rokhmanova and Solodukhin 2012), while the utility of the project is considered as levels of achievement of the goals achieved during the project implementation. Alternatively, to this approach, the models have been proposed to optimize the project portfolio within the investment program of development inclusive of risks and corporate social responsibility of the company, which adheres to a stakeholder management as discrete institutional alternatives (Lihosherst, Mazelis and Chen 2015, Mazelis, Solodukhin, Chen and Tarantaev 2016). The models are based on an approach that takes into consideration the need to use the principles of corporate social responsibility when developing strategic plans of activity (Maltseva 2009). For example, additional indicators of social and state value are introduced along with indicators of economic efficiency, and evidence of the efficiency of their account is provided in order to reflect a stakeholder significance of the project.

In the context of the increasing uncertainty, it seems promising to use the fuzzy set approach, where the verbal expert estimates of the input parameters, possible results of the projects implementation and the emerging risks are transformed into fuzzy sets with a subsequent formulation and solution of fuzzy optimization problems. Fuzzy optimization models with fuzzy objective functions and fuzzy constraints allow to obtain various solutions at various exogenously specified confidence levels (Anshin 2015). Increased attention in the works on project and portfolio investment in recent years has been paid to the use of fuzzy sets (Wei Zhou 2014).

Risks are accounted in the model within the framework of the portfolio investment theory of H. Markowitz using the scenario approach.

In the continuation of the paper of the authors (Lihosherst, Mazelis and Chen 2015), a modification of fuzzy models and an algorithm for their solution, which does not use the intermediate defuzzification of fuzzy variables at a rather early stage and the formulation of an optimization model using medians of fuzzy numbers, are proposed.

1. Model and algorithm of solution

This study will consider a company whose main stakeholders are: company personnel, founders and investors; society; structures and bodies of state administration. Each of the stakeholders has its own requests in relation to the company.

Let's assume that the company has N projects $\mathrm{P}_1,\ \mathrm{P}_2, \dots, \mathrm{P}_N$. The goal is to form an optimal project portfolio taking into account their risks, utility, available resources and investment capabilities of the company. This task will be solved using a scenario approach that allows to foresee changes in the internal and external environment and assess the risks of projects and the portfolio in general. L possible scenarios of changes in the environment $E_1, E_2, \dots, E_L$ with probabilities $p_1, p_2, \dots, p_L$ are considered.

The experts are offered a certain linguistic scale that allows to convert verbal estimates into fuzzy numbers in order to model uncertainty during setting of the input parameters of the investment projects and assessing the results of projects implementation. Each project P_n is described by the following indicators: utility u_n; amount of resources required for implementation R_n. The utility of project P_n is found using the utility function U. The utility for each project and scenario u_n^l is considered as a random variable depending on external and internal factors that are functions of time. Utility variances $D_{u_n^l}$ will be considered as a measure of project and portfolio risk.

A binary variable x_n describes the inclusion of the project in the portfolio:

- if $x_n = 0$, the project is not included in the portfolio;

- if $x_n = 1$, the project is included in the portfolio.

The following algorithm for constructing and solving a fuzzy model is proposed:

- Definition of a set of scenarios $S_1, S_2, \dots, S_L$ and fuzzy estimate of probability of each of them. Expert estimates of probabilities are generalized (aggregated) and normalized (see: Ptuskin, 2004). They result in normalized fuzzy probabilities of scenarios $p_1, p_2, \dots, p_L$.
- Assessment of the level of satisfaction of the requirements of the owners, investors and personnel. To do so, the indicator of economic efficiency of the project is calculated, represented as the net present value of the project:

