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RISK ANALYSIS IN SMART FARMING CONDITIONS

ABSTRACT

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The dissertation was discussed and directed for defense at a meeting of the Department of Computer Systems at the Faculty of Mathematics and Informatics of the University of Plovdiv "Paisii Hilendarski", held on 08.05.2026.

The dissertation contains 131 pages, 16 figures, 8 tables and 102 literary sources.

The list of author's publications consists of 2 titles.

The defense of the dissertation will take place on 10.07.2026 at 13.00 in the Conference Hall of the New Building of the University of Plovdiv, Plovdiv. Plovdiv.

The materials on the defense are available to those interested in the Secretariat of FMI, New Building of the University of Plovdiv, office. 330, every working day from 8.30 a.m. to 5.00 p.m.

Scientific jury

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Title: Risk Analysis in Smart Farming

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General characteristics of the dissertation

Agriculture is characterized by a high degree of uncertainty due to the interaction of natural, economic and technological factors. In the context of climate change, increased market volatility and increasing sustainability requirements, financial risk in the agricultural sector is becoming systemic and has an impact on both individual farms and the financial stability of wider economic structures.

At the same time, the development of smart agriculture creates new opportunities for data collection, processing and analysis in real time through the integration of information systems, sensor technologies and analysis algorithms. Despite the availability of diverse digital solutions, there is a lack of an integrated approach in scientific and applied practice to share agronomic, climate and financial data for the purpose of systematically managing financial risk.

In this context, the present dissertation examines the problem of developing a model and system for identification and analysis of financial risk in the conditions of smart agriculture through adaptation of an existing platform.

Relevance of the study

The relevance of the study is determined by several key factors:

- the growing financial vulnerability of farmers as a result of climate and market shocks;
- the limited effectiveness of existing risk management tools, including index insurance and traditional financial mechanisms;
- the need for integration of heterogeneous data (agricultural, financial, climate);
- the growing role of digitalization and smart systems in agribusiness management.

The presence of these factors determines the need to develop new conceptual and technological solutions for analysis and management of financial risk.

Purpose, object and subject of the study

The purpose of the dissertation is to develop and substantiate a conceptual, methodological and architectural model for identification and analysis of financial risk in the conditions of smart agriculture, based on the integration of agricultural, climatic and financial data.

The subject of the study is the financial risks in agricultural enterprises.

The subject of the study is the methods, models and information systems for identification, analysis and management of financial risk, as well as the possibilities for their integration into smart farming platforms.

Objectives of the study

To achieve the set goal, the following main tasks have been formulated:

1. Analysis of the essence and classifications of financial risks in the agricultural sector.
2. Research of modern electronic systems and digital technologies for risk management.
3. Identify the limitations of existing solutions, including integration and data quality issues.
4. Analysis of the conditions for the development of smart agriculture in Europe and Bulgaria.
5. Study of the architecture of the ZEMELA platform.
6. Development of adaptation of the event model for financial risks.
7. Design of a risk identification and analysis system architecture.
8. Assessment of the feasibility of the proposed solution.

Structure of the dissertation

The dissertation is structured in an introduction, four chapters, a conclusion and a bibliography. The dissertation is 131 pages long and contains 16 figures, 8 tables and 102 literary sources.

- Chapter One provides an analytical overview of financial risks and electronic systems in agriculture.
- The second chapter examines the theoretical foundations and classifications of risks.
- In Chapter Three, a mathematical model for the identification of financial risks is developed.
- Chapter Four presents the program implementation of a risk analysis system within the ZEMELA platform.

Chapter 1. Financial Risk and Electronic Systems in Agriculture

The first chapter examines the relationship between financial risk and electronic systems in agriculture, focusing on the importance of digitalization for the sustainable development of the agricultural sector. The main types of financial risks faced by farmers are analyzed - market, credit, operational and climatic. Modern electronic systems and technologies (such as farm management systems, satellite monitoring, IoT and blockchain solutions) are presented, which support the assessment, management and mitigation of risks. The work focuses on the role of digital platforms in planning, financial forecasting and decision-making processes. The challenges associated with the implementation of electronic systems are also pointed out - high initial investments, need for training and cybersecurity

Financial risk in the agricultural sector is a multi-layered phenomenon that encompasses risks at the level of the economy, markets and the financial system. At the simplest level, it involves credit and liquidity risk: the farmer may experience a shortage of operating cash during the season and/or fail to service loans in the event of a drop in revenue or a sharp increase in the cost of inputs. This is especially critical in intensive crops that require upfront investments (seeds, fertilisers, fuel) and have one-time seasonal revenues. Analyses of agricultural financing and liquidity management practices address precisely these mechanisms and recommend adaptive liquidity buffers and seasonal lending. [1]

Price volatility is a separate key component of financial risk: fluctuations in the prices of major crops, fertilizers and energy directly alter profitability margins. Recent empirical research demonstrates a strong relationship between price and volatility in energy markets (natural gas, oil), fertiliser market and agricultural product prices, which increases the risk of sudden financial shocks for farmers and cooperatives. Managing this risk requires hedging, contractual arrangements, and stabilization policies in extreme volatility. [2]

Production risk (due to climatic extremes, drought, floods, pests and diseases) is a direct cause of loss of yields and revenues. These events also generate secondary financial effects, such as increased borrowing, liquidity pressures and higher insurance premiums. Official guidelines on risk management in agriculture divide risks into normal/mock and catastrophic and emphasize the need for combined strategies: disaster prevention, insurance and public support for catastrophes. [3]

The problem of basis risk in index insurance is particularly relevant: when the compensation is paid on the basis of an index (e.g. rainfall or average yields per region), it may not coincide with the actual loss of the particular farmer. A large body of literature shows that high underlying risk reduces the demand and efficiency of index insurance; Therefore, new studies propose methods for decomposition of underlying risk and optimization of indices. [4]

