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# Forecasting the Risk of Bankruptcy in Poorly Formalized Processes

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**Abstract.** There is a class of complex systems characterized by dynamism, multi-link structural elements, multi-stage, multi-linked chain of processes. Moreover, each of these processes occurs under conditions of stochastic and non-stochastic uncertainty in the initial information, internal and external environment, which predetermine the uncertainty of the nature of the development of the situation. Decision-making problems in such systems are divided into two types: 1) decision-making problems under risk conditions, when uncertainty conditions are only probabilistic, stochastic in nature; 2) decision-making problems under conditions of uncertainty, when the accompanying conditions are of a non-stochastic nature, and also when the necessary reliable statistical data is unknown. In tasks of the second type, risks are manifested to a greater extent than in the first. At the same time, risk should be considered – as an object, event, phenomenon – as a formal mathematical category in accordance with its following information interpretation: risk is information uncertainty, fuzziness of the "object – subject – environment" system and its individual elements. The measure of this uncertainty determines the measure of danger, possible damage, loss from the implementation of some decision or event. The existence of risk is associated with the inability to predict the future with 100 % accuracy. Based on this, the main property of risk should be singled out: risk occurs only in relation to the future and is inextricably linked with forecasting, and therefore with decision-making in general (the word "risk" literally means "making a decision", the result of which is unknown). Following the above, it is also worth noting that the categories "risk" and "uncertainty" are closely related and are often used as synonyms. In conditions when the initial factors are given in the form of fuzzy characteristics, other approaches based on the intelligent technologies of Soft Computing are widely used for forecasting. When evaluating alternative decision-making options for risk assessment under uncertainty, the problem of developing fuzzy models based on fuzzy inference rules arises. But there is no universal method for constructing fuzzy evaluation models. The advantage of fuzzy logic lies in the possibility of using expert knowledge about a given object in the form of if "inputs", then "outputs". In the paper a bankruptcy risk model is developed in poorly formalized processes for the purpose of forecasting.

**Keywords:** risk level, risk classification, decision-maker, fuzzy Sugeno model, indicators, finance, risk level knowledge base, Soft Computin

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# Прогнозирование риска банкротства в слабо формализованных процессах

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**Реферат.** Существует класс сложных систем, характеризующийся динамичностью, многозвенностью структурных элементов, многостадийностью многосвязной цепочки процессов. Причем каждый из этих процессов происходит

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в условиях стохастической и нестохастической неопределенности в исходной информации, внутренней и внешней среде, которые предопределяют неопределенность характера развития ситуации. Задачи принятия решений в таких системах разделяют на два типа: 1) задачи принятия решений в условиях риска, когда условия неопределенности носят только вероятностный, стохастический характер; 2) задачи принятия решений в условиях неопределенности, когда сопровождаемые условия имеют нестохастическую природу, а также когда необходимый доверительный статистический материал неизвестен. В задачах второго типа риски проявляются в более значительной степени, чем в первых. При этом следует рассматривать риск как объект, событие, явление – в качестве формальной математической категории в соответствии со следующей ее информационной интерпретацией: риск – это информационная неопределенность, нечеткость системы «объект – субъект – среда» и ее отдельных элементов. Мера этой неопределенности определяет меру опасности, возможного ущерба, проигрыша от реализации какого-то решения или события. Существование риска связано с невозможностью с точностью до 100 % прогнозировать будущее. Исходя из этого следует выделить основное свойство риска: риск имеет место только по отношению к будущему и неразрывно связан с прогнозированием, а значит, и с принятием решений вообще (слово «риск» в буквальном переводе означает «принятие решения», результат которого неизвестен). Следуя вышесказанному, стоит также отметить, что категории риск и неопределенность тесно связаны между собой и зачастую употребляются как синонимы. В условиях, когда исходные факторы задаются в виде нечетких характеристик, для прогнозирования широко используются другие подходы, основанные на интеллектуальных технологиях мягких вычислений. При оценке альтернативных вариантов принятия решений для оценки рисков в условиях неопределенности возникает проблема разработки нечетких моделей, основанных на правилах нечеткого вывода. Но универсального метода построения нечетких оценочных моделей не существует. Преимущество нечеткой логики заключается в возможности использования экспертных знаний о данном объекте в виде если «входы», то «выходы». В статье разработана модель риска банкротства в слабо формализованных процессах с целью прогнозирования.

