ELIT
Economic Laboratory Transition
Research Podgorica

Montenegrin Journal of Economics

For citation:

Morozko, N., Morozko, N., Didenko, V. (2022), "Applying on of the theory of fuzzy logic in the financial management of small companies",
Montenegrin Journal of Economics, Vol. 18, No. 4, pp. 49-60.

Applying the Theory of Fuzzy Logic in the Financial Management of Small Companies

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ARTICLE INFO

Received November 03, 2021
Revised from December 03, 2021
Accepted January 12, 2022
Available online October 15, 2022

JEL classification: G32, M21, O16.

DOI: 10.14254/1800-5845/2022.18-4.5

Keywords:

Financial management;
fuzzy logic model;
entrepreneurship

ABSTRACT

The changes taking place at the present stage require adequate changes in the assessment of the sustainable development of small business, allowing to reduce risks and ensure a sufficient level of financial stability of companies, which determines the relevance of the issues under consideration. The aim of the study is to identify methods for ensuring sustainable development of entrepreneurship, which will qualitatively model the processes of making financial decisions under conditions of uncertainty. The study forms a logical structure for sustainable development of entrepreneurship, which establishes a certain set of rules for the strategy to achieve the goal of the system. In the presence of uncertainty, there is a risk of ineffective management, in which the planned goals are not achieved. These questions can be solved based on the fuzzy logic model. A model of fuzzy sets for sustainable development of entrepreneurship is proposed, with the help of which a business entity can model variations in the development of entrepreneurial initiative, identify strengths and weaknesses and compare alternative options for doing business. The stages of implementation of the proposed fuzzy logic model are described in detail. The options for identifying the current state of the company with the interpretation of the conditions for diagnosing the financial state of the company are considered. Studies have shown the possibility of effective use of the principles of fuzzy logic and modeling in solving problems of developing entrepreneurial potential and making management decisions in conditions of uncertainty.

INTRODUCTION

Ensuring timely management of the digital transformation process requires the development of flexible methods for managing the functioning of the company, which will eliminate the negative trends associated with the influence of the cross-industrial paradigm. Most of the firms in each country are small and medium-sized companies whose sustainable development depends on many factors. Any changes and

transformations in the business are associated with a high degree of risk, which affects the financial stability of the company. In turn, the sustainability of small and medium-sized companies acts as an important resource in maintaining the sustainable development of the country's economy (Sinkovics et al., 2021, Morozko, et al., 2020c; Wach, 2020). A holistic approach to methods for determining the sustainability of companies allows you to obtain an objective assessment of the efficiency of the functioning and development of companies (Cantele and Zardini, 2018, Moldavska and Welo, 2019).

Sustainable development of small businesses depends on the ability to innovate, while the influence of systematic factors becomes dominant, the degree of uncertainty increases, which together leads to the complexity of managing the risks arising from making financial decisions (Chang and Cheng, 2019; Suttipun and Arwae, 2020; Stanek-Kowalczyk, 2021). Based on the flexibility of financial management processes, it becomes possible to minimize the risks associated with the digital transformation of small businesses (Morozko et al., 2020a).

With the digital transformation of any company, there are issues of reducing the risks associated with the type of business. Analysis of the development of entrepreneurship using fuzzy logic allows you to take into account the distinctive characteristics of the activities of each company. A number of scientists (Ladeira et al., 2019) propose to develop a fuzzy cognitive map to identify and analyze the determinants of digital entrepreneurship. In conditions of fierce competition and incomplete information, dynamic monitoring of the business environment is carried out, an algorithm for making management decisions to reduce risks is used. The parameters of sustainable development of small businesses in the context of digital transformation can be substantiated by the methods of fuzzy logic theory, which corresponds to rapidly changing situations.

The use of approaches to assessing the development of companies based on fuzzy sets allows one to take into account the flexibility of financial decisions (Okwu and Nwachukwu, 2019, Ramos et al., 2019, Naeem et al., 2020). Informed decision-making based on qualitative comparative analysis with fuzzy sets in entrepreneurship allows you to take into account uncertainty and risks (Douglas et al., 2020, Kraus et al., 2018; Das and Pal, 2020; Pezeshki and Mazinani, 2019). Many new realities associated with digital transformation require the development of measures to reduce risks and ensure a sufficient level of financial stability of companies, which predetermines the relevance of the research topic.