Finally, there are systemic/macro risks: a build-up of losses due to large-scale climate shocks linked to ecosystem degradation or disruption of supply chains can lead to waves of non-performing loans and put pressure on the banking sector and regional economies. International institutions and scientific reviews consider "nature-related" and climate-driven financial risks as potentially systemic, which requires the inclusion of the agricultural sector in macroprudential policies, stress tests and consideration of the sustainability of loan portfolios [5]

In practical terms, effective financial risk management in agriculture combines: adaptive lending and liquidity instruments, price risk hedging instruments, a combination of traditional and index insurance with better constructed indices (aimed at reducing underlying risk), investments in preventive measures against natural disasters, and the inclusion of the agricultural sector in financial assessments of systemic risks by banks and supervisors. Cross-sectoral cooperation between farmers, insurers, commercial and government institutions is recommended to increase the overall sustainability of the system [6] [7]

Integration into the ZEMELA platform of a system for identification of financial risks in agriculture. It is a regional platform for smart agriculture, the initial functionality of which is focused on monitoring the vegetation of agricultural crops. The flexible and adaptable architecture of the platform allows it to be expanded with new modules and services. The present study, presented in a dissertation, demonstrates one such adaptation of ZEMELA, aimed at building a system for identification and management of financial risks in the agricultural sector [8] [9].

Key Takeaways from Chapter 1

The digitalization of agriculture creates new opportunities for risk management through:

- integration of FMIS and ERP systems;

- use of satellite and sensor data;
- application of algorithms for analysis and forecasting;
- development of fintech and blockchain solutions.

There are significant limitations, including:

- lack of standardised integration between different systems;
- problems with data quality and accessibility;
- the presence of basis risk in index insurance;
- digital exclusion and insufficient infrastructure;
- cyber risks.

The analysis carried out shows that there is a need for integrated systems that combine different types of data and provide a comprehensive framework for financial risk management.

Chapter 2. Theoretical foundations of financial and agricultural risks

The second chapter of the dissertation is devoted to the study of the essence, characteristics and classifications of financial and agrarian risks, as well as the principles and methods of their management.

Financial risk is considered as the probability of adverse financial results due to uncertainty in the economic environment. In the agricultural sector, this risk is characterised by a strong dependence on external factors, including climatic conditions, market dynamics and the institutional environment.

Governance and risk are interrelated components of the economic system. Risk management is a factor of competitiveness, a way to ensure the overall sustainability of the company and its ability to withstand adverse results. Lam provides a practical guide to the application of risk management principles, with particular emphasis on the cost-risk relationship and the need for cost-effective management [10]

Special attention is paid to the effectiveness of risk management, which is considered as a function of the enterprise's ability to minimize losses while maintaining profitability.

In a narrow sense, risk management includes the individual, collective and societal activity(s) to reduce or eliminate a certain risk and its negative consequences. In a broader sense, risk management is the specific system of social order that predetermines the behavior of agents and determines the way in which various risks, rights, resources and activities are provided, protected, exchanged, coordinated, stimulated and challenged [11]

Individual forms of risk management are not equally effective, as they have different potential to reduce the likelihood and impact of risk, and require different costs [12]

Key takeaways from Chapter 2

Financial risk management is an integral element of the strategic leadership of any organization. Effective identification, analysis and control of risks creates conditions for financial stability, competitiveness and sustainable development. The approach to risk should be systematic, based on clear principles, quantitative analysis and continuous monitoring of the external and internal environment. In conclusion, risk management is not just a safety mechanism, but a key tool for achieving optimal profitability and long-term sustainability of the business.

Chapter 3. Mathematical Model for Financial Risk Identification

To identify possible financial risks, a mathematical model has been developed in Chapter Three. In general, the model is built in the following steps:

1. Creating a parametric space.
2. Building an index space.
3. Construction of interval space.
4. Specifying the types of risks in the interval space.

3.1. Parametric space. From the variety of parameters characterizing the financial condition of a company, 13 with the greatest importance for the task are selected. We define this space as $SPACE_{par}$= P1 x P2 x … x P13, where the primary indicators of the company in question selected for reporting are denoted by P_i, i = 1, …, 13. The name and nature of the indicators are summarised in the Table 2. Output parameters.

Table 2. Output parameters

Parameter	Name	Nature of the indicator
P1	Equity	Own financial resources of the enterprise
P2	Capital raised	Attracted financial resources from external sources
P3	Total liabilities	Liabilities to creditors and suppliers
P4	Total assets	Set of economic resources
P5	Short-term assets	Short-life current assets
P6	Short-term liabilities	Liabilities maturing up to one year
P7	Inventories	Tangible current assets
P8	Cash	Highly liquid financial assets
P9	Earnings before interest and taxes (EBIT)	Operating financial result
P10	Interest Expense	Financial cost of attracted capital
P11	Cash flow from operating activities	Net cash result of the main activity

P12	Free cash flow (FCF), as a percentage of revenue	Relative monetary measure (ratio between free cash flow and sales revenue)
P13	Total revenue	

The purpose of the analysis, the type of indicator and the source of information are given in Table 3

Table 3. Output parameters

Parameter	**Purpose in analysis**	**Indicator type**	**Source**
P1	Assessment of the capital structure and financial sustainability	Balance Aggregate	Balance sheet
P2	Analysis of financial leverage and indebtedness	Balance Aggregate	Balance sheet
P3	Solvency and financial risk assessment	Balance Aggregate	Balance sheet
P4	Analysis of resource potential and asset structure	Balance Aggregate	Balance sheet
P5	Assessment of liquidity and working capital	Balance Aggregate	Balance sheet
P6	Short-term solvency analysis	Balance Aggregate	Balance sheet
P7	Analysis of the warehouse policy and the turnover of resources	Balance Aggregate	Balance sheet
P8	Assessment of immediate liquidity	Balance Aggregate	Balance sheet
P9	Analysis of the management of temporarily free cash resources	Balance Aggregate	Balance sheet
P10	Assessment of operational efficiency and profitability	Reporting indicator	Profit and Loss Statement
P11	Debt Financing Cost Analysis	Reporting indicator	Profit and Loss Statement
P12	Assessment of the ability to generate cash	Cash flow indicator	Statement of cash flows
P13	Assessment of the efficiency of free cash generation in relation to the sales volume and financial sustainability of the enterprise	Monetary efficiency indicator (profitability of cash flows)	Cash Flow Statement and Profit and Loss Statement

As a value expression, these parameters are real numbers, which makes the number of elements of parametric space infinite. A classic problem arises for symbolic artificial intelligence (in particular, for solving problems through search) – an infinite space of solutions.

