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Original paper

# Fuzzy-logic model for feasibility study of project implementation: Projects investment risk

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**Abstract**

This article poses and solves the problem of evaluating the feasibility of innovative project's financing in the face of uncertainty due to the need to combine both quantitative and qualitative characteristics. It is suggested to build a range of tools for assessing the investment risks on the basis of the mathematical fuzzy logic methods, which allow the use and accumulation of specialists' knowledge. A logical-linguistic model allowing the establishment of relationship between input and output parameters when assessing the attractiveness level of projects has been developed on the basis of production rules compiled by experts. The model is implemented with the help of MATLAB system and allows, in conditions of uncertainty, making scientifically and quantitatively sound decisions when financing investment projects.

*Keywords:* Investment risk, logical-linguistic model, fuzzy logic.

## 1 Introduction

Currently, one of the dominant factors in the economic development of any country is the formation of innovative mechanisms aimed at preserving, developing and using scientific and technical knowledge in material production. The main task of the innovative mechanisms is to form the functional support, in which a special role belongs to the investment activity at all levels: Federal, regional, municipal and institutional. One of the key tools for implementing the innovative projects is investments, which form the scientific and technical basis of production and are the driver of economic development, at both macro and micro levels. Currently, the issues of investment decision-making in the implementation of innovative projects that contribute to the sustainable development of organizations are given special attention in scientific research, as evidenced by a wide range of scientific publications Wagner, Bode [38], Kardes, et. al [23], Lehtinen, et. al [29], Nachbagauer, Schirl-Boeck [31]. An integral part of investment activity is the presence of risks. The market economy is characterized by a high degree of uncertainty: The changes in market conditions, the behavior of market entities, the geopolitical situation, etc. Investment activity becomes meaningless without taking into account the risk factors. The investment risk we understand as possibility of undesirable, negative events as a result of investment of the resources in the project. As a result of investments, there is always a chance that the investor may lose resources invested in the project. Investment risks are potential threats to the investment process associated with the loss of invested funds. But, nevertheless, the success of investment activity largely depends on the ability of the investor to assess the magnitude of these losses, the emerging level of risk and to make an investment decision on this basis.

In modern science, there is a wide variety of approaches to assessing investment risks and the methods used to assess them. Among the modern studies that model social, technical, economic, environmental, and political risks, we can distinguish the works Kim, Lee [25], Cavusgil, Deligonul [7]. Common works in which the risk assessment of investment

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projects is carried out on the basis of the methodology of analytical and simulation modeling Borodin, Mityushin, Streltsova, Kulikov, Yakovenko, Namitulina [5], Wu [41], Williams et. al [40]. Risk assessment of investment projects is a multi-criteria task with conflicting criteria, which requires finding some compromise. This has aroused great interest among researchers in the application of game-theoretic methods to optimize decisions made in the development of investment projects Bai, Zhou, et. al [2], Wang, et. al. [39]. Among the indicators that assess the level of risk, along with quantitative ones, qualitatively expressed characteristics are also used. This led to the use of the mathematical apparatus of fuzzy logic and coarse sets in the development of investment risk assessment models in modern research Qu, et. al. [32], Huang, Wei [17]. Noting the high importance of the research results presented in the works of modern scientists, the problem of assessing investment risks is not sufficiently studied. In modern research, the issues of computer processing of qualitatively expressed indicators in the assessment of investment risks of innovative projects are not sufficiently developed.

This article hypothesizes the greatest impact of the following types of risks on the success of projects: economic, social, technical and environmental. It is advisable to use the mathematical methods that allow processing the qualitative characteristics for quantitative assessment of investment risks as an integral indicator taking into account the factors mentioned above. The aim of the article is to build a logical-linguistic model that allows, in conditions of uncertainty caused by the presence of qualitative characteristics, to conduct an assessment of the investment feasibility of innovative projects' implementation.

This article contributes to the development of fuzzy-logical models of risk assessment in the implementation of investment projects. As a leading method for creating a mathematical model, the article suggests the mathematical apparatus of fuzzy logic.

## 2 Literature foundations

In the scientific literature there are various concepts for assessing the risks to which the projects are exposed. According to the authors Djakovic, Andjelic, Petkovic [10], Asimit, Li [1]; Vaitkevicius [16] the risk assessment tools should be developed using an integrated approach that takes into account a number of problems. Moreover, the information characterizing the level of risk should not be uniform. The researchers play a large role in assessing the investment environment in which the investment project is being implemented. In this regard, market volatility is a frequently used indicator in assessing the risk of investment activity. Thus, the author of Degiannakis [9] proposed an approach to forecasting the market volatility in assessing the occurrence of risk situations.

A distinctive feature of the research is the assessment of a long-term memory and the heterogeneous autoregressive models to determine the European Union stock market indices. The author assesses the methods used in terms of the forecasting horizon. The studies of Chen, Chiang [8] are dedicated to an empirical analysis of the relationship between stock value downside risk and its expected returns. The authors developed a two-level model that allows taking into account the level of uncertainty based on switching Markov modes and solving the problem of compromise in the risk-return mode. The interagency relationship between the volatility index and stock market returns on the example of India was studied by Shaikh [33]. The research results showed a negative correlation between the daily change in the volatility index and the value of stocks, which can be used to diversify the investment portfolio.

The increased interest of the authors of modern scientific developments in the value assessment of risks (VAR) Kang, Li [22], Lee [28], Miletic and Miletic [40], Zhou, Yang, et.al [19] should also be noted. In all works, the attention is drawn to the fact that the VAR assessment provides a significant flexibility to investors in the decision-making process when implementing a portfolio strategy. In the conditions of the global financial crisis, the accurate measurements and risk allocation are extremely important, as they allow managing the investment portfolio effectively. To evaluate VAR, it was proposed to apply the statistical data processing methods and optimization methods. In industrialized countries, the financing of fundamental innovative projects is provided by the state. To do this, a wide variety of mechanisms for public procurement of innovative products, the allocation of various preferential credit guarantees, the formation of various forms of public-private partnerships, etc. are in place. The issue of optimizing investments provided to public-private partners, assessing their potential in implementing investment projects is a very difficult task.

