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Fuzzy Multi-Period Models for Optimizing an Institution's Project Portfolio Inclusive of Risks and Corporate Social Responsibility

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Abstract

Fuzzy multi-period optimization models of supporting decision-making for the selection of project portfolio in the program for an institution's strategic development are suggested. In the face of uncertainty, it seems promising to use a fuzzy-set approach, in which the verbal expert assessment of the possible impact of the implementation of projects and emerging risks are transformed into fuzzy sets, followed by formulation and solution of fuzzy optimization problems. Corporate social responsibility of the institution is manifested in setting objectives, taking into account the interests of all stakeholders. The risks are taken into account in the framework of Markowitz' portfolio selection theory using a scenario approach. A function of general specific utility is used as a fuzzy objective function, the fuzzy arguments of which are the levels of achievement of the institution's strategic objectives as a result of the project by the periods given the importance of the objectives and the value of the project discounted costs. It is assumed that the project utility will depend on how the levels of achievement of the strategic objectives grow by periods, while different level growth rates are preferred for different objectives. It is also assumed that different structures of investing resources by periods differ in preference, and therefore additional fuzzy resource constraints are introduced for each time period in the model. Analytical set of the fuzzy objective function is based on a previously proposed universal method for constructing the utility function of an arbitrary number of variables (criteria) at any relationships between variables. A method of setting membership functions of fuzzy general specific utility of projects within the different scenarios is suggested. All constraints in the models are also fuzzy. Fuzzy optimization problems are reduced to the crisp ones and are solved using standard methods. The use of the proposed models is demonstrated by the example of the university.

Keywords: program for an institution's strategic development, project portfolio, corporate social responsibility, utility function, scenario-based approach, fuzzy model.

INTRODUCTION

This article is a continuation of the authors' works on the problem of pre-selection of reconstruction and development projects (strategic activities) within the formation of the program for an institution's strategic development.

In previous works, the authors proposed crisp one-period and multi-period models for optimizing a project portfolio within the framework of the investment program of development inclusive of risks and corporate social responsibility of an institution, adhering to stakeholder management as a discrete institutional alternative [1-4].

The models are based on an approach that takes into account the need for corporate social responsibility in the development of strategic plans [5] including strategy maps [6, 7] which allows to consider the levels of achievement of the objectives achieved as a result of implementation of projects as utilities of these projects.

This approach is an alternative to the approach in which additional indicators are introduced to reflect the stakeholder significance of the project, such as social significance and national importance [8-10].

An approach, in which an assessment of project compliance with the various objectives of the company is taken into account in deciding on the project inclusion in the portfolio, is quite common. For example, in the work [11], the process of project selection in the portfolio is carried out taking into account compliance with the planned project results and the company's strategic objectives in the field of sustainable development. The problem of alignment of the company's objectives and projects was also considered in the works [12-20]. Various approaches to quantify the conformity of projects with strategic objectives have also been proposed in these and other works. In this regard, the work [21] can be highlighted, in which the alignment of objectives and projects are implemented through a series of steps: objective – link of the value chain – strategic results – project. The author proposes the indicators of compliance of objectives and portfolio, indicators of integrated evaluation of achievement of objectives, and methods of their calculation.

The disparity of different objectives for the institution is accounted for in most of these works, while at the same time their possible interdependence (the presence of the causal relationships between them) is not taken into account. We must recall that our proposed models consider the strategic objectives that directly relate to the satisfaction of the stakeholders' demands. They are objectives of the top level of the strategy map (objectives of "stakeholders" perspective) [7, 23] so these objectives can be considered independent, as there is no direct cause-and-effect relationship between them. However, such links are present at the level of the underlying perspectives.

Fuzzy-set models of the project portfolio optimization play a special role in the formation of the project portfolio. Using fuzzy-set approach allows to take into account the inaccuracy of the earlier project evaluations, when there is no accurate information on financial flows and resource costs, as well as allows for an expert evaluation of the non-financial indicators of the project on the linguistic scales [14]. Fuzzy optimization models with fuzzy objective functions and fuzzy constraints allow to obtain different solutions for different exogenously specified satisfaction degrees [12].
In this regard, it seems promising to expand the models previously proposed by the authors using the tools of a fuzzy-set theory. The goal of this work is to develop fuzzy multi-period models for optimizing an institution's project portfolio inclusive of risks and corporate social responsibility.

