Fuzzy Compliance Risk Monitoring System*

Nadiia Vasylkiv[1,†], Mykhailo Luchko[1,†], Oleh Boberskyy[1,†] and Mykhailo Khliboyko[1,†]

[1] *West Ukrainian National University, 11 Lvivska Str., Ternopil, 46009, Ukraine*

Abstract

The article examines the compliance system as a key mechanism for ensuring that companies adhere to regulatory requirements, internal policies, and ethical standards. It analyzes the main compliance risks associated with constant legislative changes, staff turnover, the introduction of new technologies, and modifications to products, goods, and services. A fuzzy logic-based approach to managing these risks is proposed, enabling the automation of monitoring processes and minimizing human error. The developed fuzzy compliance risk assessment system incorporates four key variables: legislative regulation, product changes, staff turnover, and technological factors. The Mamdani mechanism and Gaussian-type membership functions were used for modeling. The modeling results confirmed the system's accuracy, scalability, and applicability in real-world conditions. Implementing this approach enhances risk management efficiency, ensures business stability, and strengthens the company's market reputation.

Keywords

Fuzzy System, Fuzzy Logic, Compliance System, Risk-oriented operation, Legislative Compliance.

1. Introduction

During their activities, business entities encounter changes driven by various external and internal factors. Compliance refers to a set of measures aimed at ensuring adherence to the norms and standards established by current legislation or internal regulations [1]. It encompasses various areas, including finance, data protection, environmental protection, competition, employee rights, and other critical aspects of organizational and individual activities. In the European Union, key compliance areas have been identified. For instance, the General Data Protection Regulation establishes rules for processing and storing personal data [2], anti-corruption legislation aims to combat corruption and enhance business transparency, antitrust policies promote fair competition, and environmental regulations set standards for emission reduction and waste management to protect the environment.

To effectively implement compliance measures, organizations develop internal policies that align with current standards, conduct regular audits and staff training, and utilize automated risk monitoring systems. These mechanisms help ensure that organizations operate in accordance with modern regulations. Compliance is not only a legal requirement but also a crucial tool for promoting transparency, fostering trust in business, and supporting sustainable development.

Failure to meet compliance requirements can have serious consequences for organizations, affecting both their financial stability and overall operations. One of the most significant risks is the imposition of heavy fines [3]. Additionally, regulatory violations may lead to restrictions or even the suspension of a company's operations, significantly impacting its profitability. Another critical consequence is reputational damage, as non-compliance can severely undermine the trust of customers, partners, and investors, ultimately weakening the company's competitiveness in the long run.

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* Corresponding author.

† These authors contributed equally.

nvs@wunu.edu.ua (N. Vasylkiv); m.luchko@wunu.edu.ua (M. Luchko); oleg_boberskyi@ukr.net (O. Boberskyy); mihayloh.com@gmail.com (M. Khliboyko)

0000-0002-4247-7523 (N. Vasylkiv); 0000-0001-6499-4188 (M. Luchko); 0009-0005-7951-338X (O. Boberskyy)

Implementing compliance provides companies with several important benefits, among which increasing trust from customers and partners holds a special place. Adhering to current standards demonstrates a business's responsibility, helping to strengthen its reputation. Compliance also helps mitigate the risks of fines and other sanctions, ensuring the company's legal protection [3]. Additionally, developing a sustainable business model that aligns with modern requirements enhances long-term stability and competitiveness in the market.

However, in today's business environment, companies face several challenges related to compliance implementation [4]. Constant updates to legislation require businesses to adapt quickly to new regulations, which is often a complex task. This also demands significant investments in cutting-edge technologies and employee training to ensure compliance readiness. Moreover, the high liability associated with compliance violations adds further pressure, as even minor infractions can result in serious consequences, such as substantial fines. For instance, violations of labor laws can lead to penalties amounting to several thousand dollars [5].

Thus, the compliance system is a key element in ensuring business legality and transparency while contributing to the harmonization of activities. MATLAB is widely used in economics due to its powerful capabilities for calculations, modeling, data analysis, and visualization. It also enables the assessment of financial risks, including market, credit, and operational risks. Specialized functions allow for the creation of data forecasting models to address a wide range of challenges in complex information environments, such as predicting future stock market prices [6]. Fuzzy systems facilitate data prediction by prioritizing information for more effective management [7].

