Application of fuzzy decision support systems in IT industry functioning

Dudnyk Oleksii[1[0000-0003-3876-5247]], Sokolovska Zoia[1[0000-0001-5595-7692]], Alexander Gegov[2[0000−0002−6166−296X]], Farzad Arabikhan[2[0000−0002−4336−2007]]

[1] *Odessa National Polytechnic University*, Economic Cybernetics, Ukraine
frightempire@gmail.com, nadin_zs@te.net.ua
[2] *University of Portsmouth*, School of Computing, UK
{alexander.gegov, farzad.arabikhan}port.ac.uk

Abstract. The information technology (IT) market occupies a significant place in the world's economy and in times of rapid digitalization will only continue to increase its influence. Under conditions of environment's increased functioning entropy caused by crises or military conflicts, the importance of IT industry's stable functioning can't be overstated. This paper considers the possibility of fuzzy decision support systems (DSS) efficient usage to forecast and predict the dynamics of IT industry functioning at a scope of a single country, using Ukraine's IT industry as an example.

The software platform used for demonstration purposes is the authentically designed fuzzy DSS FuzzyKIDE. The mathematical basis of platform's functioning is fuzzy logic, which makes it possible to take into account the influences of a set of factors of different nature and obtain a reasonable assessment with potentially inaccurate information. The structure of DSS is offered, using a combined model of the semantic network and fuzzy implication rules. Fuzzy rules are based on predetermined relationships between key influence factors, the analysis of which is offered as well.

The use of the DSS is aimed at forming a holistic forecast of IT industry development. The operation of the DSS is demonstrated on the example of Ukraine's IT industry functioning in different points in time. Comparing the conclusions of the DSS with the historical statistical data of Ukraine's IT industry functioning proves the feasibility of fuzzy DSS usage.

Keywords: IT industry, development trends, fuzzy logic, decision support system, FuzzyKIDE software platform

1 Introduction

This paper starts with a short statistical analysis of recent changes in the international market and how the IT industry is part of this change. The possibilities of using the apparatus of fuzzy logic are stated to improve decision making capabilities on macro-economy scale. That is followed by a section on the DSS application design, which describes the development of the fuzzy DSS for IT industry dynamics forecasting. The next section focuses on the application of the fuzzy DSS, discussing data collection and fuzzy logic-based analysis. The article concludes with a section on

conclusions, summarizing the research findings and highlighting the contributions and limitations of the study.

The role of digital data and technology in today's world is rapidly expanding, fueled by the exponential growth of digital data aggregation and the increasing use of big data analytics, artificial intelligence, cloud computing, and digital platforms. As more devices connect to the Internet and more people use digital services, the digital economy is evolving at an increasing pace. At the heart of much of this activity is the IT industry, which plays a crucial role in the economy by not only providing a potential source of income but also driving cross-growth and making changes in various sectors of the economy. Technologies such as cloud computing, big data analysis, the Internet of Things, artificial intelligence, and more are already transforming the way businesses design, produce, and provide services. IT industry is an essential component of the digital economy, serving as a reliable measure of its effectiveness.

Over the past decade, the growing importance of large technology companies and digital platforms has become most apparent. A significant shift is evident when comparing the sectors of the 20 largest companies in the world by market capitalization in 2009 and 2020. In 2009, the top 20 companies were dominated by oil and gas companies, which represented 39% of the total market capitalization. Financial services followed with a 14% share, while technology and household services accounted for 15%. However, by 2020, the situation had changed dramatically. The share of technology and household services had grown to 43%, while financial services' share had decreased significantly to 10%. Additionally, the telecommunications and basic materials sectors were completely absent from the list of top 20 companies in 2020 (see Table 1) [1, 2].

Given the numerous crisis phenomena in the world economy, the significance of key players in the IT industry and the IT industry itself has been amplified. Determining an appropriate mathematical framework for IT industry’s operations research is a major challenge, especially when dealing with complex tasks that involve numerous qualitative factors that cannot be fully formalized or quantified. In such cases, relying solely on quantitative methods is often inadequate. Additionally, the presence of indirect influences and complex relationships further complicates the use of stochastic approaches. The conceptual problem can be addressed through the use of fuzzy logic. This involves processing fuzzy incoming information and using fuzzy mathematics to transform the fuzzy result information into a meaningful conclusion for analytical assessment and forecasting.