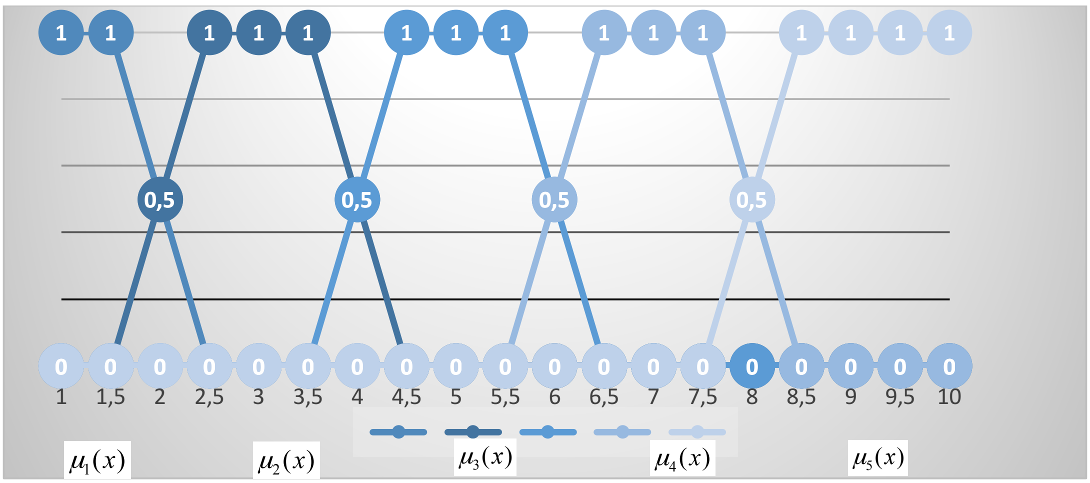
$$NPV_n^t = \sum_{t=1}^{T_n} \frac{CF_{nt}^l}{(1+r)^t} - \sum_{t-1}^{T_{inv}} \frac{I_t}{(1+r)^t}, (1) \qquad (1)$$

where: n is a project number, l is a scenario number, t is a period number, T_n is time of the project implementation; T_{inv} is term of investment, r is a market interest rate corresponding to the project time T_n; CF_{nt}^l is the net profit of the project at the moment of time t for scenario l, I_t is amount of investment at the moment of time t. Net profit of the project and amount of investment are fuzzy trapezoidal numbers.

- Evaluation of social S_n and state G_n significance of project P_n using a fuzzy set theory. Social S_n and state G_n significances of the project have a number of parameters for their evaluation: s_i, $i \in \overline{1;p}$ and g_i, $g \in \overline{1;m}$, respectively.

The set of parameters is the same for all projects. Values of parameters for each project are determined based on expert estimates. At the same time, it is quite difficult to set these values in the form of a crisp number, and it is much easier for the expert to formulate the values of the characteristics as verbal estimates, taking subjective notions and sensations into consideration. One such way to simplify the task for experts is using a fuzzy set approach. Therefore, verbal estimates transformed into fuzzy trapezoidal numbers are used as estimates of the values of the parameters of social and state significances (Figure 1).

Figure 1. System of trapezoidal membership functions on the carrier [0;10].



Let's consider the following term sets of the linguistic variables s_i and g_i:

$s_i = \{\text{Very low; Low; Average; High; Very high}\}$;

$g_j = \{\text{Very low; Low; Average; High; Very high}\}$.

Let's introduce a system of five corresponding trapezoidal membership functions to describe the term sets (Zadeh 1978):

$\mu_1(x) = (0; 0; 1{,}5; 2{,}5), \mu_2(x) = (1{,}5; 2{,}5; 3{,}5; 4{,}5), \mu_3(x) = (3{,}5; 4{,}5; 5{,}5; 6{,}5),$
$\mu_4(x) = (5{,}5; 6{,}5; 7{,}5; 8{,}5), \mu_5(x) = (7{,}5; 8{,}5; 10; 10)$

The membership functions built are shown in Figure 1. The social S_n and the state G_n significances of project P_n are found using the following formulas:

$$\hat{S}_n = \sum_{i=1}^{p} w_i \hat{s}_i(\Pi_n), \tag{2}$$

$$\hat{G}_n = \sum_{j=1}^{m} v_j \hat{g}_j(\Pi_n), \tag{3}$$

where: $\hat{S}_n$, $\hat{G}_n$ are levels of social and state significance of the project, w_i, v_j are weights of parameters describing social or state significance; $\hat{s}_i(\mathrm{P}_n)$ is a value of parameter s_i for project P_n; $\hat{g}_i(\mathrm{P}_n)$ is a value of parameter g_i for project P_n.