2. Risks in the compliance system

Non-compliance within the compliance system can create significant risks for companies, affecting their financial stability, reputation, and operational activities [8]. One of the most serious consequences is financial loss, particularly in the form of fines, which can reach substantial amounts. Additionally, legal repercussions – such as lawsuits, restrictions, or even suspension of operations—pose a serious threat to businesses, especially in highly regulated industries.

Given the importance of the compliance system and the necessity of adhering to current regulations, four key areas of risk management have been identified:

- Adherence to legislation;
- Changes in products, goods, or services;
- Changes in personnel;
- Changes in technology.

In line with modern demands, laws and regulations undergo regular changes. Legislative changes significantly impact the compliance system, requiring companies to adapt their policies, procedures, and IT systems to meet new requirements. This necessitates staff training, strengthening internal controls, and increasing expenditures on legal support and infrastructure modernization. New laws are often introduced to enhance transparency, accountability, and fraud prevention, leading to stricter reporting and monitoring requirements. To respond effectively, companies must proactively invest in compliance development, thereby mitigating the risks of fines and reputational damage. For example, Council Directive 2006/112/EC of 28 November 2006, which establishes the common system of value-added tax in the European Union, has undergone numerous amendments since its adoption. As of January 1, 2025, this Directive has been amended 33 times [9]. Similarly, Ukraine's Tax Code, the fundamental document of its tax system, was amended 19 times in 2024 alone [10].

Changes in legislation require companies to review their internal policies and procedures to ensure compliance with new regulations. New laws may necessitate employee training, particularly in accounting, legal support, IT, and finance.

Expanding the product range and launching new products increase market, financial, operational, legal, and reputational risks for enterprises. These risks arise from factors such as low demand, high costs, production difficulties, regulatory restrictions, and potential loss of brand trust. To mitigate these risks, it is essential to conduct a thorough market analysis, test products, and develop effective risk management strategies. Additionally, expanding the product range complicates logistics and inventory management, raising the likelihood of supply disruptions. To address these challenges,

companies should prioritize market analysis, product testing, and strategic risk management to facilitate successful implementation.

Staff turnover significantly impacts enterprise risks, as human resources are essential to its stability and efficiency. The loss of qualified employees leads to a reduction in accumulated knowledge and experience, which can slow down work processes or decrease the quality of products and services. New employees require time to adapt, temporarily lowering productivity. Additionally, recruiting and training new personnel incur significant financial costs, and poor hiring decisions can result in further losses.

Staff turnover also affects corporate culture and company reputation. Mass layoffs or frequent rotations can lower overall employee qualifications, directly impacting the ability to handle non-standard and complex situations. In 2021, the staff turnover rate in Ukraine was 26.4% [11]. The average turnover rate in 2022 was 24.7%, while a 2023 study reported an average of 17.3% [12].

Legal risks are also a significant concern. Violations of labor laws or conflicts with employees can lead to lawsuits and fines. Therefore, staff turnover increases enterprise risks in multiple aspects. To minimize these risks, it is essential to ensure effective rotation planning, proper recruitment, transparent communication with the team, and the development of adaptation programs for new employees.

The risks associated with implementing new technologies within a company include high implementation costs, potential production failures, decreased product quality, legal issues, and reputational damage due to non-compliance with standards or negative public perception, all of which can impact competitiveness. To mitigate these risks, companies must carefully plan processes, train personnel, and implement effective control mechanisms.

Overall, non-compliance risks within the compliance system present a significant challenge for businesses. Avoiding these risks requires a systematic approach, including regular updates to internal policies, investment in technology, and continuous staff training to ensure compliance with modern regulatory requirements.

3. Components of a fuzzy compliance risk monitoring system

The application of fuzzy logic to compliance risk assessment tasks enables the development of hardware or software solutions that operate in real-time, can be easily scaled, and eliminate the subjectivity of individual experts or the rapid fluctuation of information [13]. The use of specialized risk management software allows businesses to effectively and promptly identify potential threats, analyze their impact, and implement appropriate strategies to mitigate them [14; 15]. These systems employ algorithms to detect hidden risks and forecast possible future scenarios.