A rational model of public-private partnerships was proposed by Yasyukyavichyus, Vasilyauskaite [18], Kuchta [26]. The model can serve as a decision support tool to assess the feasibility of implementing an investment project. Engineering economics deals with the problems of making investment decisions, the methods of which are based on the assessment of time value. In life situations, the accurate assessment of investment characteristics is fraught with significant difficulties due to the uncertainty in which the ongoing investment projects are immersed. In this regard, a wide range of scientific papers is devoted to the development of analysis methods based on the use of fuzzy algebra and fuzzy logic. The methods of investment analysis in a fuzzy environment were developed in the studies Belokrylova, Belokrylov, Streltsova, Tsygankov, Tsygankova, [3], Kahraman, Onar, Oztaysi [20], Kahraman, et.al. [19], Kahraman, Ruan, Tolga [21], Kaufmann and Gupta [31]. Based on the proposed methods, a methodology has been developed for constructing the semantics (membership function) of fuzzy sets used in determining the current value of projects. The uncertainty-reducing approaches in the analysis of economic systems were developed in the studies of Gradojevic, Gencay [14], Cao, Luo, Ni, Luo, Zhang [6], Dubois, Prade [13]. The use of fuzzy models in a control to simplify the computational procedures was proposed in the article by Dombey, Tóth-Laufer [11]. The authors improved the neoclassical Solow model to ensure the growth rate of the technological process through the proposed alternative growth path based on the application of scientific and technical knowledge. Given the fact that the growth rate of technological progress is constantly changing, the authors proposed to decompose the general path of economic growth into components: capital and products. In accordance with the proposed model of economic growth, the growth parameters were identified, and their numerical simulation were applied to the Polish economy in a century-long horizon. The constructed models made it possible to evaluate the various options for the annual rate of economic progress of the Polish economy.

The use of a fuzzy-logical approach for decision-making in public administration in dealing with citizens is stated in studies by Bobar, Božanić, Djurić, Pamučar [4]. In contrast to the traditional intuitive service evaluation methods, the authors proposed the tools based on the formal ranking method of Thomas Saati. In contrast to the well-known method, the authors proposed the use of a fuzzification procedure that allows processing the poorly structured information expressed in natural language forms. A new arithmetic approach to the control with apply of the analytical fuzzy logic programming was proposed in the studies of Dombi, Szépe [12]. Instead of a logical conclusion, the authors developed a new method for calculating a linear combination of membership functions and a new defuzzification operation. The advantage of the method is its superiority from the classical method in accuracy. A comparative analysis of the defuzzification methods of fuzzy sets in the context of environmental risk assessment, as well as the determination of modern trends and prospects in the design of genetic fuzzy systems were made by Užga-Rebrovs, Kuešova [35] and Herrera [15]. The authors described the basic principles of fuzzy inference to assess the dynamics of environmental risk depending on the changes in adverse factors. The emphasis is placed on the choice of fuzzification methods transferring the factors real values into the values of linguistic variables, as well as the defuzzification methods. The general theoretical and practical problems in the implementation of fuzzy logical control of technical systems are revealed in the studies of Larsen [27]. The author provides a formal description of two different cement kiln management projects. The conclusion is drawn on the effectiveness of decision-making based on the use of the analytical fuzzy logic programming. A fuzzy control system based on the brain emotional learning was developed in the studies of Hsu, Su, Lee T. [16]. The system consists of fuzzy controllers that perform the function of suppressing inadequate responses. Summing up the analysis, we can conclude that the mathematical programming of the fuzzy-logical modeling is actively used in the modern research. The theoretical and practical results achieved so far allow us to conclude that fuzzy logic is a promising tool for decision-making in the management of poorly structured objects. It makes it possible to process the knowledge of specialists expressed in the high-quality linguistic descriptions and represented by logical constructions of a natural language.

But, despite the wide range of research conducted in the field of creating tools for assessing investment risks, not all aspects are effective. The disadvantages of the proposed methods and models are the use of traditional approaches for assessing the investment attractiveness, which are narrow in the conditions of the modern economy. The need to use not only economic, but also other indicators, such as environmental, etc., requires the construction of economic and mathematical tools that operate with integral indicators based on the convergence of quantitatively and qualitatively expressed characteristics. Currently, the tools for assessing investment risks require adaptation to changes not only in the quantitative composition of indicators, but also to changes in their formal representations. When analyzing the fuzzy logic model tools proposed in the modern literature, their drawback is the lack of the possibility of constructing formal expressions of the dependencies of input parameters on output parameters and, consequently, the impracticability of the task of estimating the degree of influence of variations of each of the input variables on the change in the response value.

In this article, we propose a synthesis of fuzzy logic methods and the method of planning an experiment in the model of analyzing the investment attractiveness of projects.This article proposes a logical-linguistic model for evaluating the investment alternatives with application of the mathematical fuzzy logic programming, developed by a professor at the American University Zadeh [43]-[44] and having the properties of adaptation to the specified changes. The research results of this article are the development of previous studies Ziyadin, Streltsova, Borodin, et.al. [46], Vasylieva, Jurgilewicz, Poliakh, Tvaronavičienė, Hydzik, [37], Szetela, Mentel, Bilan, [34].