To determine the weights of the parameters, they are ranked by their significance for the portfolio. The weights of the parameters of indicators of social and state significance are calculated according to the Fishburn formula:

$$w_i = \frac{2(p-i+1)}{p(p+1)}, \tag{4}$$

$$w_j = \frac{2(m-j+1)}{m(m+1)}, \tag{5}$$

where: i, j are numbers of parameters; p, m are a number of parameters of social and state significances.

- Determination of fuzzy utility of projects for each scenario according to the formula:

$$\hat{u}_n^l = u(\mathrm{P}_n, C_l) = NPV_n^l \sqrt{\hat{S}_n} \sqrt{\hat{G}_n} \tag{6}$$

Formulas based on the expansion principle are used to perform operations with trapezoidal fuzzy numbers (Zadeh 1978). The degree dependence on variables of social and state significances models the effect of saturation of utility by these variables.

- Calculation of fuzzy expectation of utility of project $\mathrm{P_n}$:

$$m_n = E(u_n^l) = \sum_{l=1}^{L} u_n^l p_l \tag{7}$$

and fuzzy elements of covariance matrix of utilities of projects i and j:

$$v_{ij} = \sum_{l=1}^{L} (u_n^l - m_i) \cdot (u_j^l - m_j) \cdot p_l \tag{8}$$

- Setting resource constraints:

$$R_{port} = \sum_{i=1}^{N} x_i R_i \tag{9}$$

where: R_i is required amount of resources for a project, which is a fuzzy number.

- Calculation of the portfolio utility:

$$m_{port} = \sum_{i=1}^{N} x_i m_i \tag{10}$$

- Determination of the portfolio risk using the following formula:

$$\sigma_{port}^2 = \sum_{i,j=1}^{N} x_i x_j v_{ij} \tag{11}$$

- The company's project portfolio is formed using the criterion of the maximum expected utility, with restrictions on the degree of the portfolio risk and the amount of resources required for its implementation:

$$\begin{cases} \sum_{i=1}^{N} x_i m_i \to max; \\ \sum_{i,j=1}^{N} x_i x_j v_{ij} \le \sigma_{port}^2 \\ \sum_{i=1}^{N} x_i R_i \le R_{port}\,. \end{cases} \quad (12)$$

- Conversion of the fuzzy model (12) into a precise formulation using the approach presented in the work (Anshin, Demkin, Nikonov, and Tsarkov 2008). The confidence levels $\lambda_{\sigma^2}, \lambda_R, \gamma$ are fixed for restrictions on risk, resources and objective function, respectively. The result is the following system of relations:

$$\begin{cases} m \to max; \\ N_{\sum x_i m_i}(m, m, \infty, \infty) \ge \gamma; \\ N_{\sum x_i x_j v_{ij}}\left(\sigma_{port}^2\right) \ge \lambda_{\sigma^2}; \\ N_{\sum x_i R_i}\left(R_{port}\right) \ge \lambda_R; \\ x_i \in \{0,1\}. \end{cases} \quad (13)$$

Here $N_A(B) > \gamma$ means that number A meets the constraint B with the confidence level γ. For fuzzy trapezoidal numbers, the relations in (13) using formulas from (Dubois and Prade 1988, Wang and Hwan 2007) are presented in the form of crisp inequations and result in the crisp task of Boolean quadratic programming, which can be solved using typical packages of numerical optimization programs.

2. Results and discussion

The above fuzzy set model of formation of the project portfolio can be applied in real conditions. Let's consider an example of formation of a portfolio of real projects of the development and construction company conducting activity on the market of the Primorsk Territory.