The application of fuzzy logic algorithms and modern evaluation methods in economic enterprise management enables a more accurate analysis of its current state, enhances management processes, and improves operational efficiency. The implementation of advanced evaluation mechanisms helps enterprises optimize their economic management capabilities and contributes to their further development [16].

For system analysis, four factors influencing compliance indicators have been identified: legislative regulation of activities, the existing range of goods, products, or services, human resources, and technological aspects of operations. The MATLAB R 2018a software is used to develop the fuzzy system.

The overall structure of the proposed fuzzy system is presented in Figure 1.

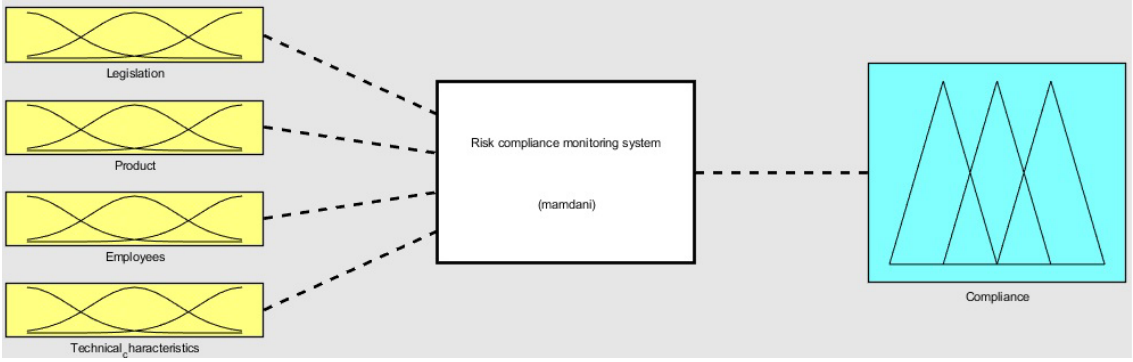

Figure 1: The general structure of the fuzzy risk-oriented compliance system

The selection of membership functions for input variables is a key stage in fuzzy logic systems and other data processing models. This ensures optimal data representation and analysis efficiency [16]. Gaussian-type functions were used for the input variables. These functions are based on the Gaussian distribution and have a smooth, symmetric shape, making them well-suited for modeling variables with continuous values.

Data analysis is a crucial step in developing models that account for uncertainty and variability [18; 20]. For example, in economics, such models are used to forecast changes in indicators, allowing for the consideration of both current trends and potential fluctuations. As a result, businesses and analytical institutions can plan their actions more effectively and reduce risks [17; 19]. This study is based on the analysis of accounting and managerial data, as this information is generally considered a reliable source for tracking the dynamics of a company's performance. To analyze adherence to legislation, document analysis and comparison methods are applied, while other indicators are examined using financial analysis, comparison, and grouping methods.

Proper selection and configuration of these functions significantly enhance data analysis and decision-making efficiency. All input and output variables of the developed system have been assigned conditional values within the range [0;1].

All indicators are expressed as percentages, representing changes relative to the total volume. This approach ensures standardized data comparison and facilitates the analysis of individual factors' impact on overall indicators. It is particularly useful for visualizing trends, assessing change dynamics, and making strategic decisions [21; 22]. Examples of using artificial intelligence for data analysis and rule-based systems development are discussed in [23-26].

The first indicator is Legislation, which reflects the regulatory framework governing business activities. The Legislation indicator ranges from [0;1]. Expressed as a percentage, this indicator serves as a crucial tool for assessing the impact of legal and regulatory changes on business and accounting activities. In this context, continuous monitoring of legislative changes is essential to avoid compliance risks, adapt business processes in a timely manner, and ensure adherence to current requirements. This approach contributes to the stability of business operations and strengthens a company's market reputation.

Significant legislative changes may lead to delays in tracking current regulations, which, in turn, can result in fines. An acceptable threshold for legislative changes is set at 3% of the total volume of norms, decrees, and laws directly affecting business operations.

For the variable Legislation, the following classification is proposed:

- low value s ∈ [0;0.03);
- medium value m ∈ (0.03;0.1);
- high value h ∈ (0.1;1).

Figure 2 presents the general form of the membership functions for the Legislation variable.