The aim of the study is to substantiate the use of fuzzy logic methods in diagnosing sustainable development of entrepreneurship, which will allow to qualitatively model the processes of making financial decisions under conditions of uncertainty.

The use of the mechanism of the theory of fuzzy sets allows obtaining significant competitive advantages in comparison with classical (deterministic) solutions of economic problems and ensuring the maintenance of financial stability of small companies for their continuous development.

1. METHODOLOGY

Modern conditions for the functioning of business in any country are associated with uncertainty and instability (An and Dorofeev, 2019). The development of business financial stability management requires the development of informed decisions taking into account the changing conditions.

The methodology includes a mechanism for forming the logical structure of sustainable development of entrepreneurship, which establishes a certain set of rules for the strategy to achieve the goal of the system. The authors (Khefacha and Belkacem, 2015; Kalinic and Krisp, 2019; Sahana and Patel, 2019) note that fuzzy set theory offers an approach to solving multidimensional and complex problems.

The novelty of the research lies in the proposed paradigm of fuzzy sets for sustainable development of entrepreneurship, with the help of which a business entity can model variations in the development of entrepreneurial initiative, identify strengths and weaknesses, and compare alternative options for doing business.

In the concept of a system of fuzzy control sets, an adequate correspondence of uncertainty factors acting on the system is distinguished (Zadeh, 1965; Dziwińsk and Bartczuk, 2020, Pramanik et al.,

2019; Kadam et al., 2019; Mohebbi et al., 2021, Bolos et al., 2019; Marcek, 2018). The risk management system acts as a complex dynamic object that corresponds to the hierarchical principle of construction. The paradigm of hierarchical construction of control systems for complex dynamic objects is based on fuzzy set technologies that take into account the uncertainty of the factors of the external and internal environment (Mikhailov, 2018).

In economic information, when determining the parameters of risk conditions, it is impossible to unambiguously determine the quantitative and qualitative values of the indicators; these values can be placed only in the confidence intervals. In such conditions, it is advisable to use the theory of fuzzy sets. The use of a fuzzy set system includes the following sequential actions: the purpose of the control system is determined; the most significant factors are selected; the current state of the system is set; rules of action are established that transfer the system to the design state; the projected final state of the system is formed.

Much recent research into the applicability of probability theory to accounting for uncertainty points to the limitations of classical probability theory. Since the main limitation of probability theory is to consider a set of statistically homogeneous random events, in the absence of statistical homogeneity, the use of this theory is ultimately inapplicable.

Using fuzzy-multiple approaches, almost all probable forecasts of the development of events are calculated. The isolation of the company's business processes directs research to the need to take into account the uniqueness of the company, the specifics, in this case, fuzzy sets act as a tool for calculating opportunities.

The method based on the use of fuzzy set theory allows diagnostics based on modeling economic processes based on fuzzy numbers and obtaining calculations of the degree of probability of a certain level of financial stability of the company. This method refers to the complex methods of researching management systems, acts as a way to optimize performance. The theory of fuzzy sets allows to adequately take into account the existing types of uncertainty.

2. DATA

Correlation analysis of the financial indicators of small business organizations based on statistical data revealed that a significant part of the relative indicators show similar dynamics, therefore, some indicators are redundant for analyzing the financial condition of the company. For small business organizations, it is necessary to highlight the most significant indicators: current liquidity, autonomy, asset turnover, financial risk, return on assets.

The determination of the degree of probability of the determined level of financial stability of the company is carried out on the basis of the following parameters (Table 1; Table 2).

Table 1. Indicators used to assess the financial stability of a small company

Ratio	*Characteristic*	*Calculation technology*	*Recommended values*
Current Ratio (X1- CR)	Characterizes the repayment of current liabilities at the expense of only current assets	The calculation is made by dividing the amount of current assets by the amount of current liabilities	Recommended values are 2.0. The value of the coefficient largely depends on the industry affiliation of the company
Autonomy ratio (X2-AuR)	It characterizes the degree of the company's independence from external loans and borrowings.	It is determined by the ratio of equity to the total amount of capital (balance sheet currency)	The minimum value is 0.5, which indicates that the company covers all obligations.
Total Assets Turnover (X3- TAT)	Characterizes the efficiency of using the company's assets	Determined by the ratio between revenue and the average annual amount of assets	An increase in the asset turnover ratio is associated with an increase in the received revenue