The company considers four projects for implementation:

- The first project of the company P_1 is construction of a residential block of several houses with infrastructure and traffic junctions.
- The second project P_2 is construction of the concrete plant.
- The third project P_3 is construction of a highway interchange within the city, as part of the state order.
- The fourth project P_4 is infill construction of several houses.

Due to constraints on resources, investment capabilities and the level of expected risk for the company, not all projects will be included in the portfolio and implemented. The optimal composition of the portfolio must be determined. The optimal project portfolio is formed according to the algorithm described above.

1) Three scenarios for the environment development are considered: S_1 is pessimistic, S_2 is realistic and S_3 is optimistic. Probability of each scenario is determined expertly, according to the corresponding linguistic scale. The normalized fuzzy probabilities of scenarios are calculated. The results of the calculations are presented in Table 1.

Table 1. Normative fuzzy probabilities of scenarios

Scenario	Normative fuzzy probability of the scenario
S_1	(0.077; 0.227; 0.333; 0.667)
S_2	(0.385; 0.500; 0.722; 1.167)
S_3	(0.000; 0.091; 0.167; 0.333)

2) NPV is calculated using formula (1) in order to estimate the level of satisfaction of the requirements of owners, investors and company personnel for each project, taking the scenario into account. Table 2 provides the results of calculations.

Table 2. Fuzzy values of NPV of the project, taking the scenario into account

Project	Scenario		
	S_1	S_2	S_3
	Fuzzy value of NPV of the project, taking the scenario into account		
P_1	(0.890; 0.900; 0.906; 0.913)	(1.165; 1.167; 1.171; 1.173)	(1.254; 1.258; 1.260; 1.265)
P_2	(0.315; 0.317; 0.322; 0.325)	(0.481; 0.485; 0.487; 0.491)	(0.527; 0.534; 0.539; 0.542)
P_3	(0.165; 0.168; 0.170; 0.171)	(0.242; 0.246; 0.250; 0.252)	(0.295; 0.298; 0.300; 0.305)
P_4	(0.990; 1.000; 1.010; 1.015)	(1.580; 1.585; 1.587; 1.589)	(1.786; 1.788; 1.791; 1.793)

3) The key parameters of these indicators are identified, and the weights of the parameters are calculated using formulas (4), (5), respectively, after expert ranking, to calculate the social and state significances of the projects. The weight of the parameter depends on its importance for the parameter estimated. It must be noted that for each company, the sets of parameters of social and state significances will be different, in view of the specifics and peculiarities of the particular company under consideration. Two sets of parameters of social significance S_i and state significance G_i, provided in Tables 3, 4, were considered as an example.

Table 3. Parameters of social significance

Parameter name	Notation	Parameter weight, %
Level of housing provision in the city	S_1	0.25
Level of employment	S_2	0.21
Provision of the population with means of communication	S_3	0.18
State of the road infrastructure	S_4	0.14
Provision of population with medical aid	S_5	0.09
Amount of harmful substances emitted	S_6	0.09
Index of the physical volume of trade turnover	S_7	0.04

Table 4. Parameters of state significance

Parameter name	Notation	Parameter weight, %
Participation in the state program	G_1	0.33
Execution of the state order	G_2	0.26
Improvement of the city infrastructure	G_3	0.20
Influence of the state structures	G_4	0.13
Architectural merit	G_5	0.08

Then the values of the parameters of the social and state significances for each project are calculated. Table 5 provides verbal estimates of the parameters $s_i(P_1)$, $g_j(P_1)$, fuzzy values of the parameters $\hat{s}_i(P_1)$, $\hat{g}_j(P_1)$ and their weights for the project P_1 as an example.