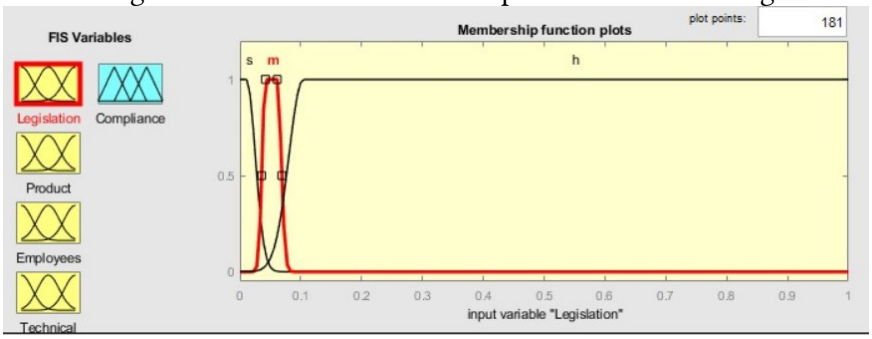

Figure 2: Membership functions of the variable Legislation

Changing the product range or modifying product characteristics is a significant strategic step that can have both positive and negative effects on a company's operational stability. The impact of these changes depends on the chosen strategy, the preparation for implementing innovations, and consumer response. Introducing new products can complicate logistics, inventory management, and demand forecasting. Predefined implementation stages for new products help minimize risks.

Employee training facilitates adaptation to new conditions and ensures operational stability. However, a large-scale product change or expansion can increase business risks. Therefore, the share of innovations within the total volume of products, goods, or services determines the impact on the compliance system. For the variable Product, the boundaries are defined as follows:

- low value s ∈ [0;0.15);
- medium value m ∈ (0.15;0.35);
- high value h ∈ (0.35;1).

Figure 3 shows the general form of the membership functions of the Product variable.

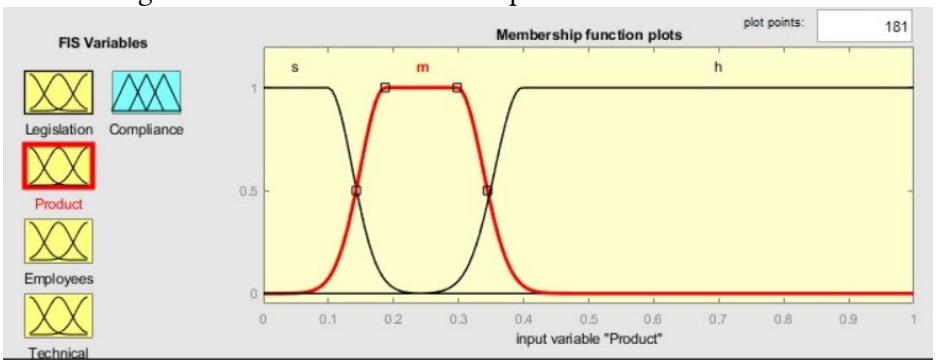

Figure 3: Membership functions of the variable Product

Staff turnover significantly impacts the effectiveness of a company's compliance system, as workforce stability is crucial for ensuring adherence to regulatory requirements and internal standards. A high turnover rate can create risks for compliance tasks, whereas a stable workforce enhances their effective execution.

Highly qualified employees who leave the company take with them essential knowledge and skills needed to maintain compliance. This is particularly critical in industries where compliance requires specialized expertise, such as finance or pharmaceuticals. New employees may not fully understand regulatory requirements or the company's internal policies, which could lead to unintentional violations of laws or internal standards.

For the variable Employees, the boundaries are defined as follows:

- low value s ∈ [0;0.1);
- medium value m ∈ (0.1;0.2);
- high value h ∈ (0.2;1).

Figure 4 shows a general view of the membership functions of the variable Employees.