## 3 Research methods

Despite the fact that a large number of scientific studies have been devoted to assessing the investment attractiveness of innovative projects based on the use of quantitative indicators, the methods, models and algorithms proposed so far do not allow formalizing many arising situations and thereby solving these problems. Often, the investment attractiveness of innovative projects is evaluated mainly on the basis of processing the economic and financial indicators. The hypothesis about the need to develop and implement the developing innovative projects that are able to function in a changing environment has been accepted in the article. At the same time, the emphasis is placed on sustainable development, in which the project is able to maintain its functions not only in the economic, but also in the social and environmental spheres. Economic stability involves the increase of innovative projects' profitability (profitability index, internal rate of return, modified internal rate of return), net present value, etc. A common drawback of the existing approach is the need to use quantitative source data. But each innovative project, in addition to quantitative ones, is characterized by a multitude of qualitative initial data creating an immeasurable uncertainty that must be taken into account when assessing the investment attractiveness of innovative projects. It is uncertainty that creates the conditions of risk when assessing the attractiveness of innovative projects, i.e. the hazard conditions for the complete or partial loss of invested resources. These circumstances make it necessary, firstly, to adapt the quantitative characteristics to the possibility of their use with qualitative indicators, and, secondly, to use a mathematical programming that can process the various types of uncertainties and maintain a balance between economic, social and environmental indicators. In this regard, the article proposes the statement of the task of assessing the investment attractiveness of innovative projects as an investment risk based on the use of the mathematical apparatus of soft computing. In the given task for joint processing of determinate data with uncertainty factors, the quantitative indicators were adapted to qualitative characteristics. The conceptual scheme of the assessment system of the innovative projects' investment attractiveness is shown in Figure 1.

The study of the innovative projects' investment attractiveness is carried out on the basis of cybernetic principles using feedback. In accordance with Figure 1, the investor assesses the investment risk of a set of innovations $\{Progect_1, Progect_2, ..., Progect_n\}$ through an analysis of investment attractiveness using a vector indicator $\{Profit_1, Profit_2, Profit_3, Cost, Ecology\}$, the components of which are the following: $Profit_1$ – profitability index; $Profit_2$ – internal rate of return; $Profit_3$ – modified internal revenue rate; $Cost$ – net present value; $Ecology$ – ecological security level.

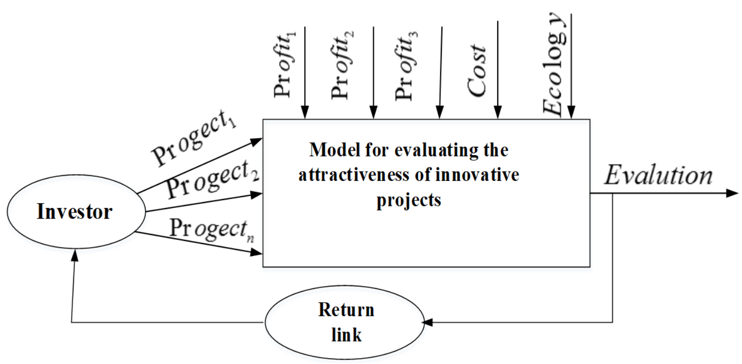


Figure 1: The conceptual scheme of the assessment system of the innovative projects investment risk.

As an output parameter, the level of innovative feasibility $Evalution$ of implementing an innovative project is considered as an indirect indicator of the investment risk. The task is set in this way to find the relationship between evaluating the investment feasibility $Evalution$ of implementing an innovative project $Progect_i$, $i = \overline{1,n}$ and indicators $Profit_1$, $Profit_2$, $Profit_3$, $Cost$, $\{Profit_1, Profit_2, Profit_3, Cost, Ecology\}$:

$$Evalution = \varphi(Profit_1, Profit_2, Profit_3, Cost, Ecology).$$

For dependency $\varphi : (\{Profit_i\}_{i=1}^3, Cost, Ecology) \to Evalution$, the demands are made to maintain a balance between economic, social and environmental indicators. The quantitative indicators $Profit_1, Profit_2, Profit_3, Cost$ are transformed into qualitative characteristics described formally by the following linguistic variables: $\langle Profit_i, \Theta, U, \mu_{Profit}\rangle$, $i = \overline{1,3}$, $\langle Cost, \Theta(Cost), U, \mu_{Cost}\rangle$. A variable $\Theta$ is a term-set of characteristics $Profit_1, Profit_2, Profit_3, Cost$ consisting of a set of qualitative indicators $\Theta = \{Low, Average, High\}$. Value $U$ identifies the universality of characteristics, and $\mu_\mu = \{\mu^\eta_{Low}, \mu^\eta_{Average}, \mu^\eta_{High}\}, \eta = \{Profit_1, Profit_2, Profit_3, Cost\}, \mu^\eta_\alpha : U \to [0, 20]$, if $\eta \in \{Profit_i\}^3_{i=1}$ and $\mu^\eta_\alpha : U \to [0, 10]$, if $\eta = Cost$ – semantics of fuzzy sets $\alpha \in \{Low, Average, High\}$.

Environmental safety level *Ecology*, as well as the output value, which reflects the degree of feasibility of implementing an innovative project, are represented by linguistic variables $\langle Ecology, \Theta, \mu_{Ecology}\rangle$, $\langle Evalution, \Theta, \mu_{Evalution}\rangle$, $\mu^{Ecology}_\alpha : U \to [0, 10]$, $\mu^{Evalution}_\alpha : U \to [0, 10]$.

A formal description of the semantics of fuzzy sets is obtained by applying the method of expert assessments. A group of experts was interviewed in accordance with this method. The results of the survey were the content of the matrix $\gamma = \|\gamma_{ij}\|$ with a certain number of lines $m$ and columns $k$.The matrix elements take the values $\gamma_{ij} \in \{0, 1\}$, $i = \overline{1, m}$, $j = \overline{1, k}$. Rows $i$ of the matrix $\gamma = \|\gamma_{ij}\|$ we identified the number of the expert in the group of specialists participating in the survey, and the columns $j$ – numbers from the universe $U$ the fuzzy set under analysis. At the intersection of the line with the number $i$ and the column with the number $j$ the expert must put one or zero in case of agreement or disagreement that the number $u \in U$ in the column header $j$ corresponds to the evaluation of a fuzzy set. The article presents the results of expert assessments of semantics $Low, Average, High$ fuzzy sets of a linguistic variable *Ecology*, presented in Table 1.