Thus, it is often necessary to incorporate the knowledge and expertise of many different experts, and this can be achieved through the use of intelligent information technologies, such as DSS. While the utilization of such systems is not new, their application and research over the last few decades has undergone significant fluctuations, from an active development phase to a decline, and currently, to a trend of scientific resurgence and practical adoption by experts in diverse domains. By applying this tool in combination with fuzzy logic apparatus, it is possible to assess the development directions of the IT sector, which facilitates timely identification of problem areas and decision-making in the hierarchy of IT industry management. That includes strategic planning for specific IT clusters and product/outsourcing IT companies pro-

fessional associations, such as the IT Ukraine Association, which has a strategic partnership with various IT clusters.

Table 1. Market capitalization represented by the top 20 companies in 2009 and 2020

Industry	2009			2020			Change in market capitalization 2009-2020 (%)
	Market capitalization		№ of companies	Market capitalization		№ of companies	
	Bn $	%		Bn $	%		
Oil and gas	1264	39.64	7	1,741	13.68	1	37.74
Financial services	455	14.27	3	1379	10.84	4	203.08
Telecommunications	324	10.16	2	-	-	-	-100.00
Technologies	293	9.19	2	5,528	43.45	6	1786.69
Consumer goods	267	8.37	2	291	2.29	1	8.99
Pharmaceutical	264	8.28	2	941	7.40	3	256.44
Domestic services	204	6.40	1	2,844	22.35	5	1294.12
Basic materials	118	3.70	1	-	-	-	-100.00

To be more specific, it could be used in various areas, such as the formulation of regulatory policies for the industry's growth, including tax legislation; providing a favorable business environment for cluster development, both domestically and internationally; promoting a balance between the product and IT outsourcing sectors, favoring the integrated product approach and supporting an effective investment policy towards industry entities, which involves attracting foreign and domestic investors, reinvesting profits into growth, investing in IT education, and enhancing the human capital. Thus, continuous monitoring and forecasting of global and regional IT industry trends will aid in developing viable solutions aimed at fostering the industry's balanced growth, increasing the value of software products and services, directing financial resources to the economy, and boosting the industry's share in the country's GDP.

2 DSS application design

We propose a novel development, namely a fuzzy DSS called FuzzyKIDE, which is an applied software implementation of the mathematical apparatus of fuzzy logic. The architecture and technology of the software platform exhibit typicality, demonstrating its potential for solving a wide range of problems under conditions, where inaccurate data are prevalent, utilizing effective mechanisms of logical inference. The general architecture of the system is shown in Fig. 1.

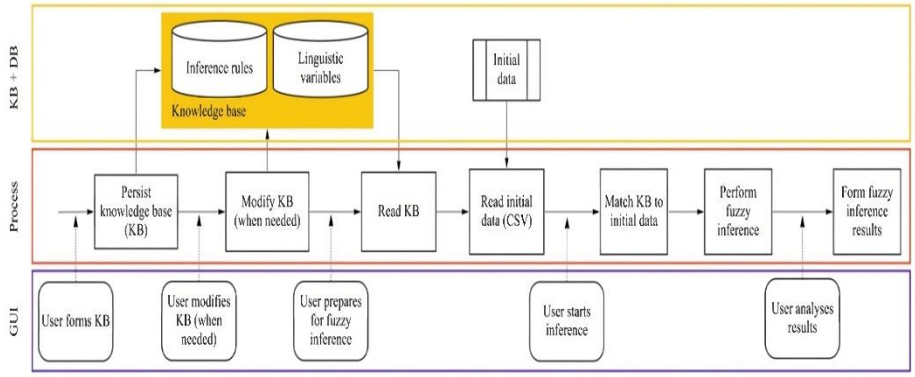

Fig. 1. FuzzyKIDE DSS application design.

The system operates based on a simplified knowledge base structure comprising easily comprehensible fuzzy rules and linguistic variables of a specific type.

IF (X=A) THEN (Y=C),
X:Initial:[A:Trapezoidal:(A1,A2,A3,A4)|B:Trapezoidal:(B1,B2,B3,B4)|…],
Y:Derivative:[C:Trapezoidal:(C1,C2,C3,C4)|D:Trapezoidal:(D1,D2,D3,D4)|…].