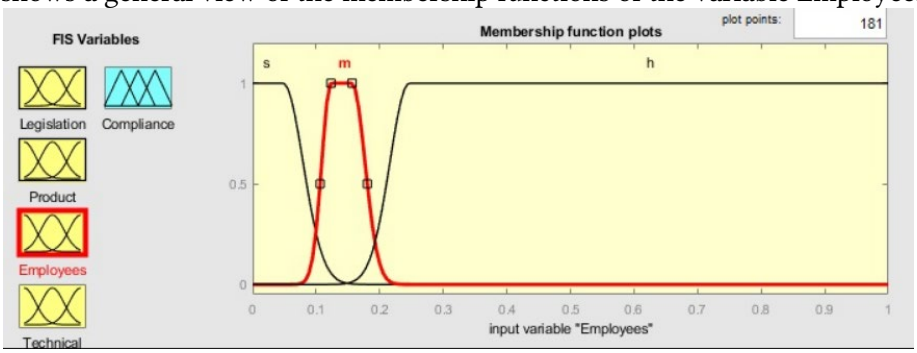

Figure 4: Membership functions of the variable Employees

Technological factors in production play a key role in shaping and developing the compliance system, as they can significantly impact risk management efficiency, regulatory compliance, and adherence to internal company policies. Through the automation of routine production processes, a company can reduce the risk of human error and enhance the accuracy of compliance execution. However, changes in technical components can lead to discrepancies and errors in operations.

For the Technical specifications variable, the boundaries are defined as follows:

- low value s ∈ [0;0.15);
- medium value m ∈ (0.15;0.3);

- high value h ∈ (0.3;1).

Figure 5 presents the general form of the membership functions for the Technical specifications variable.

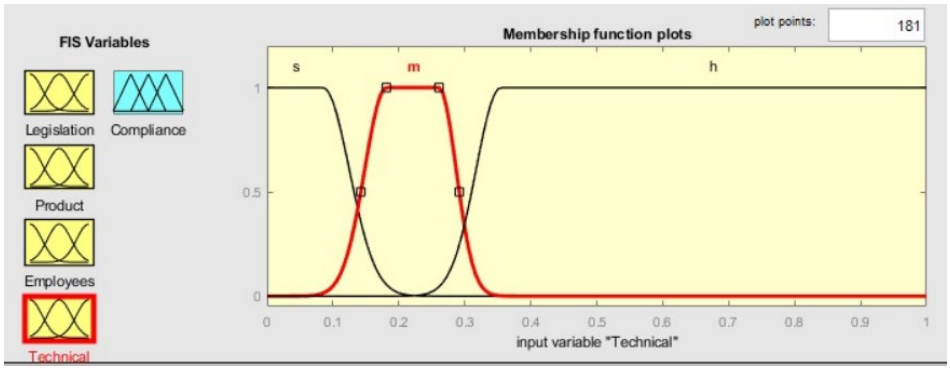

Figure 5: Membership functions of the variable Technical specifications

Although the compliance system is designed to ensure a company's adherence to legal and internal standards, it also carries its own risks. These risks can affect the system's effectiveness, the company's reputation, and its financial performance. To assess the fuzziness of an enterprise's Compliance risk system, the Mamdani mechanism should be used, as the relationship between input and output variables follows the logical "if-then" inference. A Gaussian-type function is applied to determine compliance system risks. For the Compliance risk system indicator, the characteristics are defined as follows:

- low level s ∈ [0;0.35);
- medium level m ∈ (0.35;0.7);
- high level h ∈ (0.7;1).

Figure 6 shows a general view of the membership functions of the output of the fuzzy compliance system.

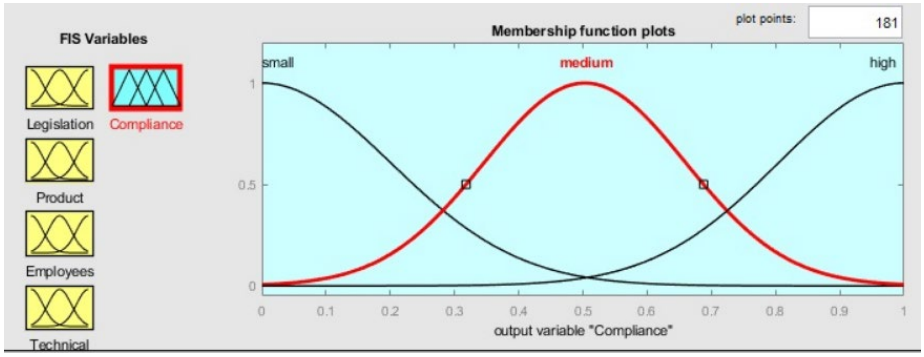

Figure 6: The membership functions of the output of the fuzzy compliance system

Each input variable has three states, along with an additional state for missing information. If data is missing for two variables, this indicates a high risk within the compliance system, while the absence of data for three variables makes it impossible to accurately assess the business entity's operational status. To create the fuzzy system, 4×4×4×4−13=242 rules are defined. Figure 7 presents an example of constructing a rule base for a fuzzy risk-based compliance system.