**Ключевые слова:** уровень риска; классификация рисков; лицо, принимающее решение; нечеткая модель Сугено; индикаторы; финансы; база знаний риска; мягкие вычисления

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## Introduction

For complex processes characterized by uncertainty (inaccuracy, non-stochasticity, incompleteness, fuzziness) in the initial information and situations of the external and internal environment, it is usually not possible to build simple adequate mathematical models. Information about the parameters of such processes is expressed by experts in the form of words and sentences, i.e. in linguistic form. In such cases, it is advisable to use modeling, decision-making and control systems that use the tools of soft computing technology (Soft Computing) [1, 2].

Risk is understood as the possible danger of losses arising from the specifics of certain natural phenomena and activities of human society. The risk can be managed, that is, various measures can be used to predict the occurrence of a risk event to a certain extent and take measures to reduce the degree of risk [3, 4].

Risks have a very big impact on people's behavior. Therefore, their analysis can help in explaining certain actions performed by certain subjects. It should be borne in mind that it is practically impossible to take into account all risk factors, so the assessment is based on certain assumptions, and the result is approximate to a certain extent. However, this does not diminish the importance of developing an appropriate risk strategy.

The development of a risk strategy goes through a number of successive stages, among which are:

1. Risk classification.
2. Identification of factors that increase and decrease a specific type of risk.
3. Analysis of the identified factors in terms of the strength of the impact on the risk.
4. Assessment of a specific type of risk.
5. Establishment of the optimal level of risk.
6. Analysis of individual operations in terms of compliance with an acceptable level of risk.
7. Development of risk reduction measures.

The effectiveness of the organization of risk management is largely determined by the classification of risk. Risk classification should be understood as the distribution of risk into specific groups according to certain characteristics in order to achieve the set goals [11, 12]. Scientifically based risk classification allows you to clearly determine the place of each risk in their overall system. It creates opportunities for the effective application of appropriate methods, risk management techniques.

In conditions when the initial factors are given in the form of fuzzy characteristics, other approaches based on the intelligent technologies of Soft Computing are widely used for forecasting [5, 6, 16–21]. When evaluating alternative decision-making options for risk assessment under uncertainty, the problem arises of developing fuzzy models based on fuzzy inference rules. But there is no universal method for constructing fuzzy evaluation models. The advantage of fuzzy logic lies in the possibility of using expert knowledge about a given object in the form of "if "inputs", then "outputs" [22–29].

**Formulation of the problem**

Successful analysis of the risk of bankruptcy of the enterprise can be carried out only on the basis of the following basic conditions [12–14]:

1. The analysis is based on the results of the longest possible monitoring of the enterprise.

2. The forms of accounting used in the analysis should accurately reflect the actual financial condition of the enterprise.

3. For the purposes of the analysis, only the indicators that are most important in terms of their relevance to the bankruptcy of the enterprise are used. This is possible only when the DM assesses not only the financial condition of the enterprise, but also its position in the industry.

4. The analyst must have appropriate bankruptcy statistics, which must be verified in terms of industry, country and period under review.

All of the above shows that a given expert-analyst needs to form an idea of what is "good" and "bad" within the scope of the industry to which the enterprise belongs.

Classical probability is a characteristic sign of a general set of events, not of an individual object or event. By looking at a separate entity, we describe its relationship to the whole group on a probabilistic basis. But the uniqueness of any type of enterprise is that it can be viable even when it has very weak capabilities, and vice versa. The uniqueness of the destiny of the enterprise encourages the researcher to look carefully at the enterprise, not to use the "same pattern", but to find its specific side, not to look for similarities, but to look for and describe different aspects. There is no place for statistical probability in such an approach. The researcher feels this inwardly and shifts the main emphasis from predicting bankruptcy to recognizing a situation that separates the enterprise from the bankrupt.