MODELS

As before, we consider the problem of optimizing the program of an institution's development taking into account corporate social responsibility and constraints on resources, investment volumes, as well as risks. This problem is a problem of portfolio investment [23, 24]

There are *N* projects $P_1, P_2, \ldots, P_N$ that impact *K* strategic goals $G_1, G_2, \ldots, G_K$ of an institution.

It is expected that $G_1, G_2, \ldots, G_K$ are objectives of a top level of the strategy map (objectives of "stakeholder's" perspective), the achievement of which is directly related to the satisfaction of the stakeholders' demands.

The strategic objectives have different significance (importance) in terms of impact on the institution's mission. In a crisp setting, the objectives' weights $w_1, w_2, \ldots, w_K$ were determined using one of the methods described in [25, 26].

In the fuzzy case, the weights of objectives can be defined as fuzzy numbers (for simplicity, triangular or trapezoidal). Experts can be presented with a certain linguistic scale (term-set of the linguistic variable "*k*-th objective's weight"), for example, {Very low; Low; Below average; Average; Above average; High; Very high} with specified membership functions. In the future, expert opinions are summarized (aggregated) and normalized as proposed in the work [27]. The result is the normalized fuzzy weights of objectives. Note that the sum of the normalized fuzzy weights is a fuzzy number, "blurry" around unity.
The optimal portfolio needs to be generated from these projects based on the existing resources of the organization, the risks of projects and their utilities.
To simulate the internal and external conditions, we shall apply a scenario approach: let's consider *L* scenarios of possible changes in internal and external environments $S_1, S_2, \ldots, S_L$, where $p_1, p_2, \ldots, p_L$ are probabilities of these scenarios. The probabilities of scenarios may also be defined as fuzzy numbers (similarly as objective's weight). These probabilities (just like, indeed, crisp probabilities of

scenarios) are not classical, but rather express the degree of expert confidence in certain changes in internal and external conditions.

Each of the projects P_n is described with the following indicators:

- levels of achievement of the objectives $A_n^l = \left(a_{n1}^l, a_{n2}^l, \dots a_{nK}^l\right)$ in the implementation of the project within the framework of the scenario S_l;
- volume of the resources B_n necessary for the realization.

Let's suppose that investment of resources in the framework of the project is carried out in unequal installments over *T* time periods, i.e. $B_n = \sum_{t=1}^{T} B_n^t$. In the fuzzy case, B_n^t values can also be expertly specified as fuzzy numbers with the appropriate linguistic scale, and the value B_n is calculated as the sum of fuzzy numbers.

In each period, there is an increase in levels of achievement of the relevant objectives. Thus, sequences $\left(a_{nk}^{l1}, a_{nk}^{l2}, \dots, a_{nk}^{lT}\right), \sum_{t=1}^{T} a_{nk}^{lt} = a_{nk}^l, k = 1, \dots, K, n = 1, \dots, N, l = 1, \dots, L$ appear.

It is assumed that for some strategic objectives, the rapid growth of their achievement level is more "advantageous", while for other objectives the slow growth may be preferred. Accordingly, the utility of the relevant project should depend on the growth rate of the level of achievement of the objectives.

Numbers a_{nk}^{lt} can also be fuzzy. The linguistic variable "Growth of the level of achievement of the *k*-th objective in the period *t* within the *l*-th scenario in result of implementation of the *n*-th project" may have the same term-set as for the objective weight.

It is assumed that different structures of resource investment differ in preference by periods due to the fact that the cost of resources and difficulty of their access may vary in different periods. In this regard, the fuzzy value of discounted costs can be calculated for each project P_n $(n = 1, \dots, N)$. In this case, the discount rate can also be set as fuzzy.

Thus, for each objective G_k within project P_n in the implementation of scenario S_l, we have a set $\left(a_{nk}^{l1}, a_{nk}^{l2}, \dots, a_{nk}^{lT}, B_n'\right)$, which determines $\tilde{u}_{nk}^l$ – the specific utility of project P_n regarding objective G_k in the implementation of scenario S_l.