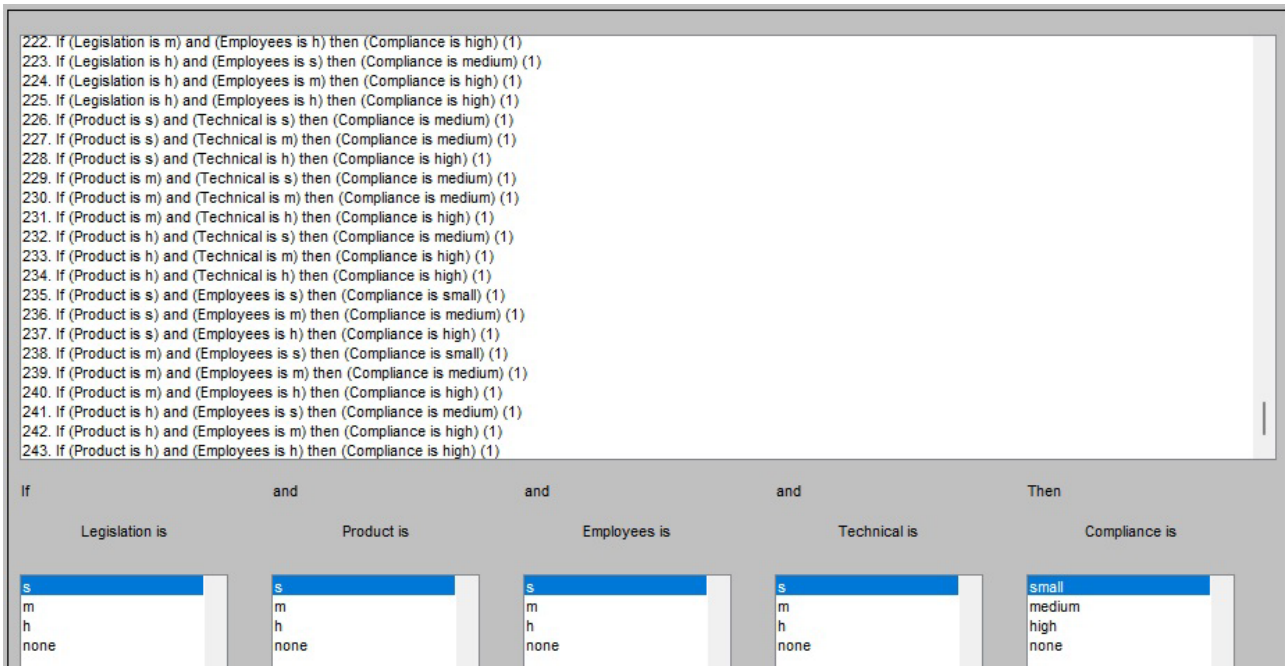

Figure 7: An example of building a rule base for a fuzzy risk-based system

4. Results of the fuzzy system modelling

To assess the accuracy of the proposed fuzzy compliance risk assessment system, Figure 8 presents the results of its performance.