As a result of processing the data in Table 1, the values of the membership functions of the fuzzy set were determined by the formula $\mu_o = \frac{\sum_{i=1}^m \gamma_{ij}}{k}$. Fig. 2, 3, 4 clearly demonstrate the expediency of choosing trapezoidal membership functions of terms $Low, Average, High$.

Table 1: Results of the expert survey of fuzzy sets $Low, Average, High$ a linguistic variable *Ecology*

| Fuzzy sets | Experts | Elements of the universe $U$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| *Low* | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| | 3 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| | 4 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| *Average* | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 |
| | 4 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | 5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| | 6 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| *High* | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 4 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| | 5 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 6 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |

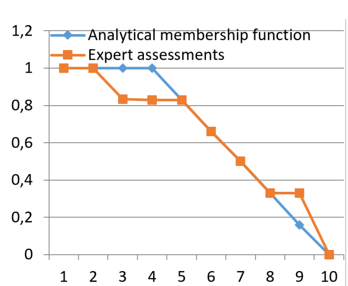


Figure 2: Graph of the membership function of the fuzzy *Low* set of the linguistic variable *Ecology*.

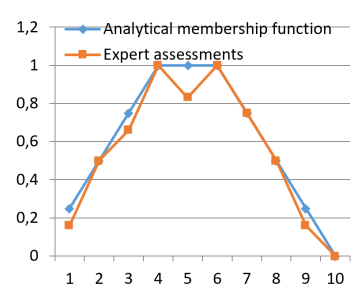


Figure 3: Graph of the membership function of the *Average* fuzzy set of the linguistic variable *Ecology*.

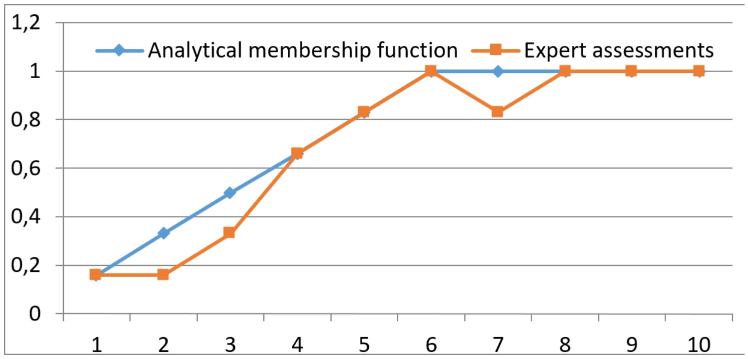


Figure 4: Graph of the membership function of the fuzzy set $High$ of the linguistic variable $Ecology$.

Semantics of fuzzy sets of linguistic variables $Profit_1, Profit_2, Profit_3, Cost$ it was built in a similar way. Analytic expressions for membership functions of fuzzy sets $Profit_1, Profit_2, Profit_3, Cost, Evalution$ are as follows:

$$\mu_{Low}^{Profit_i} = \begin{cases} 0, Profit_i < 0; \\ 1, 0 < Profit_i < 5; \\ \frac{20-Profit_i}{15}, 5 < Profit_i < 20; \\ 0, Profit_i > 20; \end{cases} \quad (1)$$

$$\mu_{Average}^{Profit_i} = \begin{cases} 0, Profit_i < 0; \\ \frac{Profit_i}{5}, 0 < Profit_i < 5; \\ 1, 5 < Profit_i < 10; \\ \frac{20-Profit_i}{10}, 10 < Profit_i < 20; \\ 0, Profit_i > 20; \end{cases} \quad (2)$$

$$\mu_{High}^{Profit_i} = \begin{cases} 0, Profit_i < 0; \\ \frac{Profit_i}{10}, 0 < Profit_i < 10; \\ 1, 10 < Profit_i < 20; \\ 0, Profit_i > 20; \end{cases} \quad (3)$$

$$\mu_{Low}^{Cost} = \begin{cases} 0, Cost \leq 0; \\ \frac{10-Cost}{10}, 0 < Cost \leq 10; \\ 0, Cost > 10; \end{cases} \quad (4)$$

$$\mu_{Average}^{Cost} = \begin{cases} 0, Cost < 0; \\ \frac{Cost}{5}, 0 \leq Cost < 5; \\ \frac{10-Cost}{5}, 5 \leq Cost \leq 10; \\ 0, Cost > 10; \end{cases} \quad (5)$$

$$\mu_{High}^{Cost} = \begin{cases} 0, Cost < 0; \\ \frac{Cost-10}{10}, 0 \leq Cost \leq 10; \\ 0, Cost > 10; \end{cases} \quad (6)$$

$$\mu_{Low}^{Ecology} = \begin{cases} 0, Ecology < 0; \\ 1, 0 \leq Ecology < 4; \\ \frac{10-Ecology}{6}, 4 \leq Ecology < 10; \\ 0, Ecology \geq 10; \end{cases} \quad (7)$$

$$\mu_{Average}^{Ecology} = \begin{cases} 0, Ecology < 0; \\ \frac{Ecology}{4}, 0 \leq Ecology < 4; \\ 1, 4 \leq Ecology < 6; \\ \frac{10-Ecology}{4}, 4 < Ecology \leq 10; \\ 0, Ecology > 10; \end{cases} \quad (8)$$

$$\mu_{High}^{Ecology} = \begin{cases} 0, Ecology < 0; \\ \frac{Ecology}{6}, 6 < Ecology \leq 10; \\ 1, 6 \leq Ecology \leq 10; \\ 0, Ecology > 10; \end{cases} \quad (9)$$

$$\mu_{Low}^{Evolution} = \begin{cases} 0, Evolution < 0; \\ \frac{Evolution}{5}, 0 \leq Evolution < 5; \\ 0, Evolution > 10; \end{cases} \quad (10)$$

$$\mu_{Average}^{Evolution} = \begin{cases} 0, Evolution < 0; \\ \frac{Evolution}{5}, 0 \leq Evolution < 5; \\ \frac{10-Evolution}{5}, 5 \leq Evolution \leq 10; \\ 0, Evolution > 10; \end{cases} \quad (11)$$

$$\mu_{High}^{Evolution} = \begin{cases} 0, Evolution < 0; \\ \frac{10-Evolution}{5}, 0 \leq Evolution \leq 10; \\ 0, Evolution > 10; \end{cases} \quad (12)$$

Graphs of the membership function are shown in figures 5-8.