The general specific utility $\tilde{u}_n^l$ of project P_n in the implementation of scenario S_l is found as follows:

$$\tilde{u}_n^l = \sum_{k=1}^{K} w_k \tilde{u}_{nk}^l . \qquad (1)$$

The previously developed crisp multi-period models proposed a special procedure for determining the value $\tilde{u}_{nk}^l$ using the set $\left(a_{nk}^{l1}, a_{nk}^{l2}, \ldots, a_{nk}^{lT}, B_n'\right)$. It is based on the construction of T+1-dimensional surface being an approximation (with the required accuracy) of the graph of the function $\tilde{u}_k = f\left(x_1, x_2, \ldots, x_T, x_{T+1}\right)$ regarded as a function of utility: $\tilde{u}_k \in [0,1]$, $x_t \in [0,1], t = 1, \ldots, T$, interval of the change of the variable x_{T+1} is defined by constraints on resources.

The universal method of constructing such surfaces for the utility functions of an arbitrary number of variables (criteria) at any relationships between the criteria is given in the work [28]. The method consists in generating of the issues of a particular type for a survey of experts using some algorithm, determining the function values at the corresponding points based on the experts' responses and calculating values of the function at any given point from its domain.

In the fuzzy case, the values $\tilde{u}_{nk}^l$ (and hence $\tilde{u}_n^l$) will also be fuzzy numbers. In this case, the membership functions $\tilde{u}_{nk}^l$ can be defined as follows:

$$\mu_{\tilde{u}_{nk}^l}(\tilde{u}_k) = \sup\left\{\mu_1(x_1) \cdot \mu_2(x_2) \cdot \ldots \cdot \mu_{T+1}(x_{T+1}) \middle| (x_1, \ldots, x_{T+1}) \in (f)^{-1}(\tilde{u}_k)\right\}, \tilde{u}_k \in [0,1]. \qquad (2)$$

In accordance with the proposed procedure for the surface built for the G_k objective, fuzzy values $\tilde{u}_{nk}^l$ can be determined for all N projects for all L scenarios. Thus, all you need is to build K surfaces (for each objective) and to find $K \cdot N \cdot L$ of the fuzzy variables $\tilde{u}_{nk}^l$.

Levels of achievement of objectives in each period, and, therefore, the general specific utilities $\tilde{u}_n^l$ will be regarded as fuzzy random variables that depend on a number of external and internal factors, which are functions of time. The dispersions of the general specific utilities $D\tilde{u}_n^l$ will be used as a risk measure. At the same time, both expectations and the dispersions of general specific utilities will also be fuzzy numbers.

Let's define a binary variable y_n that takes the values 0 and 1, as follows:

- y_n = 0, if project n is not included in the program for the development of the institution;

- $y_n = 1$, if project n is included in the program for the development of the institution;

The following scheme to analyze and construct the optimal portfolio is suggested:

1. For each of N projects under consideration, we fuzzily define the costs in each of T periods under consideration and calculate the discounted costs of the project.
2. We determine the fuzzy weight coefficients of K upper-level strategic objectives.
3. For each objective, we build a surface, which is an approximation of the graph of a specific utility function considered as a function of T+1 variables (criteria), where the first T criteria are a possible increase in the level of achievement of objective in each of the T periods, and the last criterion is discounted costs of the project that ensured the growth of the level of achievement of objective.
4. We define a set of scenarios $S_1, S_2, \ldots, S_L$ and fuzzily estimate the probability of each of them $p_1, p_2, \ldots, p_L$.
5. For each scenario for each project, we define its fuzzy specific utilities with respect to each objective (with the help of built surfaces and formula (2)), and calculate a fuzzy general specific utility of the project using formula (1).
6. We find the fuzzy expectation of the utility of the project n:

$$m_n = E(\tilde{u}_n^l) = \sum_{l=1}^{L} \tilde{u}_n^l p_l \; . \tag{3}$$

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

$$v_{ij} = \sum_{l=1}^{L} (\tilde{u}_i^l - m_i)(\tilde{u}_j^l - m_j) p_l \; . \tag{4}$$

7. Fuzzily set the upper limit on the available resources B_0.
8. Accept the utility of the portfolio as the value $m_{port} = \sum_{i=1}^{N} y_i m_i$, the portfolio risk – as the value $\sigma_{port}^2 = \sum_{i,j=1}^{N} y_i y_j v_{ij}$.