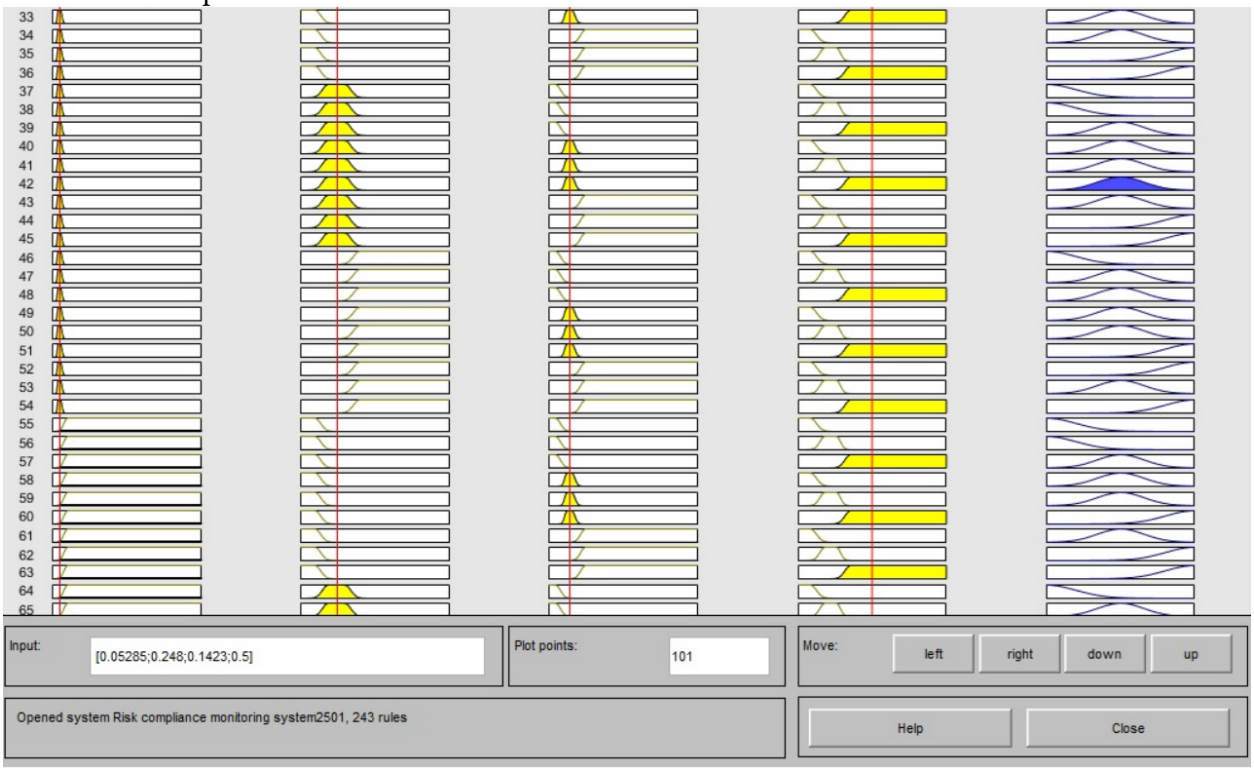

Figure 8: Results of the fuzzy system for determining compliance system risks

Table 1 presents the results of the fuzzy system.

Table 1
Results of the fuzzy risk-based compliance system

The value of the Legislation variable	The value of the Product variable	The value of the Employees variable	The value of the Technical specifications variable	The result of the fuzzy risk-oriented compliance system
0,12	0,5	0,6	0,25	0,628
0,02	0,08	0,15	0,21	0,384
0,008	0,10	0,07	0,12	0,386
0,14	0,18	0,31	0,28	0,619
0,2	0,31	0,07	0,02	0,511
0,34	0,15	0,05	0,80	0,533
0,06	0,09	0,11	0,54	0,611
0,11	0,30	0,21	0,28	0,641
0,07	0,08	0,15	0,33	0,604
0,14	0,19	0,21	0,20	0,628
0,04	0,07	0,11	0,15	0,473
0,02	0,08	0,09	0,07	0,383
0,50	0,21	0,05	0,35	0,501

For example, let's consider one of the options. If the Legislation variable is 0.50, the Product variable is 0.21, the Employees variable is 0.05, and the Technical specifications variable is 0.35, then the result of the fuzzy risk-oriented compliance system is 0.501. This result suggests that the company should prioritize improving legal compliance and technical standard adherence to reduce the overall risk level.

The dependence of the output variable value on certain input data is represented by the value surfaces shown in Figures 9-11.