To deal with this problem (also known as *an exponential explosion*) it is necessary to look for a heuristic of the nature of the problem being solved, which would allow us to limit the space of solutions to reasonable limits where a search for a solution would be successful.

The next steps of the proposed approach aim at this.

3.2. Index space. We define index space as $SPACE_{ind}$ = I1 x I2 x … x I8, where the individual indexes are marked with I_i, i = 1, …, 8. This 8-dimensional space is obtained by reducing the parametric space as shown in the Table 4. Risk indices.

Table 4. Risk indices

Index	**Name**	**Reduction formula**
I1	D/E ratio	P2 / P1
I2	Leverage	P3 / P4
I3	Total liquidity ratio	P5 / P6
I4	Quick liquidity ratio	(P5 - P7) / P6
I5	Immediate liquidity ratio	P8 / P6
I6	Interest coverage ratio	P9 / P10
I7	Operating cash flow ratio	P11 / P6
I8	Free cash flow (as % of revenue)	P12 / P13

The nature, purpose and type of indices are summarized in the Table 5. Risk indices.

Table 5. Risk indices

Index	**Nature**	**Purpose**	**Type**
I1	Capital structure ratio	Assessment of indebtedness and financial leverage	Structural financial ratio
I2	Financial Multiplier	Assessment of the effect of the use of foreign capital on profitability	Structural financial ratio
I3	Current liquidity indicator	Assessment of the ability to cover short-term liabilities	Liquidity ratio
I4	Accelerated liquidity indicator	Liquidity assessment excluding stocks	Liquidity ratio
I5	Cash liquidity indicator	Assessment of immediate solvency	Liquidity ratio
I6	Debt service indicator	Debt Interest Ability Assessment	Solvency ratio
I7	Monetary sustainability indicator	Assessment of the ability to cover liabilities with operating cash flow	Cash coefficient
I8	Relative monetary indicator	Evaluation of the efficiency of generating free cash flow relative to sales	Monetary indicator

Although with this step we were able to reduce the 13-dimensional parametric space to an 8-dimensional one, the new index space continues to be infinite (the value expressions of the indices are again real numbers).

3.3. Interval space. This *space is obtained again by means of reduction, and for each index we define 5 intervals. Thus,* $SPACE_{int}$ *= IN1 x IN2 x ... x IN8 .where IN i for i = 1, ..., 8 are defined as given* in Table 6.

Table 6. Index intervals

Index	IN1	IN2	IN3	IN4	IN5
I1	0.7 – 0.9	0.3 – 0.5	1.0 – 1.3	1.5 – 2.0	> 2.0
I2	0.35 – 0.50	0.20 – 0.35	0.50 – 0.60	0.60 – 0.70	> 0.70
I3	2.0 – 2.6	> 2.6	1.8 – 2.0	1.2 – 1.5	< 1.0
I4	0.9 – 1.2	> 1.2	0.8 – 0.9	0.6 – 0.8	< 0.6
I5	0.30 – 0.40	0.40 – 0.60	0.20 – 0.30	0.10 – 0.20	< 0.10
I6	3.0 – 4.5	> 4.5	2.0 – 2.5	1.0 – 2.0	< 1.0
I7	1.5 – 2.5	> 2.5	1.0 – 1.5	0.8 – 1.0	< 0.8
I8	10 – 15%	> 20%	5 – 10%	0 – 5%	< 0%

This reduction is crucial to get finite space. $SPACE_{int}$ contains 32768 (8^5) elements. This is because we are no longer interested in the values themselves, but in belonging to the intervals, i.e. there are two possibilities – whether or not it belongs to the corresponding interval (0 or 1).

3.4. Specifying the types of risks in the interval space. In this last step of creating the mathematical model, we are already able to specify 5 characteristic points R1, R2, ..., R5, which correspond to the types of risks that we seek to identify through our model.

The character points are specified as follows:

- R1 = I_1 x I2 x … x I8 $IN\in_1$
- R2 = I_1 x I2 x … x I8 $IN\in_2$
- R3 = I_1 x I2 x … x I8 $IN\in_3$
- R4 = I_1 x I2 x … x I8 $IN\in_4$
- R5 = I_1 x I2 x … x I8 $IN \in_5$

Table 7 summarizes the corresponding types of risks along with their characteristics, interpretations, assessments and possible strategies for overcoming.