Using the assumptions, ratios and designations above, it is suggested to form the project portfolio using the following models.

<u>Model one</u>. Development program of the institution is formed by the criterion of the maximum of the program utility under the restrictions on the amount of risk of the program (σ_0^2), and the volume of resources required for the implementation of the program (B_0):

$$\begin{cases} \sum_{i=1}^{N} y_i m_i \to \max, \\ \sum_{i,j=1}^{N} y_i y_j v_{ij} \le \sigma_0^2, \\ \sum_{i=1}^{N} y_i B_i \le B_0. \end{cases} \tag{5}$$

Model two. Development program of the institution is formed by the criterion of the minimum of the program risk under the restrictions on the volume of resources required for implementation of the program (B_0), and the value of the program utility (m_0):

$$\begin{cases} \sum_{i,j=1}^{N} y_i y_j v_{ij} \to \min, \\ \sum_{i=1}^{N} y_i m_i \ge m_0, \\ \sum_{i=1}^{N} y_i B_i \le B_0. \end{cases} \tag{6}$$

The formulated models of formation of the optimal portfolio of projects of the development program of the institution are fuzzy Boolean quadratic programming problems. These problems are reduced to the crisp Boolean quadratic programming problems (7) and (8) using the techniques described in the works [12, 29, 30], and then can be solved by standard methods.

$$\begin{cases} m \to \max, \\ N_{\sum y_i m_i}(m, m, \infty, \infty) \ge \gamma, \\ N_{\sum y_i y_j v_{ij}}(\sigma_0^2) \ge \lambda_{\sigma^2}, \\ N_{\sum y_i B_i}(B_0) \ge \lambda_B, \\ y_i \in \{0,1\}. \end{cases} \tag{7}$$

$$\begin{cases} \sigma_0^2 \to \min, \\ N_{\sum y_i y_j v_{ij}}(\infty, \infty, \sigma_0^2, \sigma_0^2) \ge \gamma \\ N_{\sum y_i m_i}(m_0) \ge \lambda_m, \\ N_{\sum y_i B_i}(B_0) \ge \lambda_B, \\ y_i \in \{0,1\}. \end{cases} \tag{8}$$

Here $N_A(B) \geq \gamma$ means that the fuzzy number A satisfies the fuzzy constraint B with a satisfaction degree γ. $\gamma, \lambda_{\sigma^2}, \lambda_m, \lambda_B$ are satisfaction degrees for the objective function and constraints on risk, utility and budget portfolio.

In this case, if $A = < a_1; a_2; a_3; a_4 >$ is a trapezoidal fuzzy number, and $B = < 0; 0; b_3; b_4 >$ is a trapezoidal fuzzy upper bound, then $N_A(B) \geq \gamma$ is equivalent to the inequation $(1-\gamma)a_3 + \gamma a_4 \leq \gamma b_3 + (1-\gamma)b_4$. If $B = < b_1; b_2; 0; 0 >$ is a trapezoidal fuzzy lower bound, then $N_A(B) \geq \gamma$ is equivalent to the inequation $\gamma a_1 + (1-\gamma)a_2 \geq (1-\gamma)b_1 + \gamma b_2$.
For each project portfolio, which is a solution of crisp optimization problems, we calculate a fuzzy risk, fuzzy utility and fuzzy budget. These fuzzy portfolio characteristics can be converted into crisp values using defuzzification technique.