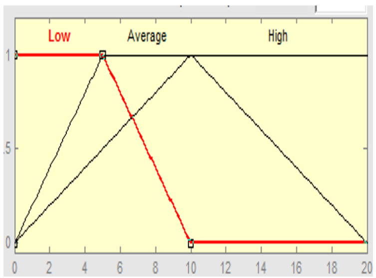


Figure 5: Graphs of linguistic variable of linguistic variable membership functions $Profit_i$.

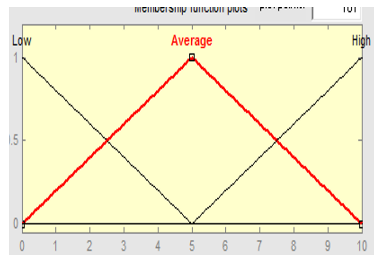


Figure 6: Graphs of linguistic variable of linguistic variable membership functions $Cost$.

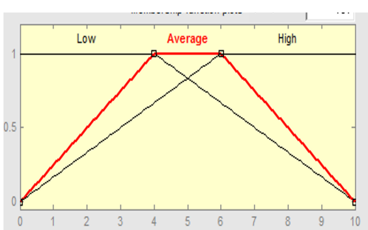


Figure 7: Graphs of linguistic variable of linguistic variable membership functions $Ecology$.

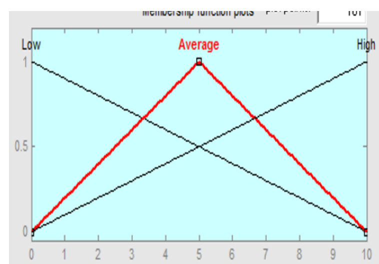


Figure 8: Graphs of linguistic variable of linguistic variable membership functions $Evalution$.

Dependency $\varphi : (\{Profit_i\}_{i=1}^{3}, Cost, Ecology) \to Evalution$ is based on production rules introduced by experts.

## 4 Research results and discussion

The dependence $\varphi : (\{Profit_i\}_{i=1}^{3}, Cost, Ecology) \to Evalution$ of the investment feasibility indicator $Evalution$ of financing an innovation project $Progect_i$ on qualitative characteristics $Profit_1, Profit_2, Profit_3, Cost$, $\{Profit_1, Profit_2, Profit_3, Profit_4, Cost, Ecology\}$ is based on the use of the knowledge of specialists formulated in the form of inference rules, having the following form:

$$W : if\ Profit_i\ is\ T_j\ and\ Cost\ is\ T_k\ and\ Ecology\ is\ T_x\ Then\ Evalution\ is\ T_\varepsilon$$

where $T_i, T_j, T_k, T_\varepsilon \in \{Low, Average, High\}$.

The structure of the fuzzy system for assessing the investment attractiveness of innovative projects is shown in Figure 9.

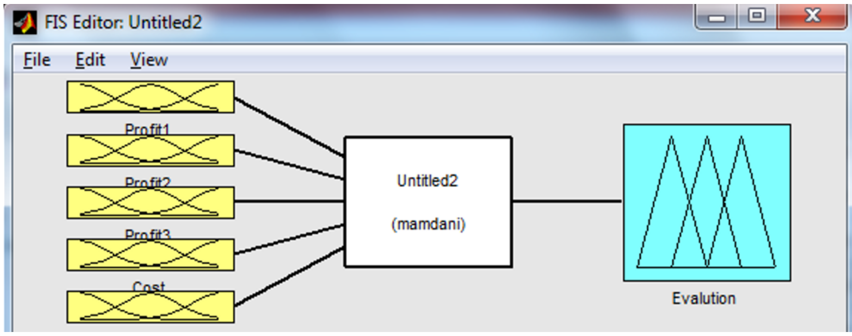


Figure 9: The structure of the fuzzy system for assessing the quality of innovative projects.

The constructed fuzzy-logical model for assessing the quality of innovative projects makes it easy to vary the quantitative values of the input parameters $Profit_1, Profit_2, Profit_3, Cost$, $\{Profit_1, Profit_2, Profit_3, Profit_4, Cost, Ecology\}$ while analyzing the quality of portfolio projects (Figure 10).

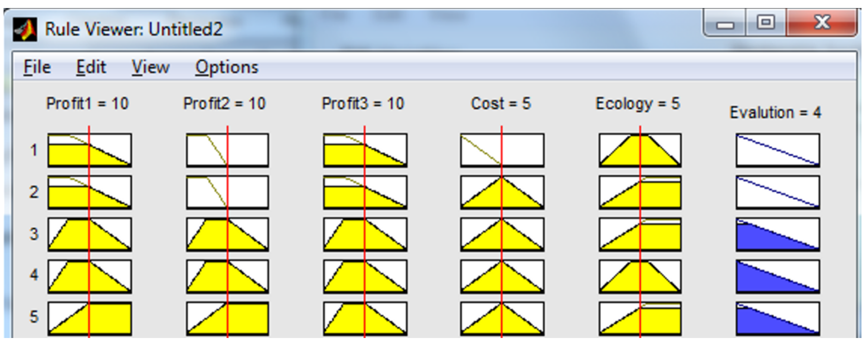


Figure 10: The result of the functioning of the evaluation system of innovative projects.