Financial leverage (X4- FL)	Characterizes the amount of borrowed funds per unit of own funds	Determined by the ratio of borrowed capital to equity capital	For most companies, an acceptable value is less than one (≤ 1)
Return on assets (X5- ROA)	It characterizes the return on the use of all assets of the company.	It is determined by the ratio of net profit and the average asset value for the period under consideration	The ratio shows the ability of the organization to create profit without taking into account the capital structure

Source: compiled by the authors

Table 2. Values of the selected indicators, calculated according to the data of the ABC company for the period under review

Name indicator	*Designation indicator*	*2016 year*	*2017 year*	*2018 year*	*2019 year*	*2020 year*
Current Ratio	CR	1,1241	0,9862	1,5473	1,8914	1,7410
Autonomy ratio	AuR	0,3215	0,4563	0,2580	0,4723	0,5012
Total Assets Turnover	TAT	1,9783	2,8523	1,7456	1,1258	2,0159
Financial leverage	FL	0,6389	0,5147	0,7892	0,5247	0,4123
Return on assets	ROA	0,0417	0,0258	0,0147	0,0369	0,0423

Source: compiled by the authors

3. RESEARCH QUESTIONS

With uncertainty, there is a risk of ineffective management, in which the planned goals are not achieved. These questions can be solved based on the fuzzy logic model. Consider the technology of the fuzzy logic mechanism using the example of a conditional small business company ABC. The complex of procedures of the fuzzy logic mechanism includes a number of stages (Figure 1).

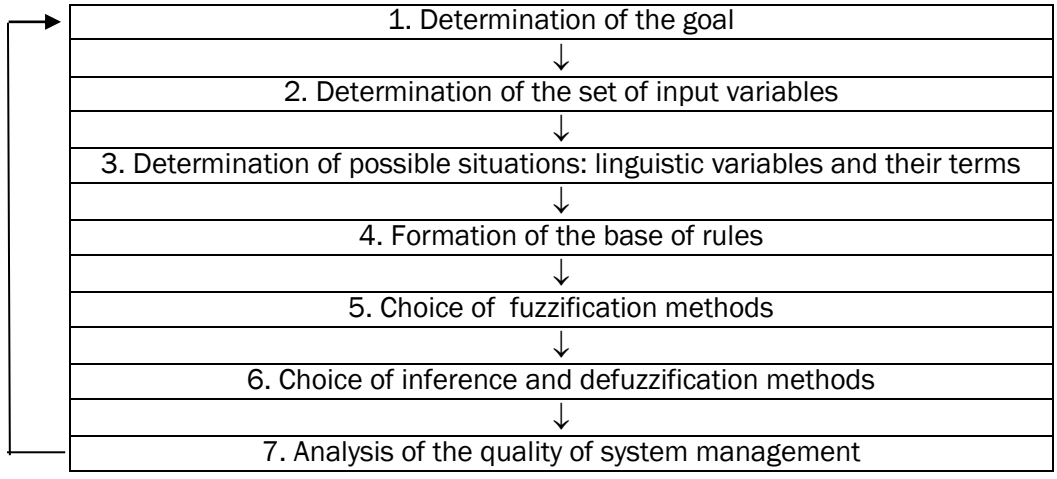

Figure 1. Stages of fuzzy logic mechanism procedures

Source: compiled by the authors.

3.1 Model Stages

Let's describe the implementation of each stage of the model.

Stage 1. The goal is the stable financial condition of the company.

Stage 2. Selection of indicators of a stable financial condition of the company. As input variables characterizing the financial condition of a small company, taking into account the consistency and opinions of experts, we choose a number of indicators X = {Xi} (Table 1).

For an objective analysis, the assumption is introduced that the system of indicators {X} is sufficient, the specified number of indicators is taken into account and, at the same time, duplication of indicators is eliminated (Table 2).

A certain i-th indicator in relation to a certain n-th level of the state of the company can be compared with the assessment pni of the significance of this indicator in determining the degree of financial instability. For example, when assessing the financial stability of the company, they attach more importance to indicators of autonomy, the ratio of borrowed and equity capital, less importance to indicators of the availability of working capital with own funds and flexibility of equity capital. For each company, it is set taking into account the specifics of the pin scale system:

$$r_1 \geq r_2 \geq ...r_N \tag{1}$$

In general, when ranking factors, the Fishburne rule is used, according to which the significance of the i-th indicator is determined by the formula (2):

$$r_i = \frac{2(N-i+1)}{(N+1)N} \tag{2}$$

It is allowed to take an equivalent influence of indicators in terms of significance, in this case, the level of significance is determined by 1 / N, which is taken according to the indicators under consideration (CR, AuR, TAT, FL, ROA) of a small company ABC.