It will be necessary for experts to distinguish a number of separate financial indicators. It can be said about the experts that it best describes the specific aspects of the enterprise's activities and describes a number of completed sets that give a complete picture of the purpose of the enterprise. Conducting a selection of indicators using his long-standing experience for analysis is highly effective. There are no two companies that have the same good approach to the same indicators. Or more precisely: the importance of different indicators for this or that enterprise will vary. Therefore, the expert is faced with the difficult task of selecting and differentiating analytical factors. It is possible to analyze the hierarchy of indicators classified by groups (financial stagnation, liquidity, profitability, etc.), but in normal cases they form a chaotic set.

Therefore, in this and subsequent cases, the growth of each $X_i$ indicator is associated with a decrease in the risk of bankruptcy and an improvement in the situation of the enterprise under consideration. If the opposite idea is used for a given indicator, the analysis will need to replace it with other indicators. For example, it is preferable to replace the ratio of cash in the assets of the enterprise with the ratio of the share of private funds in assets.

For each indicator $X_i$, we adjust the significance level $r_i$ settings for its analysis. To assess this level, all indicators should be placed in descending order of significance, in the following order:

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

If the system of indicators is structured in descending order of their significance, then the significance $r_i$ of the $i$-indicator can be determined according to Fishbern's rule [15]:

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

Fishbern's rule reflects the fact that nothing is known about the significance of indicators other than (1). In that case, the estimate (2) corresponds to the maximum value of the entropy of the uncertainty of the information available about the object under study.

If all indicators are of equal significance (a system with equal advantage), then Table 1.

*Table 1*

**Risk level knowledge base**

| Name of indicators | Risk level | | |
|---|---|---|---|
| | low | average | high |
| $X_1$ | $\lambda_{11}$ | $\lambda_{12}$ | $\lambda_{13}$ |
| $X_2$ | $\lambda_{21}$ | $\lambda_{22}$ | $\lambda_{23}$ |
| … | … | … | … |
| $X_N$ | $\lambda_{N1}$ | $\lambda_{N2}$ | $\lambda_{N3}$ |

Here is an approach that transforms an expert into quantitative assessments that allow him to best express own fuzzy assumptions with the help of words. If the expert knows the enterprise from the inside, it will not be difficult to identify the factors that affect the processes of insolvency (including management errors), to adjust the quantitative indicators to these factors and to normalize them. One of the existing approaches to solving this problem is to use fuzzy mathematical methods.

## Development of Bankruptcy Risk Model

It is assumed that the following are known: 1) ($X_r$, $y_r$) selected experimental data, $r = \overline{1, M}$, where $X_r = (x_{r,1}, x_{r,2}, ..., x_{r,n})$ – input $n$-dimensional vector, and $y_r$ – the output vector corresponding to it; 2) Takagi-Sugeno rules of the fuzzy knowledge base [7, 9, 31]:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} - w_{jp} \text{ with weight}\right) \rightarrow \tag{3}$$
$$\rightarrow y = b_{j,0} + b_{j,1}x_1 + b_{j,2}x_2 + ... + b_{j,n}x_n, \quad j = \overline{1, m},$$

$$B = (b_{1,0}, b_{2,0}, ..., b_{m,0}, b_{1,1},$$
$$b_{2,1}, ..., b_{m,1}, ..., b_{1,n}, b_{2,n}, ..., b_{m,n})^T$$

it is necessary to find such values of the coefficients of the rule conclusions that they provide a minimum of squared non-binding:

$$\sum_{r=\overline{1,M}} \left(y_r - y_r^f\right)^2 \rightarrow \min, \tag{4}$$

where $y_r^f - (X_r)$ is the output of the inputs in the $r$-row of the selection on the $B$ parameter fuzzy knowledge base.