In mentioned format, X, Y are the linguistic variables that are specified in the database of linguistic variables; A, C − fuzzy linguistic equivalents of some clear meanings associated with the corresponding linguistic variable; A, B − sets of values for the linguistic variable X; C, D – sets of values for the linguistic variable Y; (A1–A4), (B1–B4), (C1–C4), (D1–D4) – limits of crisp values for fuzzy values of A, B, C, and D, respectively; “Trapezoidal” indicates a trapezoidal type of membership function used to describe the values of a linguistic variable.

The system's fuzzy inference core is based on a simplified SNePS semantic network, which eliminates the intermediate facts base during the fuzzy inference process [3]. This results in obtaining all necessary information for fuzzy inference without repeated queries to the database or knowledge base, potentially speeding up the process.

3 Related work

Previous authors' research has explored the application of fuzzy expert systems in IT project management. The advantages of fuzzy expert systems in terms of their ability to handle uncertain and incomplete data were emphasized, which is a common challenge in project management. The research provided insights into the effectiveness of fuzzy expert systems in improving decision-making in IT project management [4].

The FuzzyKIDE system has already been tested by making simplified forecasts of Ukraine's IT industry functioning [5]. A methodology based on fuzzy logic for analyzing and predicting the state and dynamics of the product/outsourcing components of the IT industry in a country was proposed. The approach aimed to create a system for responding to crisis phenomena and non-standard situations in the industry's functioning, which could support relevant management decisions.

Building upon these works, the present study aims to generalize the usage of decision support systems to forecast IT industry development trends so it can be done in any country. As examples, we still focus on the use of fuzzy logic in our decision support system to analyze statistical data from Ukrainian IT industry and predict trends in industry development.

4 Application of fuzzy DSS for IT industry dynamics forecasting

As an example of application of FuzzyKIDE for IT industry processes forecasting, Ukraine IT industry is used. The IT industry in Ukraine has emerged as a significant contributor to the country's economy. Despite being a relatively young industry, it accounted for 37% of Ukrainian exports for services and generated USD 6.8 billion in revenues by the end of 2021. As of the beginning of 2022, the IT industry engaged 285,000 IT specialists and contributed USD 800 million in tax revenue. Additionally, the export of IT services accounted for approximately 2.7% of Ukraine's Gross Domestic Product (GDP) by the end of 2021 [6]. The National Bank of Ukraine (NBU) reported that the IT industry's influence continued to grow until the onset of the war, reaching a record monthly export figure of USD 839 million in February 2022. This marked a 43% increase from the same period in 2021, which was USD 480 million. However, in March 2022, the Ukrainian IT industry experienced a decline in exports, losing 35% of its volume of exports of computer services, which amounted to USD 317 million, as compared to the previous month [7].

The impact of hostilities on emigration among IT specialists was evaluated, given the humanitarian crisis resulting in a significant number of Ukrainian citizens being displaced. Since February 24, 2022, over 6 million Ukrainians have been forced to seek asylum in neighboring countries, with more than 2.5 million continuing on to other nations with about 100–150 thousand of those being IT specialists [8-10]. Consequently, approximately one-third of the Ukrainian population has been either internally or externally displaced. Taking this into account UNDP predicts that Ukraine's

development will significantly regress in the medium term due to the ongoing war. If the conflict continues, up to 90% of the population may fall below the poverty line [11]. Such a forecast would mean the loss of 18 years of socio-economic progress in Ukraine and a return to poverty levels seen last in 2004.

Based on the information provided, it can be concluded that new opportunities are emerging for IT investments in regions less affected by the war, such as North America, Middle East, and Africa. Additionally, the specific characteristics of the IT industry make Central Asia and India potential alternative markets. The expected increase in unemployment in Central Asia due to the return of migrant workers from Russia creates an opportunity to accelerate the development of the region's own IT sector, providing employment opportunities and creating favorable conditions for investments from abroad. India, which is already a popular market for IT outsourcing, may see increased investment as a result of the current situation [12]. The labor market crisis in Europe is another factor that needs to be taken into account. The current statistics on the emigration of IT specialists indicate that there are favorable conditions for leveling the labor market crisis in Europe through the influx of Ukrainian refugees. In the long term, this may have a negative impact on the overall Ukraine economy [13].