Figure 10 demonstrates that with a high level of profitability $Profit_i, i = \overline{1,3}$, the low cost $Cost$ and a low level of environmental safety $\{Profit_1, Profit_2, Profit_3, Profit_4, Cost, Ecology\}$, the degree of feasibility of financing an innovative project is estimated by the qualitative 'High' indicator.

Upon the undoubted advantages of fuzzy-logical models, they suffer from a number of disadvantages, among which one of the essentials is the unfeasibility of constructing an analytical relationship between the set of input and output variables, as well as the inability to assess the degree of variations influence of each of the variable-controlling input on the change in the response value. During the study of the feasibility of investment projects implementation, a significant fact is to obtain the nature of dependence in mathematical form $\varphi : (\{Profit_i\}_{i=1}^{3}, Cost, Ecology) \to Evalution$. It is indisputable that the constructed fuzzy-logical model of dependence implements implicitly those patterns that are established verbally by professional experts in the form of a set of production rules. In this article, this model was used as a black box for conducting the experiments in order to obtain a functional dependence $Evalution = \varphi : (\{Profit_i\}_{i=1}^{3}, Cost, Ecology)$.The authors performed a full factorial experiment on the constructed fuzzy-logical model INNOVATION with varying factors at two levels.

The indicators of an innovative project are considered as factor signs $\{Profit_1, Profit_2, Profit_3, Cost, Ecology\}$. The indicator $Evalution$ acts as a functional feature. $2^5 = 32$ experiments were carried out with various combinations of the values of factor signs at their lower and upper levels using the fuzzy-logical INNOVATION model. The designations of the upper and lower levels of factor signs are given in Table 2.

In accordance with the experimental design method, a transition from natural to coded levels of factors was made in accordance with the following analytical expressions:

$$Profit_1^{KL} = \frac{Profit_1^L - Profit_1^0}{\Delta Profit_1} = -1; \quad (13) \qquad Profit_1^{KT} = \frac{Profit_1^T - Profit_1^0}{\Delta Profit_1} = +1; \quad (14)$$

$$Profit_2^{KL} = \frac{Profit_2^L - Profit_2^0}{\Delta Profit_2} = -1; \quad (15) \qquad Profit_2^{KT} = \frac{Profit_2^T - Profit_2^0}{\Delta Profit_2} = +1; \quad (16)$$

$$Profit_3^{KL} = \frac{Profit_3^L - Profit_3^0}{\Delta Profit_3} = -1; \quad (17) \qquad Profit_3^{KT} = \frac{Profit_3^T - Profit_3^0}{\Delta Profit_3} = +1; \quad (18)$$

$$Cost^{KL} = \frac{Cost^L - Cost^0}{\Delta Cost} = -1; \quad (19) \qquad Cost^{KT} = \frac{Cost^T - Cost^0}{\Delta Cost} = +1; \quad (20)$$

$$Ecology^{KL} = \frac{Ecology^L - Ecology^0}{\Delta Ecology} = -1; \quad (21) \qquad Ecology^{KT} = \frac{Ecology^T - Ecology^0}{\Delta Ecology} = +1. \quad (22)$$

Table 2: Designation of factor signs levels

| Designation of factor signs levels | | | | | |
|---|---|---|---|---|---|
| Factor signs | $Profit_1$ | $Profit_2$ | $Profit_3$ | $Cost$ | $Ecology$ |
| The natural value of the lower level of factorial feature | $Profit_1^L$ | $Profit_2^L$ | $Profit_3^L$ | $Cost^L$ | $Ecology^L$ |
| The natural value of the upper level of factorial feature | $Profit_1^T$ | $Profit_2^T$ | $Profit_3^T$ | $Cost^T$ | $Ecology^T$ |
| Base point of the factorial feature | $Profit_1^0$ | $Profit_2^0$ | $Profit_3^0$ | $Cost^0$ | $Ecology^0$ |
| The coded value of the lower level of factorial feature | $Profit_1^{KL}$ | $Profit_2^{KL}$ | $Profit_3^{KL}$ | $Cost^{KL}$ | $Ecology^{KL}$ |
| The coded value of the upper level of factorial feature | $Profit_1^{TL}$ | $Profit_2^{TL}$ | $Profit_3^{TL}$ | $Cost^{TL}$ | $Ecology^{TL}$ |
| Base point of the factorial feature | $Profit_1^0$ | $Profit_2^0$ | $Profit_3^0$ | $Cost^0$ | $Ecology^0$ |
| Interval of factorial feature variation | $\Delta Profit_1$ | $\Delta Profit_2$ | $\Delta Profit_3$ | $\Delta Cost$ | $\Delta Ecology$ |

The results of the experiments with variations of factor signs are shown in Table 3.

Table 3 shows the results of setting up experiments with different combinations of varying factors $Profit_1, Profit_2, Profit_3, Cost, Ecology$ on the upper and lower levels.

For a factor attribute $Profit_1, Profit_2, Profit_3$ evaluated in points within the universe $U = [0, 20]$, the values 0 and 20 levels, respectively. Factor values $Cost$ vary on the universal $U = [0, 10]$, therefore, the boundaries of the segment $[0, 10]$ are its lower and upper levels, respectively. Table 3 contains the values of the factor features $\{Profit_1, Profit_2, Profit_3, Cost, Ecology\}$ in natural terms.

The planning matrix containing the values of factor features in coded expressions obtained by formulas (13-22) is presented in Table 4. The functional dependence $\varphi : (\{Profit_i\}_{i=1}^3, Cost, Ecology) \rightarrow Evalution$ was built in the class of linear models, the coefficients of which were determined on the basis of the use of the planning matrix with elements of coded values of factor features.