RESULTS

The use of the crisp multi-period models previously developed by the authors was demonstrated by the example of the practice of the Vladivostok State University of Economics and Service (VSUES). To demonstrate the proposed fuzzy models, let's take the same example as a basis for purposes of clarity of the features of the fuzzy-set tools.
Three strategic objectives "Enhancing the publication activity of the teaching staff", "Improving the academic degree holders rate of the teaching staff", "Increasing the volume of the funds attracted by the university teaching staff" are still considered. Their weights on the above linguistic scale are expertly identified. Normalized fuzzy weights of the objectives are calculated: <0.15; 0.22; 0.41; 0.57> <0.08; 0.13; 0.29; 0.43> and <0.31; 0.39; 0.65; 0.86> respectively (hereinafter we will deal with trapezoidal fuzzy numbers).
Three scenarios of possible changes in internal and external environment are also considered (pessimistic, realistic and optimistic). The probability of each scenario is expertly determined on the respective linguistic scale. The normalized fuzzy probabilities of scenarios are calculated: <0.08; 0.23; 0.33; 0.67> <0.38; 0.50; 0.72; 1.17> and <0; 0.09; 0.17; 0.33> respectively.
Next, a surface must be built for each objective, which is an approximation of the graph of specific utility function considered as a function of three variables (criteria), where the first two criteria are a possible increase in the level of achievement in each of two periods, while the third criterion is discounted costs. The values of all variables and functions are crisp numbers in the construction of surfaces.
Let's consider the same nine strategic measures (projects), the implementation of which over two periods (two years each) will contribute to the achievement of selected objectives.

1. Establishment and operation of incentive system for teaching staff who have publications in top journals.
2. Establishment and operation of the support system for young scientists, including in the framework of the "Talent Pool" program.

3. Establishment and operation of the incentive system for supervisors and graduate students.
4. Establishment and operation of the system to attract leading scientists to the university staff.
5. Establishment of a flexible system of requirements for the teaching staff hired on a competitive basis, which motivates to improve the efficiency of scientific activity.
6. Establishment and operation of student involvement in scientific research since the first years with the restructuring of the educational process.
7. Establishment and operation of the system for increasing the teaching staff academic mobility.
8. Establishment and operation of the system to involve teaching staff in students' internships at enterprises in the framework of practice-integrated learning.
9. Establishment and operation of the system for enhancing the university teaching staff image in the external environment.

Let's fuzzily define the necessary costs by periods and calculate the fuzzy discounted costs for each project. The results are shown in Table 1. Fuzzy discount rate is defined as <0.09; 0.1; 0.1; 0.115>. We should note that the project costs in the first period are in fact crisp numbers, since it is possible to determine them relatively exactly. They will be more and more "blurred" for each subsequent period.

Table 1. Project costs (mln rub.)

Project	Period 1	Period 2	Discounted costs
1	<8; 8; 8; 8>	<7; 8; 8; 10>	<12.9; 14.0; 14.0; 15.7>
2	<14; 14; 14; 14>	<13; 14; 14; 17>	<23.2; 24.4; 24.4; 27.1>
3	<10; 10; 10; 10>	<5; 6; 6; 8>	<13.3; 14.3; 14.3; 16.0>
4	<10; 10; 10; 10>	<6; 8; 8; 11>	<14.0; 15.9; 15.9; 18.5>
5	<0.3; 0.3; 0.3; 0.3>	<0.15; 0.2; 0.2; 0.3>	<0.40; 0.44; 0.44; 0.53>
6	<4; 4; 4; 4>	<3.5; 4; 4; 5>	<6.5; 7.0; 7.0; 7.9>
7	<4.8; 4.8; 4.8; 4.8>	<4.5; 4.8; 4.8; 5.5>	<8.0; 8.4; 8.4; 9.0>
8	<0.3; 0.3; 0.3; 0.3>	<0.3; 0.3; 0.3; 0.5>	<0.51; 0.52; 0.52; 0.69>
9	<2.5; 2.5; 2.5; 2.5>	<3; 3.5; 3.5; 4.5>	<4.7; 5.2; 5.2; 6.0>

Let's fuzzily define the sequences of increments in the levels of achievement of objectives by periods for each scenario. Table 2 shows an example of the respective data for the second and third projects.