Stage 3. Determination of possible situations of linguistic variables and their terms according to the selected indicators. The construction of the membership function μA (x) for each linguistic term is carried out. The term-set of the linguistic variable "Financial condition of the company" consists of the components under consideration. Each of the subsets A1... A5 has its own membership function μ1 (V)... μ 5 (V), where V is a complex indicator of the company's financial condition, and the more V, the more stable the company's condition [10, p. 42, Nedosekin].

Stage 4. It should be noted that the main types of membership functions can be: triangular, trapezoidal, Gaussian. For further calculations, we select the trapezoidal membership function of the selected indicators. The mathematical description of the trapezoidal membership function can be represented as (3):

$$\mu\ (x, a_1, a_{2,}, a_3, a_4) = \begin{cases} 0, x \leq a_1 \\ \dfrac{x - a_1}{a_2 - a_1} a_1 \leq x \leq a_2 \\ 1, a_2 \leq x \leq a_3 \\ \dfrac{a_4 - x}{a_4 - a_3}, a_3 \leq x \leq a_4 \\ 0, x \geq a_4 \end{cases} \tag{3}$$

The qualitative form of the membership function μi (V) for the analysis of the financial condition of the company is trapezoidal (Figure 2).

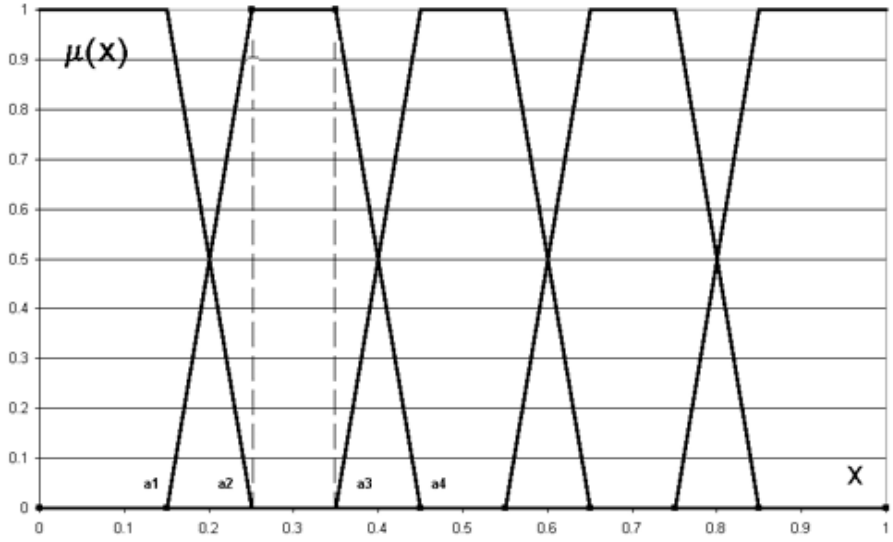

Figure 2. Membership function

Source*:* Nedosekin, p. 46

Stage 5. For the selected indicators (CR, AuR, TAT, FL, ROA), on the basis of an expert survey, intervals of values of fuzzy variables ("very low" "low" "medium", "high", "very high") were established (Table 3).

Table 3.The level of indicators by interval values

Name indicator	*Indicator value intervals*				
	very low	*low*	*medium*	*high*	*very high*
Current Ratio, CR	[0; 0,9]	[0,9;1,5]	[1,5; 1,75]	[1,75; 2,0]	[2,0; 2,5]
Autonomy ratio, AuR	[0; 0,2]	[0,2; 0,3]	[0,3; 0,5]	[0,50; 0,65]	[0,65;0,85]
Total Assets Turnover , TAT	[0; 0,54]	[0,54; 0,75]	[0,75; 1,10]	[1,10; 1,8]	[1,8; 2,5]
Financial leverage, FL	[0; 0,1]	[0,1; 0,25]	[0,25; 0,45]	[0,45; 0,75]	[0,75; 0,95]
Return on assets, ROA	[-0, 01; 0,02]	[0,02; 0,03]	[0,03; 0,05]	[0,05; 0,075]	[0,075; 0,15]

Source: compiled by the authors

Taking into account the established intervals of values of the selected indicators it is possible to determine the format of the membership functions of these indicators (Table 4).