Table 3: Results of a complete factorial experimental set up

| Variations of the natural values of factor signs (in points) | | | | | | Functional feature *Evalution* [0-10] |
|---|---|---|---|---|---|---|
| | $Profit_1$ [0-20] | $Profit_2$ [0-20] | $Profit_3$ [0-20] | $Cost$ [0-10] | $Ecology$ [0-10] | |
| 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| 2 | 0 | 0 | 0 | 0 | 10 | 4,88 |
| 3 | 0 | 0 | 0 | 10 | 0 | 5 |
| 4 | 0 | 0 | 0 | 10 | 10 | 4,91 |
| 5 | 0 | 0 | 20 | 0 | 0 | 5 |
| 6 | 0 | 0 | 20 | 0 | 10 | 4,45 |
| 7 | 0 | 0 | 20 | 10 | 0 | 4,91 |
| 8 | 0 | 0 | 20 | 10 | 10 | 4,9 |
| 9 | 0 | 20 | 0 | 0 | 0 | 6,8 |
| 10 | 0 | 20 | 0 | 0 | 10 | 5 |
| 11 | 0 | 20 | 0 | 10 | 0 | 5,8 |
| 12 | 0 | 20 | 0 | 10 | 10 | 6,4 |
| 13 | 0 | 20 | 20 | 0 | 0 | 6,7 |
| 14 | 0 | 20 | 20 | 0 | 10 | 5 |
| 15 | 0 | 20 | 20 | 10 | 0 | 6,1 |
| 16 | 0 | 20 | 20 | 10 | 10 | 7,1 |
| 17 | 20 | 0 | 0 | 0 | 0 | 5 |
| 18 | 20 | 0 | 0 | 0 | 0 | 4,8 |
| 19 | 20 | 0 | 0 | 10 | 0 | 5 |
| 20 | 20 | 0 | 0 | 10 | 10 | 3,6 |
| 21 | 20 | 0 | 20 | 0 | 0 | 6,5 |
| 22 | 20 | 0 | 20 | 0 | 10 | 5 |
| 23 | 20 | 0 | 20 | 10 | 0 | 5,5 |
| 24 | 20 | 0 | 20 | 10 | 10 | 4,6 |
| 25 | 20 | 20 | 0 | 0 | 0 | 5,9 |
| 26 | 20 | 20 | 0 | 0 | 10 | 5 |
| 27 | 20 | 20 | 0 | 10 | 0 | 8,7 |
| 28 | 20 | 20 | 0 | 10 | 10 | 5 |
| 29 | 20 | 20 | 20 | 0 | 0 | 10 |
| 30 | 20 | 20 | 20 | 0 | 10 | 5 |
| 31 | 20 | 20 | 20 | 10 | 0 | 9,9 |
| 32 | 20 | 20 | 20 | 10 | 10 | 4,5 |

Table 4: Results of a complete factorial experimental set up with factors in the encoded expression

| Variations of the natural values of factor signs (in points) | | | | | | Functional feature *Evalution* |
|---|---|---|---|---|---|---|
| | $Profit_1$ | $Profit_2$ | $Profit_3$ | $Cost$ | $Ecology$ | |
| 1 | -1 | -1 | -1 | -1 | -1 | 5 |
| 2 | -1 | -1 | -1 | -1 | +1 | 4,88 |
| 3 | -1 | -1 | -1 | +1 | -1 | 5 |
| 4 | -1 | -1 | -1 | +1 | +1 | 4,91 |
| 5 | -1 | -1 | +1 | -1 | -1 | 5 |
| 6 | -1 | -1 | +1 | -1 | +1 | 4,45 |
| 7 | -1 | -1 | +1 | +1 | -1 | 4,91 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | -1 | -1 | +1 | +1 | +1 | 4,9 |
| 9 | -1 | +1 | -1 | -1 | -1 | 6,8 |
| 10 | -1 | +1 | -1 | -1 | +1 | 5 |
| 11 | -1 | +1 | -1 | +1 | -1 | 5,8 |
| 12 | -1 | +1 | -1 | +1 | +1 | 6,4 |
| 13 | -1 | +1 | +1 | -1 | -1 | 6,7 |
| 14 | -1 | +1 | +1 | -1 | +1 | 5 |
| 15 | -1 | +1 | +1 | +1 | -1 | 6,1 |
| 16 | -1 | +1 | +1 | +1 | +1 | 7,1 |
| 17 | +1 | -1 | -1 | -1 | -1 | 5 |
| 18 | +1 | -1 | -1 | -1 | -1 | 4,8 |
| 19 | +1 | -1 | -1 | +1 | -1 | 5 |
| 20 | +1 | -1 | -1 | +1 | +1 | 3,6 |
| 21 | +1 | -1 | +1 | -1 | -1 | 6,5 |
| 22 | +1 | -1 | +1 | -1 | +1 | 5 |
| 23 | +1 | -1 | +1 | +1 | -1 | 5,5 |
| 24 | +1 | -1 | +1 | +1 | +1 | 4,6 |
| 25 | +1 | +1 | -1 | -1 | -1 | 5,9 |
| 26 | +1 | +1 | -1 | -1 | +1 | 5 |
| 27 | +1 | +1 | -1 | +1 | -1 | 8,7 |
| 28 | +1 | +1 | -1 | +1 | +1 | 5 |
| 29 | +1 | +1 | +1 | -1 | -1 | 10 |
| 30 | +1 | +1 | +1 | -1 | +1 | 5 |
| 31 | +1 | +1 | +1 | +1 | -1 | 9,9 |
| 32 | +1 | +1 | +1 | +1 | +1 | 4,5 |