Table 7. Types of risks

Feature Point	Risk	Characteristics	Interpretation	Evaluation	Strategy
R1	Minimal	The enterprise is financially stable, with a balanced capital structure, adequate liquidity and stable cash flows, allowing for active reinvestment in smart technologies.	• Debt supports growth without jeopardizing solvency • Liquidity covers at least one production cycle • Cash flows provide self-financing of digitalization	Optimal financial situation	• Expansion • Innovation • Long-term investments
R2	Low	A good but conservative combination. High stability, lower efficiency.	• Low debt and high liquidity reserves. • Weak leverage effect. • Probably *additional investment* in smart technologies.	Financially stable but inefficient	Controlled increase in investment activity
R3	Moderate	Intermediate (balanced) combination. Moderate resistance.	• Let's assume financial risk • Liquidity is sensitive to seasonal fluctuations • Limited but available capacity for technology investments	Satisfactory financial situation.	Optimization of cash flows and costs.
R4	High	Risky combination. Financial vulnerability.	• Increased indebtedness • Dependency on current income • Limited capacity to service investment debt	High risk	Restructuring of liabilities, restriction of investments
R5	Critical	Worst combination. Financial instability/crisis	• High indebtedness + low liquidity • Inability to service interest • Negative free cash flow	Financial crisis	Emergency financial intervention, refinancing or recovery plan

Main results of Chapter 3

The results achieved in Chapter 3 are:

- a formal mathematical model for assessing financial risk has been developed;
- a methodology for risk classification is proposed;
- indices and valuation intervals are defined;
- A basis has been created for the program implementation of a risk analysis system.

Chapter 4. Program implementation of a financial risk research system

The fourth chapter of the dissertation is devoted to the development and implementation of a prototype of a system for identification and analysis of financial risk in the conditions of smart agriculture.

The proposed solution is based on integration within the ZEMELA platform, using its event-oriented architecture. The main idea is to expand the functionality of the platform by including a financial risk module that processes and analyzes data from various sources. [13]

4.1 System architecture

The prototype architecture includes the following four components (Figure 3. Common architecture) which will be briefly presented in this paragraph.

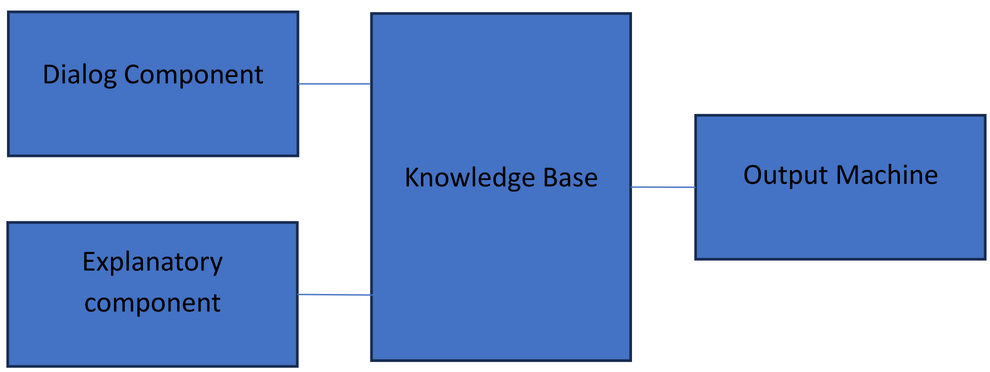

Figure 3. Common architecture

Dialog component - this component carries out the interaction between users and the system. In the form of a dialog, the user is prompted to enter the company parameters necessary for risk analysis.

Explanatory component - the results obtained during the analysis of the company in question are initially recorded in the form of a frame in the knowledge base, which is an internal representation of the system and difficult for users to understand. For this reason, we have developed this component, the task of which is to prepare the results in a format convenient for users of the system.

Knowledge base - knowledge bases are components in an intelligent system for storing, organizing and using in a structured way basic knowledge about the problem area of the problem area. In our case, the knowledge base stores the program implementation of the model presented in the previous point. The model is implemented as production rules and frames. expressive and intuitive means of expressing basic knowledge about the problem area under consideration.

Inference machine - in rule-based artificial intelligence systems, the inference engine is an essential software component that applies logical rules to a knowledge base in order to infer new information, draw conclusions or make decisions. In FIRA, based on the parameters entered by the user for the company in question, the inference machine selects and activates the rules necessary to identify the financial risk. knowledge in the form of a frame.

4.2 Development environment

The prototype was implemented in the Flex environment [14]. Flex, originally developed by LPA (Logic Programming Associates, 2025) in 1988 as a Prolog-based toolkit for LPA Prolog programmers using MS-DOS, is a versatile toolkit for expert systems and has been ported to many different hardware and software environments. The medium is widely used in industry and research in various applications, such as modeling and simulation, legal reasoning, expert advisory systems, planning, scheduling, and diagnostics.

Flex is an expressive and powerful toolkit for expert systems that supports framework-based reasoning with inheritance, rule-based programming, and data-driven procedures fully integrated into a logic programming environment. It contains its own knowledge specification language called KSL (Knowledge Specification Language). The environment uses an open architecture and allows access, extending, and changing its behavior through a layer of access functions. Because of this, Flex is often referred to as an artificial intelligence toolkit.

The combination of Flex and Prolog, i.e., a hybrid expert systems toolkit with a powerful general-purpose AI programming language, results in a functionally rich and flexible expert systems development environment where developers can tweak and improve built-in behavioral mechanisms to meet their specific requirements. Flex is attractive to different groups of developers – expert system developers who want to provide readable and maintainable knowledge bases, advanced expert system builders who want to include their own controls, artificial intelligence programmers who want access to a high-level language-based product, and Prolog programmers who need additional functionality and structures

4.3 Program implementation

In general, the programmatic implementation of the knowledge base of the FIRA prototype consists of two basic modules:

- Rules for constructing parametric, index and interval spaces.
- Rules for assessment and classification of financial risks.

Building the spaces. The parametric, index and interval spaces are constructed in parallel and iteratively sequentially along the individual 13 dimensions.