Efforts are being made to promote the IT industry in Ukraine to attract more investments and to increase workforce demand closing capability of the industry. To counteract the projected decrease in the IT sector, the Ukrainian government has established the IT Generation initiative through the Ministry of Digital Transformation of Ukraine, which aims to train IT professionals with government funding [14]. The long-term success of these initiatives is uncertain, but it's reasonable to anticipate that investors may prefer to invest in less risky regions. Due to the global economic impact of the Russian-Ukrainian war, Central Asia has the potential to emerge as a new IT outsourcing center, while India is likely to solidify its position as an existing IT outsourcing hub. Upon analysis of the present state of Ukraine’s IT industry, key patterns and interrelations between factors that impact its development were identified (refer to Fig. 2).

Using a conceptual model of these factors' interrelationships, a collection of fuzzy inference rules was established for investigating industry growth trends. It is important to note that this rule set is not comprehensive and may be extended as necessary, and another fuzzy inference may be conducted to assess additional factors.

Based on current and prior research on the Ukrainian IT industry [3], a set of initial data was compiled to forecast industry performance for the end of 2021 and 2022 under three different scenarios (refer to Fig. 3). Table 2 presents partial results from the experiments for first scenario, which tries to forecast the behavior of Ukraine IT industry by the end of 2021. Tables 3 and 4 present partial results for the second and third scenario respectively. Second scenario tries to forecast the behavior of IT industry by the end of 2022 if Russian-Ukrainian war didn’t occur and using expert prediction for 2022 as a base for comparison. Thirds scenario is similar, but the impact of Russian-Ukrainian war is considered and actual statistical data from the end of 2022 is used as a base for comparison. The results show a reasonable level of correlation between the fuzzy inference results and actual statistical data [6, 15-17].