Table 5. Values of the parameters of the social and state significance of the project P_1

Parameter notation	Verbal estimate	Fuzzy value, score	Parameter weight, %
S_1	Very high	(7.5; 8.5; 10; 10)	0.25
S_2	Average	(3.5; 4.5; 5.5;6.5)	0.21
S_3	High	(5.5; 6.5; 7.5;8.5)	0.18
S_4	Average	(3.5; 4.5; 5.5;6.5)	0.14
S_5	Average	(3.5; 4.5; 5.5;6.5)	0.09
S_6	Low	(1.5; 2.5; 3.5; 4.5)	0.09
S_7	Average	(3.5; 4.5; 5.5;6.5)	0.04
G_1	High	(5.5; 6.5; 7.5;8.5)	0.33
G_2	Very low	(0; 0; 1.5: 2.5)	0.26
G_3	High	(5.5; 6.5; 7.5;8.5)	0.20
G_4	Average	(3.5; 4.5; 5.5;6.5)	0.13
G_5	High	(5.5; 6.5; 7.5;8.5)	0.08

Final fuzzy values of the level of the social $\hat{S}_1$ and state $\hat{G}_1$ significances of the project P_1 are found using formulas (2), (3), respectively:

$$\hat{S}_1 = (4{,}68; 5{,}68; 6{,}81; 7{,}56), \hat{G}_1 = (3{,}81; 5{,}44; 5{,}68; 6{,}68).$$

The values of parameters of the social and state significances for projects P_2, P_3 and P_4 are calculated in a similar way. Fuzzy values of the level of the social $\hat{S}_1$ and state $\hat{G}_1$ significances of projects P_2, P_3 and P_4 are respectively equal to:

$$\hat{S}_2 = (2{,}64; 3{,}21; 4{,}55; 5{,}30), \hat{G}_2 = (3{,}44; 4{,}24; 5{,}47; 6{,}21);$$
$$\hat{S}_3 = (2{,}33; 3{,}08; 4{,}27; 5{,}13), \hat{G}_3 = (5{,}36; 6{,}36; 7{,}66; 8{,}07);$$
$$\hat{S}_4 = (3{,}51; 4{,}37; 5{,}44; 6{,}44), \hat{G}_4 = (1{,}11; 1{,}85; 2{,}98; 3{,}98);$$

4) Utilities of each project, taking the scenario into account, are identified according to formula (6). An example of calculating the utility for the project P_1, taking into account the scenario S_1, is provided below:

$$\hat{u}_1^1 = \hat{u}(P_1, S_1) = NPV_{11}\sqrt{\hat{S}_1}\sqrt{\hat{G}_1} = (0{,}890; 0{,}900; 0{,}906; 0{,}913)\times\sqrt{(4{,}68; 5{,}68; 6{,}81; 7{,}56)}\times$$
$$\times\sqrt{(3{,}81; 4{,}55; 5{,}68; 6{,}68)} = (3{,}7858; 4{,}575; 5{,}633; 6{,}486).$$

Table 6 shows the results of calculating fuzzy project utility values for each scenario S_1.

Table 6. Fuzzy values of the project utilities

Project	Scenario		
	S_1	S_2	S_3
	Project utility, taking the scenario into account, bln rub.		
P_1	(3.758; 4.575; 5.633; 6.486)	(4.919; 5.933; 7.280; 8.333)	(5.295; 6.395; 7.834; 8.987)
P_2	(0.948; 1.169; 1.606; 1.864)	(1.448; 1.788; 2.428; 2.816)	(1.587; 1.969; 2.688; 3.108)
P_3	(0.582; 0.743; 0.972; 1.100)	(0.854; 1.088; 1.432; 1.621)	(1.041; 1.318; 1.715; 1.962)
P_4	(1.954; 2.843; 4.067; 5.139)	(3.119; 4.507; 6.390; 8.045)	(3.525; 5.084; 7.211; 9.077)

5) Calculating the fuzzy expectations of the projects according to formula (7):

$$m_1 = (2.181;\ 4.588; 8.441; 17.041), m_2 = (0.630;\ 1.338; 2.737; 5.0563),$$
$$m_3 = (3.373;\ 0.833; 1.644; 3.278), m_4 = (1.350;\ 3.362; 7.172; 15.837).$$

Values of the covariance matrix calculated using formula (8) are provided in Table 7.