Table 2. Results of projects

Scenario	Period	Objective 1	Objective 2	Objective 3
Project 2				
Pessimistic	1	<0.010; 0.015; 0.020; 0.023>	<0; 0.003; 0.007; 0.010>	<0.005; 0.008; 0.012; 0.015>
	2	<0.024; 0.030; 0.036; 0.040>	<0.060; 0.065; 0.070; 0.075>	<0.011; 0.015; 0.020; 0.024>
Realistic	1	<0.025; 0.030; 0.035; 0.040>	<0.060; 0.064; 0.070; 0.075>	<0.019; 0.023; 0.027; 0.029>
	2	<0.040; 0.045; 0.055; 0.060>	<0.085; 0.080; 0.086; 0.090>	<0.024; 0.030; 0.036; 0.040>
Optimistic	1	<0.045; 0.048; 0.055; 0.060>	<0.012; 0.015; 0.020; 0.025>	<0.026; 0.030; 0.036; 0.040>
	2	<0.060; 0.065; 0.070; 0.075>	<0.026; 0.030; 0.035; 0.040>	<0.045; 0.048; 0.055; 0.060>
Project 3				
Pessimistic	1	<0.010; 0.015; 0.020; 0.022>	<0.075; 0.080; 0.085; 0.090>	<0.005; 0.008; 0.012; 0.014>
	2	<0.025; 0.030; 0.035; 0.040>	<0.070; 0.080; 0.086; 0.092>	<0.010; 0.015; 0.020; 0.025>
Realistic	1	<0.026; 0.030; 0.034; 0.040>	<0.006; 0.008; 0.012; 0.015>	<0.020; 0.024; 0.027; 0.030>
	2	<0.040; 0.045; 0.053; 0.058>	<0.012; 0.014; 0.020; 0.023>	<0.025; 0.030; 0.035; 0.040>
Optimistic	1	<0.045; 0.047; 0.055; 0.060>	<0.010; 0.015; 0.020; 0.024>	<0.026; 0.030; 0.035; 0.040>
	2	<0.062; 0.065; 0.070; 0.075>	<0.125; 0.130; 0.140; 0.145>	<0.045; 0.048; 0.053; 0.060>

We define 27 fuzzy values of the specific utility for each objective, using an appropriate constructed surface: for each of the nine projects for three scenarios (81 values for all three objectives in total). After that, we calculate fuzzy general specific utilities of the projects in the implementation of each scenario (Table 3) and the fuzzy expectations of utilities of the projects, and build the fuzzy covariance matrix of specific utilities of the projects.

Table 3. General specific utilities of the projects

Project	Scenario 1	Scenario 2	Scenario 3
1	<0.021; 0.037; 0.081; 0.138>	<0.035; 0.057; 0.128; 0.204>	<0.040; 0.074; 0.153; 0.240>
2	<0.013; 0.023; 0.056; 0.089>	<0.018; 0.034; 0.078; 0.119>	<0.028; 0.045; 0.105; 0.160>
3	<0.022; 0.043; 0.092; 0.149>	<0.035; 0.063; 0.133; 0.212>	<0.046; 0.080; 0.174; 0.255>
4	<0.056; 0.089; 0.181; 0.296>	<0.067; 0.105; 0.202; 0.323>	<0.073; 0.117; 0.235; 0.364>
5	<0.039; 0.065; 0.126; 0.201>	<0.051; 0.086; 0.179; 0.275>	<0.070; 0.110; 0.214; 0.340>
6	<0.010; 0.018; 0.037; 0.059>	<0.019; 0.031; 0.063; 0.101>	<0.028; 0.047; 0.093; 0.139>
7	<0.021; 0.034; 0.069; 0.108>	<0.034; 0.058; 0.114; 0.180>	<0.046; 0.081; 0.162; 0.249>
8	<0.050; 0.081; 0.151; 0.216>	<0.071; 0.100; 0.201; 0.293>	<0.079; 0.117; 0.228; 0.376>
9	<0.031; 0.045; 0.085; 0.119>	<0.049; 0.069; 0.128; 0.201>	<0.060; 0.087; 0.160; 0.261>

In order to reduce the fuzzy optimization problems to crisp optimization problems, it is necessary to set satisfaction degrees for the objective function and each constraints. In general, these satisfaction degrees can be different. In this example, they are set equal for simplicity.