Table 4. Formats of membership functions for selected indicators

Name indicator	*Options*	*Indicator level*				
		very low	*low*	*medium*	*high*	*very high*
1	2	3	4	5	6	7
Current Ratio, CR	a_1	0	0,9	1,5	1,75	2,0
	a_2	0	1,0	1,6	1,80	2,2
	a_3	0,45	1,25	1,65	1,90	2,3
	a_4	0,90	1,5	1,75	2,0	2,5
Autonomy ratio, AuR	a_1	0	0,2	0,3	0,50	0,65
	a_2	0,1	0,23	0,35	0,55	0,7
	a_3	0,15	0,25	0,45	0,6	0,75
	a_4	0,2	0,3	0,5	0,65	0,85
Total Assets Turnover , TAT	a_1	0	0,54	0,75	1,10	1,80
	a_2	0,25	0,60	0,85	1,25	2,00
	a_3	0,35	0,65	1,00	1,50	2,25
	a_4	0,54	0,75	1,10	1,80	2,50
Financial leverage, FL	a_1	0,0	0,10	0,25	0,45	0,75
	a_2	0,05	0,15	0,30	0,55	0,80
	a_3	0,07	0,20	0,40	0,65	0,85
	a_4	0,10	0,25	0,45	0,75	0,95
Return on assets, ROA	a_1	-0, 01	0,020	0,030	0,050	0,075
	a_2	0, 01	0,022	0,035	0,055	0,085
	a_3	0,015	0,025	0,045	0,065	0,095
	a_4	0,02	0,030	0,050	0,075	0,150

Source: compiled by the authors

With the help of this information, it is possible to determine the membership levels λij of fuzzy subsets from the term-set. When constructing the membership function $\{\lambda\}$, the following should be taken into account:

a) the distinctive characteristics of the analysis interval used. It should be borne in mind that in a separate interval of the analysis performed, there may be a change in the key rate, inflation rate, consumer price index, etc. (Morozko, et al., 2020b);
b) the distinctive characteristics of the type of economic activity to which the firm belongs. Each type of economic activity allows you to determine the level of sustainability based on specific requirements. As a rule, average values are accepted, which can be taken as a basis for constructing membership functions $\{\lambda\}$;
c) features of the company's position relative to other companies of this type of economic activity (volume of products on the market, financial policy, etc.)

The unique characteristic of the state of the company is determined on the basis of the obtained set of functions $\lambda_{1\text{-}5,i}$ for each value of Xi, which takes into account the type of economic activity of the company, the specifics of the business and the peculiarities of the operating conditions in the considered time interval. When using the set of functions $\{\lambda\}$, the fluctuation factor is smoothed when evaluating

the parameter under consideration, which allows ensuring the condition of comparability of situations in the analyzed time interval.

The results of calculating the levels of membership for fuzzy subsets from term sets of values of the selected indicators for the period under consideration are shown in Table 5.

Table 5. Results of calculations of membership levels

Period time	*λ*	*Membership levels of fuzzy subsets from term sets of indicator values*				
		CR	*AuR*	*TAT*	*FL*	*ROA*
2016г.	λ1	0	1	0	1	0
	λ2	0	0	0	0	0,1987
	λ3	0	0	0	0	0,5340
	λ4	0	0	0	0	0
	λ5	0,9899	0	1	0	0
2017г.	λ1	0	1	0	1	0
	λ2	0	0	0	0	1
	λ3	0	0	0	0	0
	λ4	0	0	0,1121	0	0
	λ5	0,9901	0	0,8897	0	0
2018г.	λ1	0	0,9017	0	0	0
	λ2	0	0,0919	0	1	0
	λ3	0	0	0	0	0,9698
	λ4	0	0	0,4411	0	0
	λ5	0,9799	0	0,5546	0	0
2019г.	λ1	0	1	0	1	0
	λ2	0	0	0	0	0
	λ3	0	0	0	0	1
	λ4	0	0	1	0	0
	λ5	0,9798	0	0	0	0
2020г.	λ1	0	1	0	0	0
	λ2	0	0	0	1	0
	λ3	0	0	0	0	0,8701
	λ4	0	0	0,8789	0	0
	λ5	0,9798	0	0,1456	0	0

Source: compiled by the authors

Stage 6. Selection of inference and defuzzification methods. The calculation of the complex financial indicator g (FS) is based on the formula (4) proposed by scientists [5, p.14]

$$g(FS) = \sum_{j=1}^{5} g_j \sum_{i=1}^{N} r_i \lambda_{ij} \quad (4)$$

$$g_i = 0{,}9 - 0{,}2(j-1) \quad (5)$$

- where: g_i - are the nodal points of the classifier;

j - the number of classifier levels (j = 1,... .5);

r_i - the level of significance of the indicator ($r_i = \frac{1}{N}$);

λ_{ij} - the level of belonging of the indicator to the corresponding fuzzy a lot;

$g(FS)$ - the level of financial stability of the company.