Table 7. Elements of the covariance matrix

Project	Project			
	P_1	P_2	P_3	P_4
	Values of the covariance matrix			
P_1	(-33.081; -4.899; 11.974; 335.055)	(-11.718; -1.990; 4.870; 114.633)	(-6.709; -1.130; 2.804; 66.912)	(-35.811; -5.542; 13.549; 351.013)
P_2	(-11.718; -1.990; 4.870; 114.633)	(-3.897; -0.706; 1.981; 39.225)	(-2.296; -0.419; 1.141; 22.896)	(-12.036; -1.984; 5.512; 120.091)
P_3	(-6.709; -1.130; 2.804; 66.912)	(-2.296; -0.419; 1.141; 22.896)	(-1.314; -0.221; 0.660; 13.368)	(-7.027; -1.154; 3.177; 70.098)
P_4	(-35.811; -5.542; 13.549; 351.013)	(-12.036; -1.984; 5.512; 120.091)	(-7.027; -1.154; 3.177; 70.098)	(-36.795; -5.460; 15.338; 367.733)

6) Setting resource constraints. To simplify the example, the resource constraint will be set for the financial type of resources only. Volume of the required financial investment for the projects implementation is provided in Table 8.

Table 8. Volume of the required financial investment for the projects implementation

Project	Fuzzy value of investment in the project
P_1	(2.677; 2.680; 2.686; 2.700)
P_2	(0.393; 0.395; 0.398; 0.400)
P_3	(0.197; 0.200; 0.205; 0.210)
P_4	(3.058; 3.065; 3.070; 3.078)

Constraint on financial resources of the company for implementation of the project portfolio R_0 amounts to 3.720 bln rub.;

7) The portfolio utility will be calculated using formula (9).

8) The portfolio risk will be determined using formula (10).

9) For a company striving to maximize utility, taking into account a certain level of risk and the set resource constraints, the model will take the following form, according to formula (11):

$$\begin{cases} \sum_{i=1}^{4} x_i m_i \to max; \\ \sum_{i,j=1}^{4} x_i x_j v_{ij} \le \sigma^2 ; \\ \sum_{i=1}^{4} x_i R_i \le 3{,}72 . \end{cases}$$

10) In order to reduce the fuzzy optimization task to a crisp one, it is necessary to set the significance levels for the objective function and for each constraint. In the general case, these significance levels may vary. In our example, for simplicity, let's set the significance level of the constraint on risk as $\lambda_{\sigma^2} = 0{,}95$, on resources as $\lambda_R = 0{,}95$, and on the objective function as $\gamma = 0{,}95$. Conversion to crisp upper limits on risk requires preliminary calculation of the auxiliary matrix

$R = (r_{ij})_{ij=1}^{N}$, where $r_{ij} = (1-\gamma) \cdot a_3^{ij} + \gamma \cdot a_4^{ij}$, if $v_{ij} = (a_1^{ij};\ a_2^{ij};\ a_3^{ij};\ a_4^{ij})$.

The sum of all elements of the matrix R is the exact lower bound of all possible crisp auxiliary constraints on risk under which the solution of the optimization task is the set of all the projects under consideration (at the corresponding budget). In our example, it amounts to 2,138.94. Such artificially large values of the auxiliary constraints on risk are determined by the fact that the right boundaries of the fuzzy values of the covariance matrix $(a)_4^{ij}$ significantly exceed the abscissas of the remaining vertices of the trapezium $(a_1^{ij};\ a_2^{ij};\ a_3^{ij})$ in absolute value. Conversion from a fuzzy constraint on the total costs $(b_0^1;\ b_0^2;\ b_0^3;\ b_0^4)$ to a crisp auxiliary budget constraint b_0 also occurs according to a formula where the abscissas of only two right vertices of the trapezoid are involved: $r_{ij} = b_0 = (1-\gamma) \cdot b_0^3 + \gamma \cdot b_0^4$. Due to this, it is proposed to conduct defuzzification of fuzzy risk and fuzzy budget of the selected project portfolio using the mean maximum method, as well as defuzzification of fuzzy utility.