We formulate and solve crisp problems of Boolean quadratic programming for a given satisfaction degree.

Table 4 shows some results of the application of the first model, when the university development program is formed by the criterion of maximum program utility under the specific restrictions on the amount of program risk and volume of resources.

We should note that the transition to crisp upper bound constraints on the risk requires preliminary calculation of the auxiliary matrix $R = (r_{ij})_{i,j=1}^{N}$, where $r_{ij} = (1-\gamma)a_3^{ij} + \gamma a_4^{ij}$, if $\nu_{ij} =< a_1^{ij}; a_2^{ij}; a_3^{ij}; a_4^{ij} >$. The sum of all elements of the matrix R is the greatest lower bound of all possible crisp auxiliary constraints on the risk at which the solution of the optimization problem is the set of all the projects under consideration (with the appropriate budget). In our example, it is equal to 26.40.

Such artificially high values of auxiliary constraints on the risk are caused by the fact that the right borders of fuzzy values of the covariance matrix (a_4^{ij}) are significantly larger in absolute value than the abscissas of the remaining vertices of the trapezoid $(a_1^{ij}, a_2^{ij}, a_3^{ij})$. The transition from the fuzzy constraint on total costs $< b_0^1; b_0^2; b_0^3; b_0^4 >$ to the crisp auxiliary budget constraint b_0 also occurs according to the formula, which involves the abscissas of only two right vertices of the trapezoid: $b_0 = (1-\gamma)b_0^3 + \gamma b_0^4$. In this regard, it is proposed to carry out defuzzification of a fuzzy risk and fuzzy budget of the selected project portfolio through the method of the mean maximum, just like the defuzzification of the fuzzy utility.

Table 4. Simulation of the formation of the university development program (maximization of the program utility, model one, $\gamma = 0.95$)

Auxiliary constraint on the total costs (mln rub.)	Auxiliary constraint on the risk of the project portfolio	Projects included in the portfolio	Project portfolio risk	Expected utility of the project portfolio	Total discounted costs of the project portfolio (mln rub.)
61.3	13.05	2, 4, 5, 6, 8, 9	0.116	0.666	53.4
	15.66	1, 3, 5, 6, 7, 8, 9	0.158	0.727	49.7
	19.57	3, 4, 5, 6, 7, 8, 9	0.173	0.797	51.6
66.0	13.05	2, 4, 5, 6, 8, 9	0.116	0.666	53.4
	15.66	1, 3, 5, 6, 7, 8, 9	0.158	0.727	49.7
	19.57	1, 3, 4, 5, 6, 8, 9	0.175	0.803	57.2
92.2	13.05	2, 4, 5, 6, 8, 9	0.116	0.666	53.35
	15.66	1, 2, 3, 4, 6, 8, 9	0.145	0.725	81.13
	19.57	1, 3, 4, 5, 6, 8, 9	0.175	0.803	57.17
	26.10	1, 3, 4, 5, 6, 7, 8, 9	0.221	0.891	65.54
101.0	26.40	All projects	0.256	0.951	89.95

Table 5 shows the results of the application of the second model, when the university development program is formed by the criterion of the minimum risk of the program with constraints on the volume of resources and the value of the expected specific utility.

In this case, the transition from the fuzzy lower bound constraint on expectation $< m_1; m_2; m_3; m_4 >$ to a crisp auxiliary constraint m is done according to the formula: $m = \gamma m_1 + (1-\gamma) m_2$. As a result, crisp auxiliary constraints on expectation are artificially low. At the same time, fuzzy risk, fuzzy utility and fuzzy budget are still calculated for the selected project portfolios, which are translated into crisp ones through defuzzification relative to the mean maximum.