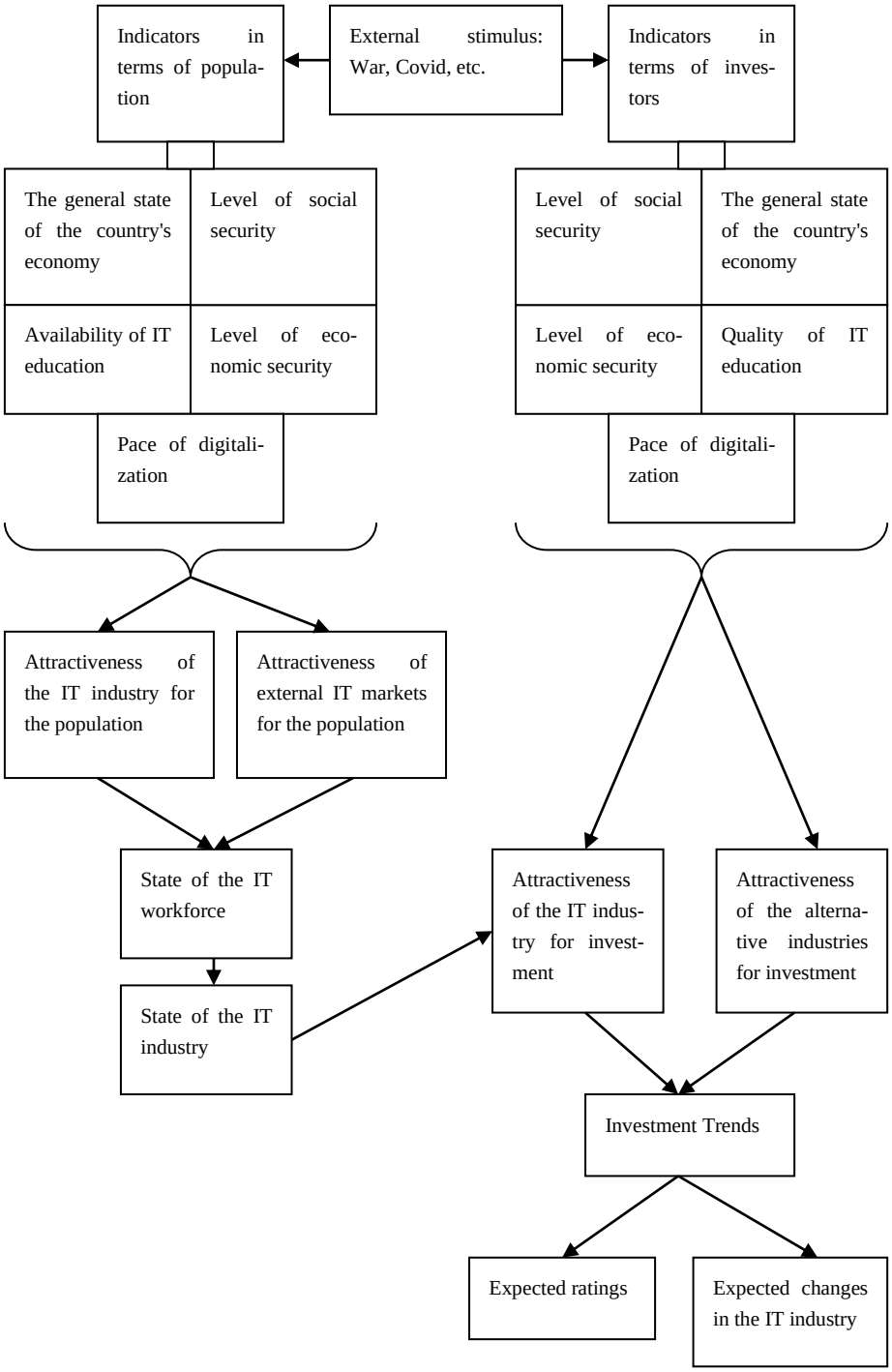

Fig. 2. External and internal factors influence graph.

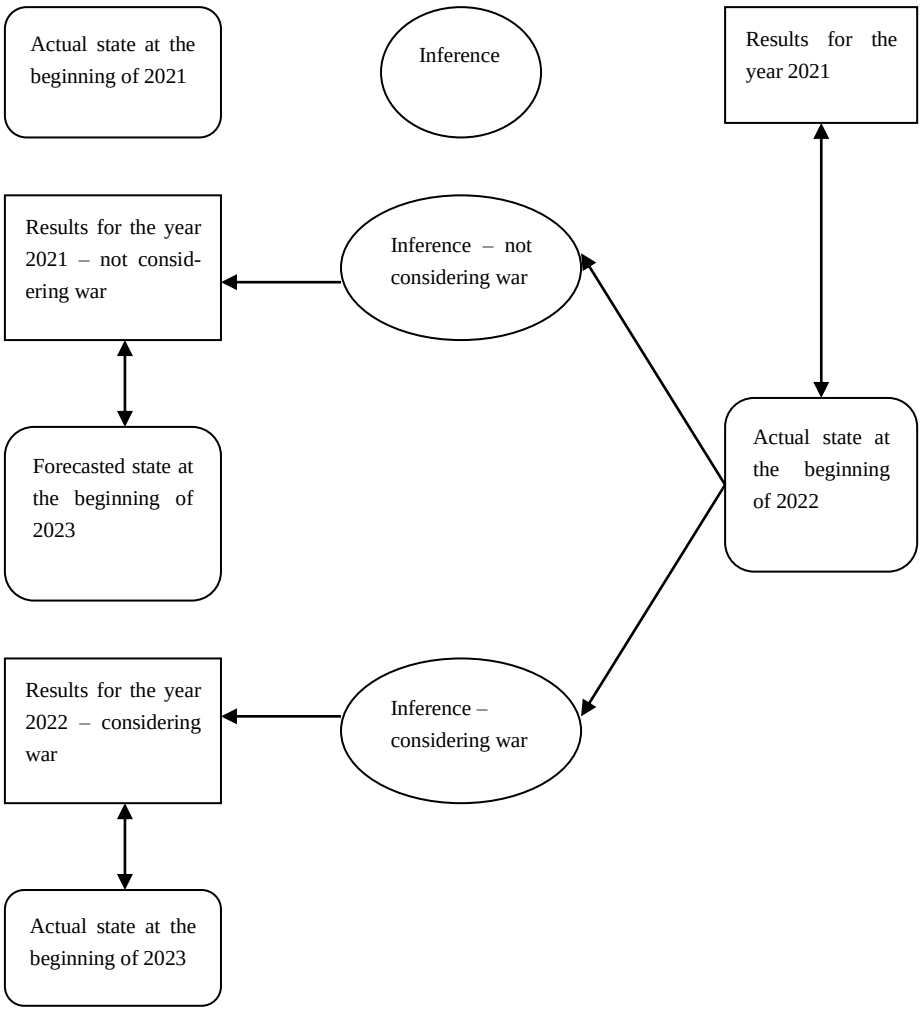

Fig. 3. Experiment scenarios overview.