In this case, a linear model of the form was built: $Evalution = a_0 + a_1 Profit_1 + a_2 Profit_2 + a_3 Profit_3 + a_4 Cost - a_5 Ecology$. Coefficients $a_j, j = \overline{0,5}$ were determined based on the expressions:

$$a_0 = \sum_{i=1}^{32} \frac{Evalution(i)}{32}; \qquad a_1 = \sum_{i=1}^{32} \frac{Profit_1(i) * Evalution(i)}{32}; \qquad a_2 = \sum_{i=1}^{32} \frac{Profit_2(i) * Evalution(i)}{32};$$

$$a_3 = \sum_{i=1}^{32} \frac{Profit_3(i) * Evalution(i)}{32}; \qquad a_4 = \sum_{i=1}^{32} \frac{Cost(i) * Evalution(i)}{32}; \qquad a_5 = \sum_{i=1}^{32} \frac{Ecology(i) * Evalution(i)}{32},$$

where $Profit_1(i), Profit_2(i), Profit_3(i), Cost(i), Ecology(i)$ – coded values of factor features in the experiment number $i = \overline{0,32}$. The result is the following linear model:

$$Evalution = 5,6 + 0,67 Profit_1 + 0,74 Profit_2 + 0,26 Profit_3 - 1,89 Cost - 0,67 Ecology. \tag{23}$$

The constructed model allows ranking the factor features $Profit_1, Profit_2, Profit_3, Cost, Ecology$ by the degree of their influence on the response *Evalution*.

The modeling results showed that the factor $Profit_2$ – the internal rate of return has the greatest positive effect on the productive feature *Evalution* (the level of innovative feasibility of implementing the investment project).

The indicators *Cost* and *Ecology* (a net present value and a level of the environmental safety) have a negative impact on the functional feature. Although this arrangement of factors in terms of the degree of influence on the result should be treated as a subjective opinion of an experts team; their experience, knowledge and gift of foresight are especially demanded in practice when making decisions in the field of assessing the innovative feasibility of implementing an investment project.

Figure 11 shows the application of the constructed fuzzy-logical model to assess the feasibility of implementing an investment project.

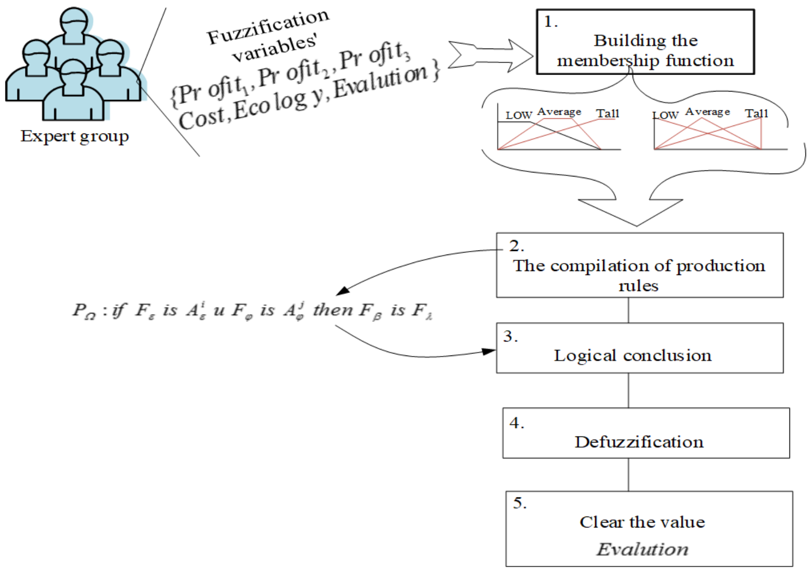


Figure 11: The application scheme of the constructed fuzzy-logical model to assess the feasibility of implementing an investment project.

The result of fuzzification is the constructed membership functions of fuzzy sets, which quantitatively describe the values of linguistic variables (block 1). The next modeling step is to compile a base of production rules (block 2), on the basis of which the dependence $\varphi : (\{Profit_i\}_{i=1}^{3}, Cost, Ecology) \to Evalution$ of the investment feasibility indicator $Evalution$ of financing an innovation project $Progect_i$ on qualitative characteristics $Profit_1, Profit_2, Profit_3, Cost$, $\{Profit_1, Profit_2, Profit_3, Cost, Ecology\}$, (block 3) is constructed according to the Mamdani algorithm. In this case, the output value $Evalution$ is presented in the form of a fuzzy set. Block 4, carrying out the defuzzification of input and output linguistic variables allows obtaining a quantitative expression of the qualitative characteristics $Evalution$.

# 5 Conclusions

The article is devoted to the construction of model tools used in investment activities in the analysis of innovative projects. The main idea of the research is not only the convergence of qualitative and quantitative methods, but also the integration of the obtained quantitative and qualitative research results. We have proposed a fuzzy logic model that allows us to analyze a portfolio of investment projects based on a combination of quantitative indicators with poorly structured qualitative characteristics. The model tools proposed in the article are based on the synthesis of mathematical devices of fuzzy logic and the method of planning experiments. The reason for the use of such a synthesis was the fact that, along with the undoubted advantages of the mathematical apparatus of fuzzy logic (the ability to adapt in the real world, accessibility to use by specialists when operating with qualitatively expressed characteristics and the ability to quickly conduct modeling), this method suffers from some disadvantages. The negative point is that the fuzzy logic approach lacks the means of structuring the dependencies between the input and output parameters of the system, which make it possible to build a formalized mathematical model. Without such tools, the created model tools are difficult to analyze mathematically from the point of view of assessing the degree of influence of each factor feature on the response value. Implementing the approach of synthesis of mathematical devices of fuzzy logic and planning of experiments, we set up a complete factor experiment based on the use of the created logical-linguistic model. Processing the results of the experiment allowed us to build an analytical relationship in the form of a linear model between the integral indicator of the investment attractiveness of the project and its input characteristics. The convergence of mathematical devices of fuzzy logic and experimental planning allowed us to formally describe the relationship between the input and output variables of the logical-linguistic model in the form of a linear equation. The advantage of the linear equation is the fact that using its coefficients, it is possible to judge the degree of influence of the input qualitatively expressed characteristics on a complex indicator that reflects the feasibility of investing in the analyzed project. The proposed integrative approach contributes to solving the problems of quantitative and qualitative description of weakly structured objects. The scientific value of the results of the research is that the proposed synthesis of methods can be used to analyze systems of different nature.

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