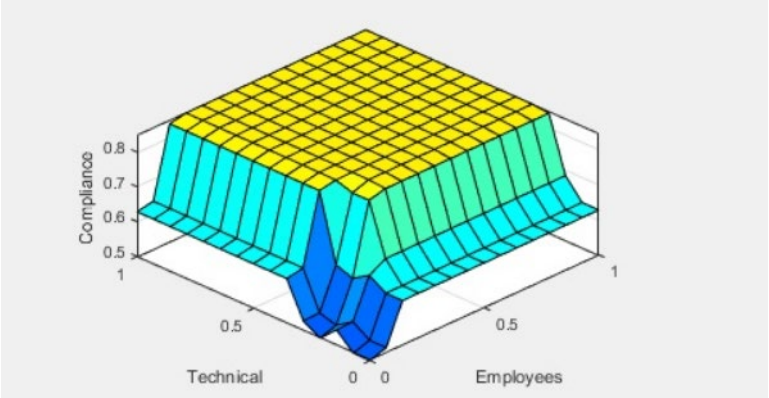

Figure 9: The dependency surface of the output variable values on Technical specifications and Employees

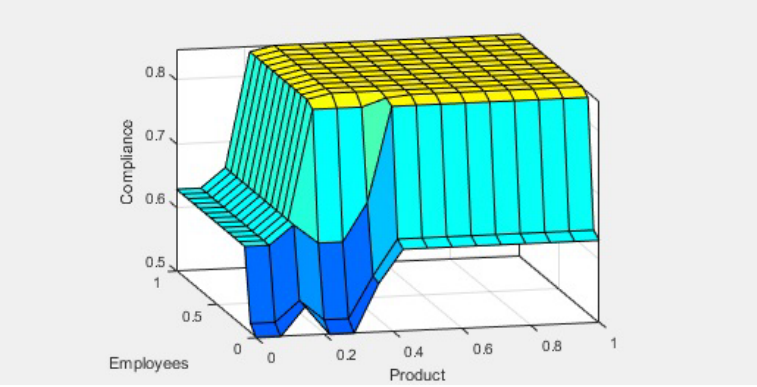

Figure 10: The dependency surface of the output variable values on Changes in Employees and Changes in Products, Goods, or Services

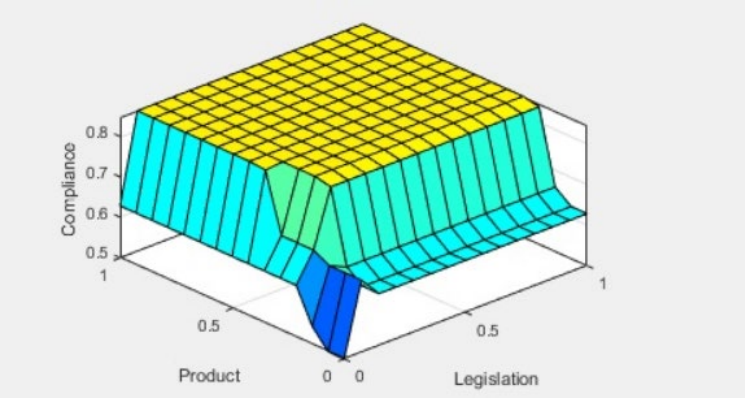

Figure 11: The dependency surface of the output variable values on Changes in Products, Goods, or Services and Legislation

The analysis of the obtained results shows that the developed fuzzy compliance risk assessment system functions correctly and can be applied to real-world facilities.

5. Conclusions

The compliance system is a key tool for ensuring compliance with legal norms, internal policies and ethical standards of the company. However, even the most thoughtful compliance system has certain risks that are important to consider. Legislation is constantly changing, and if the updated application of norms, rules, tax rates or labor laws is not implemented in a timely manner, the company may encounter legal violations. At the same time, there is a risk of too strict control, because too strict control can create a tense atmosphere in the company, which will directly affect staff turnover. Therefore, creating a special model that takes into account risks for the compliance system will allow you to constantly monitor changes that directly affect the work of the enterprise or organization. A risk-oriented fuzzy compliance system not only reduces the risks of violations, but also helps the company maintain its reputation, create trust among customers and partners and act in accordance with ethical standards.

The proposed fuzzy system can be deployed as either a software- or hardware-based fuzzy controller, depending on the enterprise's requirements and technical capabilities. The main stakeholders are business owners and shareholders, as non-compliance with legal regulations increases the likelihood of financial losses through fines, litigation or reputational risks. Owners also have an interest in the long-term stability of the business, and compliance risks can directly affect financial success. Also, the use of a vague system for identifying compliance risks is important for managers, because the development of the company's immediate goals depends on the coherence of the work. Also, in the course of work, investors assess compliance risks as part of an overall assessment of the reliability of the business.

Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT Grammar and spelling check. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the publication’s content.

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