The parametric space is built during FIRA interaction with the user. The specific values of the 13 parameters for the evaluated company are entered through the dialogue component of the system. When a rule is activated in which there are free variables (variables that have no value), then the FLEX interpreter automatically activates the dialog component. For example, in the first rule of Figure 4. the foreign_capital and equity variables for calculating the D/E ratio are free and the interpreter activates the dialog component (Figure 5. Dialog Component) managed in the present case by the Figure 6. Rules for managing the dialog component for the rule in Fig. 2. rules. Thus, the two variables get their values, thus constructing the 1st and 2nd dimensions of the parametric space.

```
/*
==================================================================
   FIRA (FInancial Risk Assessment)

   A knowledge-based system for assessing various financial risks.

   Prototype: PhD Thesis Todor Todorov
==================================================================
*/

% You can start the example by typing either 'run' or 'start'


/*
*******************************************
* DIALOG COMPONENT                        *
* ================                        *
* Rules for establishing risk parameters. *
*******************************************
*/

/* Construction of the parametric, index, and interval spaces
   ------------------------------------------------------------
   This rules establish the D/E Ratio of the company */
rule determine_de_ratio
    if  de_ratio of rframe_financial_stability is unknown
    then d_e becomes foreign_capital divided by equity.

rule de_ratio_optimal
    if d_e >= 0.7 and d_e =< 0.9
    then de_ratio of rframe_financial_stability becomes optimal.

rule de_ratio_conservative
    if d_e >= 0.3 and d_e =< 0.5
    then de_ratio of rframe_financial_stability becomes conservative.

rule de_ratio_balanced
    if d_e >= 1.0 and d_e =< 1.3
    then de_ratio of rframe_financial_stability becomes balanced.

rule de_ratio_risky
    if d_e >= 1.5 and d_e =< 2.0
    then de_ratio of rframe_financial_stability becomes risky.

rule de_ratio_worst
    if d_e > 2.0
    then de_ratio of rframe_financial_stability becomes worst.
```

Figure 4. Rules for the construction of the 1st and 2nd dimensions of the parametric space, as well as the 1st dimension of the index and interval spaces

The next five rules of Figure 4. set the conditions (constraints) for the construction of the 1st dimension of the index and interval spaces. We would like to remind you that the index space is 13-dimensional, and the interval space is 5-dimensional.

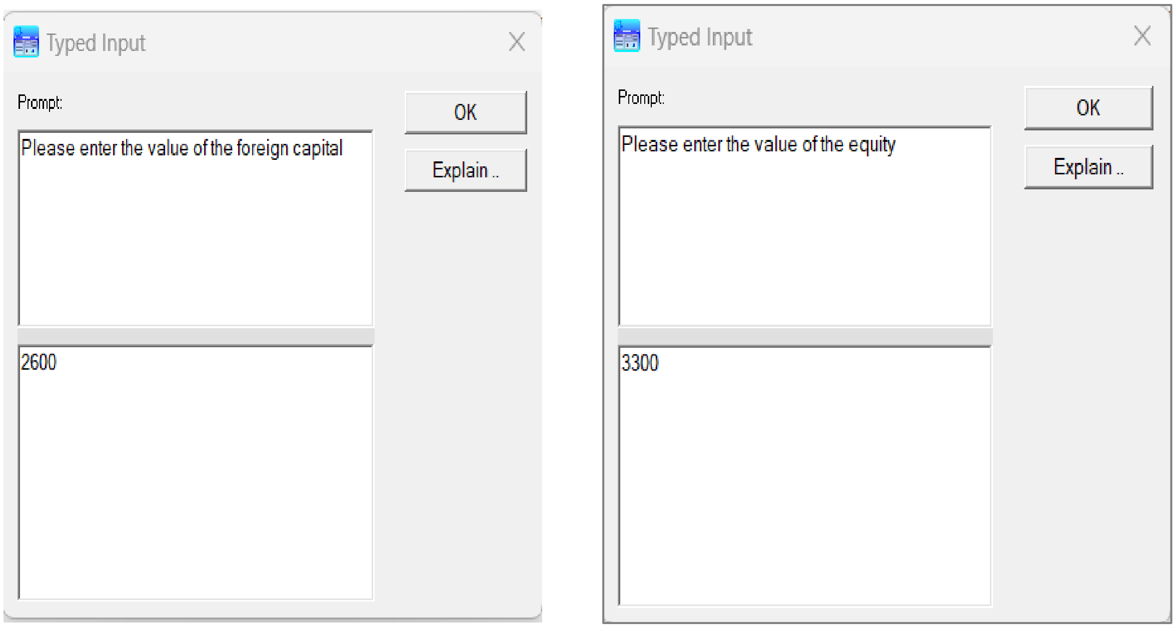

Figure 5. Dialog Component

```
question foreign_capital
   Please enter the value of the foreign capital ;
   input number.

question equity
   Please enter the value of the equity ;
   input number.
```

Figure 6. Rules for managing the dialog component for the rule in Fig. 2.

For the convenience of FIRA users, there are built-in visualizations of the interim results (Figure 7. Visualize a specific element of the index space).

```
% displays the indexes
action report_indexes ;
     do  write ('D/E Ratio: ') and write (d_e) and nl and
         write ('Financial Leverage: ') and write (fi_le) and nl and
         write ('Current Ratio: ') and write (cu_ra) and nl and
         write ('Quick Ratio: ') and write (qu_ra) and nl and
         write ('Immediate Liquidity: ') and write (im_li) and nl and
         write ('ICR: ') and write (icr) and nl and
         write ('OCF Ratio: ') and write (ocf) and nl and
         write ('Free Cash Flow: ') and write (fcf_p) and nl.


action report_rframe ;
     do  write ('de_ratio: ') and
         write (de_ratio of rframe_financial_stability) and nl and
         write ('financial_leverage_ratio: ') and
         write (financial_leverage_ratio of rframe_financial_stability) and nl and
         write ('current_ratio: ') and
         write (current_ratio of rframe_financial_stability) and nl and
         write ('quick_ratio: ') and
         write (quick_ratio of rframe_financial_stability) and nl and
         write ('immediate_liquidity: ') and
         write (immediate_liquidity of rframe_financial_stability) and nl and
         write ('interest_coverage_ratio: ') and
         write (interest_coverage_ratio of rframe_financial_stability) and nl and
         write ('operating_cash_flow_ratio: ') and
         write (operating_cash_flow_ratio of rframe_financial_stability) and nl and
         write ('free_cash_flow: ') and
         write (free_cash_flow of rframe_financial_stability) and nl.
```

Figure 7. Visualize a specific element of the index space

The other dimensions of the three spaces are constructed in a similar way.