The following fuzzy output corresponds to the input vector $X_r = (x_{r,1}, x_{r,2}, ..., x_{r,n})$:

$$y_r^f = \frac{\sum_{j=\overline{1,m}} \mu_{d_j}(X_r) d_j}{\sum_{j=\overline{1,m}} \mu_{d_j}(X_r)}, \tag{5}$$

where $d_j \equiv b_{j,0} + \sum_{i=\overline{1,n}} b_{j,i} x_{r,i}$ – the output of the $j$-rule.

The degree of execution of the conclusion of the $\mu_{d_j}(X_r) = \underset{p=\overline{1,k_j}}{\vee} w_{jp} \cdot \underset{i=\overline{1,n}}{\wedge}\left[\mu_{jp}(x_{r,i})\right] - j$ rule.

The relative degree of execution of the j-rule conclusion is defined for the input vector

$$\beta_{j,r} = \frac{\mu_{d_j}(X_r)}{\sum_{k=\overline{1,m}} \mu_{d_k}(X_r)} \text{ by } Z.$$

In this case, (5) can be rewritten as follows:

$$y_r^f = \sum_{j=\overline{1,m}} \beta_{r,j} d_j =$$
$$= \sum_{j=\overline{1,m}} \begin{pmatrix} \beta_{r,j} b_{j,0} + \beta_{r,j} b_{j,1} x_{r,1} + \\ + \beta_{r,j} b_{j,2} x_{r,2} + ... + \beta_{r,j} b_{j,n} x_{r,n} \end{pmatrix}.$$

Here the following definitions are entered:

$$Y^f = \left(y_1^f, y_2^f, ..., y_M^f\right)^T;$$
$$Y = \left(y_1, y_2, ..., y_M\right)^T;$$

$$A = \begin{bmatrix} \beta_{1,1}, ..., \beta_{1,m}, \quad x_{1,1}\beta_{1,1}, ..., x_{1,1}\beta_{1,m}, \\ ..., x_{1,n}\beta_{1,1}, ..., x_{1,n}\beta_{1,m}; \\ \vdots \\ \beta_{M,1}, ..., \beta_{M,m}, \quad x_{M,1}\beta_{1,1}, ..., x_{M,1}\beta_{1,m}, \\ ..., x_{M,n}\beta_{M,1}, ..., x_{M,n}\beta_{M,m}. \end{bmatrix}$$

In this case, the problem (4) is written in the form of a matrix in the following form: so that the vector $B$ is found, the condition is satisfied.

$$E = (Y - Y^f)^T \cdot (Y - Y^f) \rightarrow \min. \tag{6}$$

Here $Y^f = AB$.

The minimum value of quadratic $E$ is obtained at $Y^f = Y$, which corresponds to the solution of the following equation:

$$Y = AB. \quad (7)$$

The number of parameters to be adjusted for real problems is smaller than the size of the data sample, so equation (7) does not have a definite solution. In this case, the solution of the problem can be found using the nickname inversion of the matrix $A$:

$$B=(A^T A)^{-1} A^T Y. \quad (8)$$

The problems of finding the solution of (8) are related to the probability singularity of the matrix.

**Computing experiment**

Following the results of the work of the enterprise “AB” in the III and IV quarters, it is required to build a fuzzy linear model of bankruptcy risk.

1. The financial condition of the enterprise “AB” is characterized by the following financial indicators (Table 2).

*Table 2*

| $X_i$ Indicator code | Name of $X_i$ indicator | Value of $X_i$ in the 1st period ($x$I, $i$) | Value of $X$ in the 2nd period ($x$II, i)$_i$ |
|---|---|---|---|
| $X_1$ | Autonomy coefficient (coefficient of private capital to the foreign exchange balance) | 0.839 | 0.822 |
| $X_2$ | Coefficient of working capital to private equity (coefficient of net working capital to current assets) | 0.001 | –0.060 |
| $X_3$ | Intermediate liquidity coefficient (ratio of total cash and receivables to current liabilities) | 0.348 | 0.208 |
| $X_4$ | Absolute liquidity coefficient (coefficient of total cash to short-term liabilities) | 0.001 | 0.0001 |
| $X_5$ | Annual turnover of all assets (coefficient of sales revenue to the average value of assets for the period) | 0.162 | 0.221 |
| $X_6$ | Return on total capital (coefficient of net profit to the average value of assets for the period) | –0.04 | –0.043 |

Also, the risk levels are $r_1$ = 0,709 and $r_2$ = 0,713.