The calculations result in crisp coefficients of the objective function:

$$\mathrm{m}_1 = 2{,}301, \mathrm{m}_2 = 0{,}665, \mathrm{m}_3 = 0{,}396, \mathrm{m}_4 = 1{,}450.$$

The obtained values of the covariance matrix are presented in Table 9.

Table 9. Crisp values of the elements of the covariance matrix

Project	Project			
	P_1	P_2	P_3	P_4
	Values of the covariance matrix			
P_1	318.901	109.145	63.707	334.140
P_2	109.145	37.363	21.808	114.362
P_3	63.707	21.808	12.732	66.752
P_4	334.140	114.362	66.752	350.113

The "Find Solution" tool for the MS Excel add-in package is used to define the composition of the portfolio. Table 10 provides some results of the application of the model.

Table 10. Modeling of the formation of the project portfolio (maximization of expected utility of the project portfolio,γ = 0,95)

Constraint on total costs (bln rub.)	Auxiliary constraint on the risk of the project portfolio	Numbers of projects included in the portfolio	Project portfolio risk	Expected utility of the project portfolio	Total costs of the project portfolio (bln rub.)
3.72	712.98	1, 2	0.5	2.967	3.099

According to the data provided in the table, the following results were obtained in result of application of the model under consideration:

- projects for implementation are P_1, P_2;
- utility of the project portfolio $m_{port} = 2.967$;
- volume of resources required for the project portfolio $R_{port} = 3.099$.

At the solution of the standard task of optimization of the portfolio of projects, taking into account only the financial indicator of the projects NPV_n^l, the results of calculations for the example considered above are provided in Table 11.

Table 11. Modeling of the formation of the project portfolio

Constraint on total costs (bln rub.)	Auxiliary constraint on risk	Numbers of projects included in portfolio	Portfolio risk	Expected value of NPV of portfolio	Total costs of portfolio (bln rub.)
3.72	10.256	3, 4	0.5	0.819	3.287

Note: Maximization of the expected NPV of the project portfolio, $\gamma = 0{,}95$

According to the data provided in the table, the following results were obtained in result of application of the model under consideration:

- projects for implementation are P_3, P_4;
- NPV of the project portfolio $NPV_{port} = 0.819$;
- volume of resources required for the project portfolio $R_{port} = 3.287$.

The set of projects for implementation obtained in case of the use of the developed model differs from the set of projects for implementation obtained in the solution of the standard task of optimization of the project portfolio using financial indicators. Due to the fact that non-financial indicators of the social and state importance of the project, as well as constraints on the expected level of risk and the available resources for the company are taken into account in the model, a more accurate assessment of the project portfolio has been obtained, which takes into account the requirements of all stakeholders.

Conclusion

This paper proposes a fuzzy optimization model for the formation of a portfolio of investment projects, which allows to take into account non-financial indicators of social significance and state significance of projects, along with economic indicators, which allows to take into account the requirements of the main stakeholders.

Risks are managed within the framework of the portfolio investment theory of H. Markowitz using the scenario approach. The model is a fuzzy quadratic programming task with a multiplicative objective utility function, which uses expert verbal assessments of qualitative indicators of social and state significances converted to fuzzy trapezoidal numbers. The fuzzy set approach allows to model the lack of information in the implementation of each scenario for the quantitative indicator of the economic efficiency of the project "net present value". Constraints in the model are also fuzzy. The fuzzy optimization task is reduced to a crisp one at the given significance level for the objective function and constraints and can be solved by standard numerical methods. By setting various levels of reliability, the decision-maker takes into account the existing uncertainty, to a greater or lesser extent. This will change the composition of the portfolio.

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