Output Machine - when the FIRA is started, the output machine is immediately activated, as shown in the Figure 8. Output Machine. The output machine can be controlled to operate in different modes. In the standard operating mode of FIRA, the output machine activates the first appropriate rule found. After the rule has been processed, it is removed from the set of rules available for subsequent consideration and selection.

The output machine interacts with the rest of the FIRA components. For example (as explained above), if the equity and foreign capital determine_de_ratio parameters are unknown in the knowledge base when the rule is activated, then the inference engine activates the dialog component and requires the user to enter them.

```
/*
*****************************************
* STARTUP AND INFERENCE ENGINE          *
* ============================          *
* Rules to startup the system           *
* and of the inference engine.          *
*****************************************
*/


relation system_banner
    if write('Expert Financial Risk Assessment') .


% start by typing either 'run' or 'start'
action run;
     do  start .

action start;
     do  restart
     and invoke ruleset risk_rules
     and write('Expert Financial Risk Assessment') and nl
     and write('================================') and nl and nl
     and write('1. Report Index Space') and nl
     and write('---------------------') and nl
     and report_indexes and nl and nl
     and write('2. Report Interval Space') and nl
     and write('------------------------') and nl
     and report_rframe and nl
     and write('3. Explain Risk') and nl
     and write('---------------') and nl
     and report_values .

ruleset risk_rules
          contains all rules ;
          update ruleset by removing each selected rule .
```

Figure 8. Output Machine

Frame structure and explanatory component. Frames in artificial intelligence are knowledge-representation structures used to model stereotyped situations, objects, or concepts. They can be used for a hierarchical organization of knowledge. Two frames are used in the FIRA system. The first *rframe_financial_stability* contains intermediate values for the state of the eight indices for the company under consideration. In the beginning, each state is initialized as *unknown* (Figure 9. The frame structure used).

The second frame *rframe_explanation* support the explanatory component of the system.

```
/*
****************************************
* FRAME STRUCTURE                      *
* ============================         *
* Operative frames and explanation.    *
****************************************
*/

% definition of the frame supporting the risk "financial stability"
frame rframe_financial_stability  ;
     default de_ratio  is unknown and
     default financial_leverage_ratio  is unknown and
     default current_ratio  is unknown and
     default quick_ratio  is unknown and
     default immediate_liquidity  is unknown and
     default interest_coverage_ratio  is unknown and
     default operating_cash_flow_ratio  is unknown and
     default free_cash_flow  is unknown .

frame rframe_explanation ;
     default general  is unknown and
     default interpretation  is unknown and
     default assessment  is unknown and
     default risk  is unknown and
     default strategy  is unknown .
```

Figure 9. The frame structure used

Explanatory component. The role of this component is to present the type of financial risk for the company being evaluated in a way that is understandable to consumers.Figure 10. Preparation of an explanation) and a brief explanation of the risk identified.Figure 11. Risk assessment and classification).

```
% displays the final state of play
action report_values ;
     do  write ('General: ')
     and write (general of rframe_explanation) and nl
     and write ('Interpretation: ')
     and write (interpretation of rframe_explanation) and nl
     and write ('Assessment: ')
     and write (assessment of rframe_explanation) and nl
     and write ('Risk: ')
     and write (risk of rframe_explanation) and nl
     and write ('Strategy: ')
     and write (strategy of rframe_explanation)and nl and nl.
```

Figure 10. Preparation of an explanation

```
/*
*****************************************
* RISK ASSESSMENT                       *
* ===============                       *
* Rules to risk assessment.             *
*****************************************
*/

rule risk_assessment_optimal
    if  de_ratio of rframe_financial_stability is optimal and
        financial_leverage_ratio of rframe_financial_stability is optimal and
        current_ratio of rframe_financial_stability is optimal and
        quick_ratio of rframe_financial_stability is optimal and
        immediate_liquidity of rframe_financial_stability is optimal and
        interest_coverage_ratio of rframe_financial_stability is optimal and
        operating_cash_flow_ratio of rframe_financial_stability is optimal and
        free_cash_flow of rframe_financial_stability is optimal
     then general of rframe_explanation becomes 'Best (optimal) combination - high financial stability.' and
          interpretation of rframe_explanation becomes 'Debt supports growth without jeopardizing solvency, liquidity covers at least one production cycle,
          assessment of rframe_explanation becomes 'Optimal financial situation.' and
          risk of rframe_explanation becomes 'Minimal.' and
          strategy of rframe_explanation becomes 'Expansion, innovation, long-term investments.' .
```

Figure 11. Risk assessment and classification

4.4 Testing and validation

To test the prototype, 5 representative examples (one for each type of risk) of real companies with known financial results and relevant risk assessments were selected. The input parameters and indices of these test examples are summarized in Table 8. Input parameters and indexes of test examples.