2. Divide the current values of $x$ into classes according to the criteria in Table 1. The results of the classification are presented in Table 3.

*Table 3*

| $X_i$ Indicator | Value of {λ} in period I | | | Value of {λ} in period II | | |
|---|---|---|---|---|---|---|
| | $\lambda_1(x_{I,i})$ | $\lambda_2(x_{I,i})$ | $\lambda_3(x_{I,i})$ | $\lambda_1(x_{I,i})$ | $\lambda_2(x_{I,i})$ | $\lambda_3(x_{I,i})$ |
| $X_1$ | 0,200 | 0,500 | 1 | 0,2 | 0,500 | 1 |
| $X_2$ | 0,920 | 0,548 | 0,483 | 1 | 0,500 | 0,200 |
| $X_3$ | 0,562 | 0,098 | 0,444 | 0,73 | 0,866 | 0,340 |
| $X_4$ | 0,920 | 0,995 | 0,469 | 0,982 | 0,536 | 0,223 |
| $X_5$ | 0,826 | 0,772 | 0,296 | 0,711 | 0,759 | 0,423 |
| $X_6$ | 1 | 0,500 | 0,500 | 0,985 | 0,510 | 0,337 |

Based on the above formulas, the following quantities were determined:

$$\beta_{11} = 0,512; \;\; \beta_{12} = 0,483; \;\; \beta_{21} = 0,487; \;\; \beta_{22} = 0,586.$$

General form of the linear model of the enterprise bankruptcy risk is as follows:

$$r_1 = b_{10} - b_{11}\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})} - b_{12}\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})} - b_{13}\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})} - b_{14}\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})} - b_{15}\frac{\sum_{j=1}^{n}\mu^j(x_5^1)x_5^1}{\sum_{j=1}^{n}\mu^j(x_5^1)} - b_{16}\frac{\sum_{j=1}^{n}\mu^j(x_6^1)x_6^1}{\sum_{j=1}^{n}\mu^j(x_6^1)};$$

$$r_2 = b_{20} - b_{21}\frac{\sum_{j=1}^{n}\mu(x_1^{2j})x_1^{2j}}{\sum_{j=1}^{n}\mu(x_1^{2j})} - b_{22}\frac{\sum_{j=1}^{n}\mu(x_2^{2j})x_2^{2j}}{\sum_{j=1}^{n}\mu(x_2^{2j})} - b_{23}\frac{\sum_{j=1}^{n}\mu(x_3^{2j})x_3^{2j}}{\sum_{j=1}^{n}\mu(x_3^{2j})} - b_{24}\frac{\sum_{j=1}^{n}\mu(x_4^{2j})x_4^{2j}}{\sum_{j=1}^{n}\mu(x_4^{2j})} - b_{25}\frac{\sum_{j=1}^{n}\mu(x_5^{2^j})x_5^{2^j}}{\sum_{j=1}^{n}\mu(x_5^{2^j})} - b_{26}\frac{\sum_{j=1}^{n}\mu(x_6^{2^j})x_6^{2^j}}{\sum_{j=1}^{n}\mu(x_6^{2^j})}.$$

**CONCLUSION**

A bankruptcy event can include not only financial but also other parties in its list of causes, which can be expressed in both quantitative and qualitative terms. Systems of bankruptcy risk diagnosis have been established that are used simultaneously with speculative considerations of quantifiable factors that can be accurately measured.

We believe that the construction of such a system of risk assessment with modeling based on the combination of “Soft Computing” – technologies: fuzzy sets, neural networks and genetic algorithms, theory of bipolar nonlinear sets will be carried out in the near future.

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