We use formula (4) to calculate the values of the aggregate indicator g (FS) of the company (Table 6).

Table 6. The results of calculating the value of the aggregated indicator

j	g_i	$\sum \lambda ij$					$g(FS)$				
		2016г.	2017г.	2018г.	2019г.	2020г.	2016г.	2017г.	2018г.	2019г.	2020г.
1	0,9	2,2311	2,0731	1,6987	2,6987	1,6986	0,3244	0,3831	0,3888	0,4197	0,3900
2	0,7	0,1891	1,2410	1,1021	0,0000	1,0000					
3	0,5	0,5149	0,2593	0,9802	1,0000	0,8749					
4	0,3	0,0000	0,1098	0,4258	1,0000	0,8598					
5	0,1	2,2018	1,7986	1,8794	1,2897	1,4159					

Source: compiled by the authors

3.2 Results and Discussion

Stage 7. Analysis of the quality of system management based on the interpretation of the result

The interpretation of the calculation results of the value of the aggregated indicator can be made on the basis of the classifier of the levels of the complex indicator g (FS) (Table 7). The analysis of the obtained results of the complex indicator shows that for the period under review, the financial condition of a small company ABC is in a critical financial situation. It should be noted the year 2019, in which the company was in the zone of acceptable financial condition. It is recommended to consider the parameters of this period as the most appropriate for the functioning of a small company ABC.

Table 7. Classifier of the levels of the complex indicator of the financial condition of the company g (FS)

Value ranges variable	Conditional symbol	Linguistic values of a variable
[0,00; 0,19]	PC	Disastrous financial situation
[0,20; 0,39]	S	Critical financial situation
[0,40; 0,59]	E	Acceptable financial position
[0,60; 0,79]	RS	Relatively strong financial position
[0,80; 1,00]	SFC	Stable financial position

Source: compiled by the authors

The analysis of the obtained results of the complex indicator shows that during the period under review, the financial condition of a small company ABC is in a critical financial position. It should be noted that the year 2019 was in which the company was in the zone of acceptable financial condition. It is recommended to consider the parameters of this period as the most suitable for the functioning of a small ABC company. The parameters of this period for the ABC company act as indicators for developing a plan for subsequent periods. The intervals of changes in values allow for some variability of indicators.

CONCLUSIONS

The definition of sustainable development of small business in traditional ways does not take into account the uncertainties associated with the conditions for the functioning of companies. The acceptability of the theory of fuzzy logic is due to the fact that interval values of the input parameters are introduced in the modeling, since there are no generally accepted criteria for assessing a stable financial condition. In the absence of quantitative estimates of indicators, it is legitimate to use vague descriptions of these indicators. Calculations according to the considered fuzzy logic technique are carried out using a common program for an Excel computer.

Prospective recommendations in the field of entrepreneurship can be formed in the context of the synthesis of a model of fuzzy execution and a procedure for functional equivalence of the basic elements of fuzzy networks. This approach will help to formulate the problem of synthesizing a model of an adaptive fuzzy controller. The proposed model will allow in the future to transform the construction algorithm into a fuzzy system and, thus, to use optimization algorithms. Adaptive models differ from other models in that they are built simultaneously on subjective approaches and development procedures based on objective data for specific companies.

The assessment of entrepreneurial risk is carried out under the condition that the possibility of events is determined by the known assigned membership function of the corresponding fuzzy numbers, that is, the assessment of the possibility of adverse events during the functioning of the company is determined.

In the approach based on fuzzy sets, the imperfections of calculations based on the theory of probabilities are eliminated when uncertainty is taken into account. This is interpreted by the fact that when using the approach of fuzzy sets, all possible scenarios for the development of events during the functioning of the company are considered. A comprehensive assessment is determined across the entire set of assessments.

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