Table 8. Input parameters and indexes of test examples

1		Минимален	Нисък	Умерен	Висок	Критичен
2	Собствен капитал	3300	4200	2700	2100	1000
3	Привлечен капитал	2600	1700	3200	3800	4900
4	Общо задължения	2700	1800	3300	3900	5000
5	Общо активи	6000	6000	6000	6000	6000
6	Краткотрайни активи	2600	2750	2700	2700	3000
7	Краткосрочни задължения	1130	917	1421	2000	3500
8	Материални запаси	1300	700	1500	1500	1800
9	Парични средства	340	550	350	300	300
10	EBIT	700	500	550	600	80
11	Разходи за лихви	200	100	250	400	100
12	Паричен поток от оперативна дейност	2034	2568	1705	1800	200
13	Свободен паричен поток	600	1250	400	150	-200
14	Общо приходи	5000	5000	5000	5000	5000
15						
16						
17	D/E Ratio:	0.79	0.40	1.19	1.81	4.90
18	Financial Leverage / Debt Ratio	0.45	0.30	0.55	0.65	0.83
19	Current Ratio:	2.30	3.00	1.90	1.35	0.86
20	Quick Ratio:	1.15	2.24	0.84	0.60	0.34
21	Immediate Liquidity:	0.30	0.60	0.25	0.15	0.09
22	ICR:	3.50	5.00	2.20	1.50	0.80
23	OCF Ratio:	1.80	2.80	1.20	0.90	0.06
24	Free Cash Flow:	12%	25%	8%	3%	-4%

First example. The first example is of a company with minimal financial risk. On Figure 12. Results of a company with minimal financial risk FIRA results are presented. In the report generated by the system, the configurations of index and interval spaces are presented. This combination of indicators describes a balanced and moderately growing agricultural holding, combining good financial sustainability with increased use of borrowed development funds. Indebtedness is higher, but controlled, and liquidity remains at healthy levels, without unnecessary accumulation of non-working capital.

```
| ?- run.
Expert Financial Risk Assessment
================================

1. Report Index Space
---------------------
D/E Ratio: 7.878787878787878e-1
Financial Leverage: 0.45
Current Ratio: 2.300884955752212
Quick Ratio: 1.150442477876106
Immediate Liquidity: 3.008849557522124e-1
ICR: 3.5
OCF Ratio: 1.8
Free Cash Flow: 12


2. Report Interval Space
------------------------
de_ratio: optimal
financial_leverage_ratio: optimal
current_ratio: optimal
quick_ratio: optimal
immediate_liquidity: optimal
interest_coverage_ratio: optimal
operating_cash_flow_ratio: optimal
free_cash_flow: optimal

3. Explain Risk
---------------
General: Best (optimal) combination - high financial stability.
Interpretation: Debt supports growth without jeopardizing solvency, liquidity covers at least one production cycle, cash flows ensure self-financing of dig
Assessment: Optimal financial situation.
Risk: Minimal.
Strategy: Expansion, innovation, long-term investments.

yes
```

Figure 12. Results of a company with minimal financial risk

Second example. On Figure 13. Results of a company with low financial risk The results of a financial risk analysis for a real second company are presented. In the report generated by the system, the configurations of index and interval spaces are presented. This combination of indicators describes a highly stable and conservative farm, with low indebtedness, high liquidity and very good cash flows, making it resilient to climate and market shocks. The company has sufficient reserves to cover current liabilities and unfavorable seasons, and the risk of insolvency is minimal.

```
Expert Financial Risk Assessment
================================

1. Report Index Space
---------------------
D/E Ratio: 4.047619047619048e-1
Financial Leverage: 0.3
Current Ratio: 2.998909487459106
Quick Ratio: 2.235550708833152
Immediate Liquidity: 5.997818974918212e-1
ICR: 5
OCF Ratio: 2.800436205016358
Free Cash Flow: 25


2. Report Interval Space
------------------------
de_ratio: conservative
financial_leverage_ratio: conservative
current_ratio: conservative
quick_ratio: conservative
immediate_liquidity: conservative
interest_coverage_ratio: conservative
operating_cash_flow_ratio: conservative
free_cash_flow: conservative

3. Explain Risk
---------------
General: Good but conservative combination - high stability, lower efficiency.
Interpretation: Low debt and high liquidity buffer, weak leverage effect, likely underinvestment in smart technologies.
Assessment: Financially stable but inefficient.
Risk: Low.
Strategy: Controlled increase in investment activity.
```

Figure 13. Results of a company with low financial risk

Third example. The third example is of a company with moderate financial risk. On Figure 14. Results of a company with moderate financial risk FIRA results are presented. In the report generated by the system, the configurations of index and interval spaces are presented. This combination of indicators describes an aggressive and fast-growing farm that uses a significant share of debt financing to expand operations and increase profitability. Indebtedness is high and liquidity is optimized to lower levels, which means efficient use of capital, but also a limited buffer in adverse situations.

```
| ?- run.
Expert Financial Risk Assessment
================================

1. Report Index Space
---------------------
D/E Ratio: 1.185185185185185
Financial Leverage: 0.55
Current Ratio: 1.900070372976777
Quick Ratio: 0.844475721323012
Immediate Liquidity: 2.463054187192118e-1
ICR: 2.2
OCF Ratio: 1.199859254046446
Free Cash Flow: 8


2. Report Interval Space
------------------------
de_ratio: balanced
financial_leverage_ratio: balanced
current_ratio: balanced
quick_ratio: balanced
immediate_liquidity: balanced
interest_coverage_ratio: balanced
operating_cash_flow_ratio: balanced
free_cash_flow: balanced

3. Explain Risk
---------------
General: Intermediate (balanced) combination - moderate resistance.
Interpretation: Tolerable financial risk, liquidity is sensitive to seasonal fluctuations, limited but available capacity for technological investments.
Assessment: Satisfactory financial condition.
Risk: Moderate.
Strategy: Optimization of cash flows and costs.

yes
```