Table 5. Simulation of the formation of the university development program (risk minimization, model two, $\gamma = 0.95$)

Auxiliary constraint on the total costs (mln rub.)	Auxiliary constraint on the expected utility of the project portfolio	Projects included in the portfolio	Expected utility of the project portfolio	Project portfolio risk	Total discounted costs of the project portfolio (mln rub.)
61.3	0.089	5, 6, 8, 9	0.442	0.053	13.1
	0.112	4, 5, 8, 9	0.558	0.076	22.0
	0.134	4, 5, 6, 7, 8, 9	0.695	0.127	37.3
	0.157	Constraint on utility cannot be met			
66.0	0.089	5, 6, 8, 9	0.442	0.053	13.1
	0.112	4, 5, 8, 9	0.558	0.076	22.0
	0.134	4, 5, 6, 7, 8, 9	0.695	0.127	37.3
	0.157	1, 3, 4, 5, 7, 8, 9	0.843	0.194	58.6
	0.168	Constraint on utility cannot be met			
92.2	0.089	5, 6, 8, 9	0.442	0.053	13.1
	0.112	4, 5, 8, 9	0.558	0.076	22.0
	0.134	4, 5, 6, 7, 8, 9	0.695	0.127	37.3
	0.157	1, 3, 4, 5, 7, 8, 9	0.843	0.194	58.6
	0.168	1, 3, 4, 5, 6, 7, 8, 9	0.891	0.221	65.5
101.0	0.179	All projects	0.256	0.951	89.95

The γ satisfaction degree determines the kind of a crisp objective function and stiffness of constraints, and therefore has an impact on the composition of the portfolio and its fuzzy and crisp evaluations. The smaller γ is, the more the blur of fuzzy model parameters, i.e. uncertainty, is taken into account.

Table 6 shows how the composition of the optimal project portfolio at various γ changes (risk minimization, model two). A fuzzy upper bound constraint on the total costs <52.27; 61.02; 61.02; 65.83> and fuzzy lower bound constraint on the expected utility of the project portfolio <0.0815; 0.2315; 0.2315; 0.3815> are set.

If necessary, you can find more accurate γ values, at which there are changes in the composition of portfolios. 0.969 is one of such γ values.

Table 6. Simulation of the formation of the university development program at different satisfaction degrees (risk minimization, model two)

γ	Auxiliary constraint on the total costs (mln rub.)	Auxiliary constraint on the expected utility of the project portfolio	Projects included in the portfolio	Expected utility of the project portfolio	Project portfolio risk	Total discounted costs of the project portfolio (mln rub.)
0.75	62.22	0.119	4, 5, 8	0.46	0.051	16.8
0.80	61.98	0.112	4, 5, 8	0.46	0.051	16.8
0.85	61.74	0.104	5, 6, 8, 9	0.44	0.053	13.1
0.90	61.50	0.097	5, 6, 8, 9	0.44	0.053	13.1
0.95	61.26	0.089	5, 6, 8, 9	0.44	0.053	13.1
0.99	61.07	0.083	4, 8, 9	0.42	0.041	21.5

CONCLUSION

The paper proposes fuzzy multi-period optimization models of supporting decision-making for the selection of project portfolio in the program for an institution's strategic development. Corporate social responsibility of the institution is manifested in setting goals, taking into account the interests of all stakeholders. The risks are taken into account in the framework of Markowitz' portfolio selection theory using a scenario approach. A function of general specific utility is used as a fuzzy objective function, the arguments of which are the levels of achievement of the institution's strategic objectives as a result of the project by the periods given the importance of the objectives and the value of the project discounted costs. It is assumed that the project utility will depend on how the levels of achievement of the strategic objectives grow by periods, while different level growth rates are preferred for different objectives. It is also assumed that different structures of investing resources by periods differ in preference due to the fact that the difficulty and cost of access to resources may vary in different periods. Analytical set of the fuzzy objective function is based on a previously proposed universal method for constructing the utility function of an arbitrary number of variables at any relationships between variables. A method of setting membership functions of fuzzy general specific utility of projects within the different scenarios is suggested. Constraints in the models are also fuzzy. Fuzzy optimization problems are reduced to the crisp ones and are solved using standard methods. This requires an exogenous setting of satisfaction degrees for the objective functions and constraints. Setting various satisfaction degrees, the decision maker takes into account existing uncertainties to a greater or lesser extent. In this case, the composition of the portfolio will change.

Further research in this area can be directed to the development of fuzzy optimization models of rolling planning of the institution's project portfolio inclusive of risks and stakeholders' demands.

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