Figure 14. Results of a company with moderate financial risk

Fourth example. The fourth example is of a company with high financial risk. On Figure 15. Results of a company with high financial risk FIRA results are presented. In the report generated by the system, the configurations of index and interval spaces are presented. This combination of indicators describes a highly indebted and high-risk farm where growth is achieved through aggressive use of external financing. Liquidity is low and buffers to cover short-term liabilities are limited, putting the firm in a vulnerable position under adverse conditions.

```
| ?- run.
Expert Financial Risk Assessment
================================

1. Report Index Space
---------------------
D/E Ratio: 1.80952380952381
Financial Leverage: 0.65
Current Ratio: 1.35
Quick Ratio: 0.6
Immediate Liquidity: 0.15
ICR: 1.5
OCF Ratio: 0.9
Free Cash Flow: 3


2. Report Interval Space
------------------------
de_ratio: risky
financial_leverage_ratio: risky
current_ratio: risky
quick_ratio: risky
immediate_liquidity: risky
interest_coverage_ratio: risky
operating_cash_flow_ratio: risky
free_cash_flow: risky

3. Explain Risk
---------------
General: Risk combination - financial vulnerability.
Interpretation: Increased indebtedness, dependence on current revenues, limited capacity to service investment debt.
Assessment: High risk.
Risk: ????.
Strategy: Debt restructuring, investment restrictions.

yes
```

Figure 15. Results of a company with high financial risk

Fifth example. The fifth example is of a company with critical financial risk. On Figure 16. Performance of a company with critical financial risk FIRA results are presented. In the report generated by the system, the configurations of index and interval spaces are presented. This combination of indicators describes a critically financially fragile farm that is in a state of high probability of liquidity crisis and potential insolvency. Indebtedness is extremely high and liquidity is below minimum safe levels, which means that current assets are insufficient to cover short-term liabilities. cost optimization, sale of unnecessary assets and temporary restriction of investment activity in order to prevent bankruptcy and restore liquidity.

```
| ?- run.
Expert Financial Risk Assessment
================================

1. Report Index Space
---------------------
D/E Ratio: 4.9
Financial Leverage: 8.333333333333334e-1
Current Ratio: 8.571428571428571e-1
Quick Ratio: 3.428571428571429e-1
Immediate Liquidity: 8.571428571428572e-2
ICR: 0.8
OCF Ratio: 5.714285714285714e-2
Free Cash Flow: -4


2. Report Interval Space
------------------------
de_ratio: worst
financial_leverage_ratio: worst
current_ratio: worst
quick_ratio: worst
immediate_liquidity: worst
interest_coverage_ratio: worst
operating_cash_flow_ratio: worst
free_cash_flow: worst

3. Explain Risk
---------------
General: Worst combination - financial instability/crisis.
Interpretation: High debt + low liquidity, inability to service interest, negative free cash flow.
Assessment: Financial crisis.
Risk: Critical.
Strategy: Emergency financial intervention, refinancing or recovery plan.

yes
```

Figure 16. Performance of a company with critical financial risk

Main results of the study

As a result of the study, the following main results were achieved:

- Modern approaches to financial risk management in agriculture are analyzed;
- the main limitations of existing systems are identified;
- a mathematical model for risk assessment has been developed;
- an architecture of a financial risk analysis system has been created;
- A prototype of a system integrated into a smart farming platform has been implemented.

Conclusion

The present dissertation examines a topical and significant scientific problem related to the management of financial risk in the conditions of smart agriculture. As a result of the research, an integrated approach has been developed that combines theoretical, mathematical and technological solutions.

The proposed system contributes to improving the analysis and management of financial risk through the use of modern information technologies and the integration of data from various sources.

The results obtained can be used both in scientific research and in the practice of farmers, financial institutions and public authorities.

Scientific and applied scientific contributions

I. Scientific contributions

1. Development of an integrated conceptual framework for financial risk in smart agriculture
A system concept is proposed that brings together financial, agricultural and climatic factors into a single analytical framework. This approach overcomes the limitations of traditional models that consider risks in isolation and allows for a more complete and realistic description of the risk environment.

2. Systematization and expansion of the classifications of financial risks in the agricultural sector
A multi-criteria classification of risks has been developed, which includes new features such as the degree of predictability, time horizon and the possibility of insurance coverage. This contributes to a more precise modeling and analysis of risk processes.

3. Creation of a mathematical model for identification and assessment of financial risk
A formal model based on parametric representation and index risk assessment is proposed. The model allows quantitative assessment and classification of risk conditions, while providing flexibility and adaptability under different conditions.

4. Formalization of the procedure for classification of risk conditions
Rules and algorithms for classifying farms into different risk categories have been defined, which creates a basis for automated decision-making and reduction of subjectivity in the assessment.

II. Scientific and applied contributions

1. Development of an architecture of a financial risk identification system
A modular architecture is proposed, allowing the integration of different data sources and easy expansion of functionality. The architecture is consistent with the modern requirements for intelligent information systems.

2. Adaptation of the event model of the ZEMELA platform
An adaptation of an existing event-oriented model for the needs of financial risk has been carried out, which demonstrates the possibility of expanding agricultural platforms with financial functionalities.

3. Implementation of a prototype of a financial risk analysis system
A working prototype has been created that implements the proposed models and algorithms. The system demonstrates the practical applicability of the developed approach.

4. Development of a mechanism for visualization and interpretation of the results
Tools have been created for presenting the results in a user-friendly form, which supports management decision-making.

5. Demonstrating the applicability of the system in a real-world environment
Test scenarios have shown that the system can be used to assess financial risk on farms and support both producers and financial institutions.

Publications on the topic of the dissertation

1. Krasteva, I., Glushkova, T., Todorov, T., Designing a Blockchain-Based Model for Lifelong Learning Certification, September 2025, DOI: 10.1109/InfoTech67177.2025.11175956, Conference: 2025 International Conference on Information Technologies (InfoTech-2025), Proceedings, 11-12 September 2024, Bulgaria

2. Todorov, T., Tabakova-Komsalova, V., Tsheresharov, S., Stoyanov, S., Modeling Financial Risks in Smart Agriculture, 13th International Conference on Intelligent Systems (IS'26)

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