Table 2. Partial experiment results for 2021 forecast.

Indicator	Result analysis		
	Obtained result	Statistical data	Clarification
General population and IT specialists emigration trend	BELOW MODERATE	5% emigration rate	DSS forecasts no change in emigration trend, which is supported by statistical data available by the end of 2021.
IT workforce growth trend	FAST GROWTH	20% of IT workforce growth	DSS forecasts the IT workforce will continue to grow rapidly due to the popularity of IT as a workplace, driven by the availability of IT education and persistent pay inequality compared to other industries.
IT |industry subindustry shares	NO CHANGE	51% - outsourcing companies; 49% - product and start-up companies	DSS forecasts no changes in the companies' shares, which is supported by statistical data indicating a lack of stimuli for any significant shifts.
IT industry investments trend	FAST GROWTH	35% private investments growth	DSS forecasts continued fast growth of private investments into Ukraine IT industry. Growing size of IT industry and relatively cheap and highly educated IT workforce keep it attractive for investments.
Ukraine IT industry ratings	GROWTH	45th place globally	DSS forecasts continued growth of ratings. Statistical data supports that as Ukraine IT industry moved from 50th place to 45th in one year.

Table 3. Experiment results for 2022 forecast (not accounting for Russo-Ukrainian war).

Indicator	Result analysis		
	Obtained result	Experts' forecasts	Clarification
General population and IT specialists emigration trend	BELOW MODERATE	No change compared to 2021	DSS forecasts no change in emigration trend, which is in line with experts' forecasts for the end of 2022.
IT workforce growth trend	FAST GROWTH	Continued workforce growth	DSS forecasts that IT workforce will continue to grow as there are were no significant economic changes to make other industries more significantly attractive.
IT industry subindustry shares	NO CHANGE	-	DSS forecasts no changes in the companies' shares, which is in line with experts' forecasts, which indicate a lack of stimuli for any significant shifts.
IT industry investments trend	FAST GROWTH	Continued investments growth	DSS forecasts continued fast growth of private investments into Ukraine IT industry. Expected growing size of IT industry keeps it attractive for investments.
Ukraine IT industry ratings	GROWTH	No change compared to 2021	DSS forecasts continued increase in ratings for Ukraine's IT industry. Doesn't entirely match to experts' forecasts as they expected coming recession to be a counteracting factor.

Table 4. Experiment results for 2022 forecast (accounting for Russo-Ukrainian war).

Indicator	Result analysis		
	Obtained result	Statistical data	Clarification
General population and IT specialists emigration trend	MODERATE	13% emigration rate	DSS forecasts increasing emigration trend of IT specialists due to the worsening economic situation in a war-torn country, despite the industry's growing popularity compared to other sectors.
IT workforce growth trend	STABLE	<1% of IT workforce growth	DSS forecasts no change in workforce growth, which is supported by statistical data by the end of 2022.
IT industry subindustry shares	SHIFT TO PRODUCT	41% - outsourcing companies; 59% - product and start-up companies	DSS forecasts an increasing share of product companies due to preference for more financially stable workplaces. Statistical data supports this trend as outsource IT companies become less popular.
IT industry investments trend	DECLINE	50% drop in private investments	DSS forecasts a decline in Ukraine's IT industry private investments, which is supported by statistical data available by the end of 2022.
Ukraine IT industry ratings	DECLINE	60th place globally	DSS forecasts a decline in global ratings for Ukraine's IT industry, as indicated by statistical data showing a drop from 45th place to 60th.

5 Conclusions

Based on available statistics, an analytical review of global IT market trends has shown that the industry is experiencing high growth rates with potential for long-term sustainable development. However, the sector's heterogeneity, intensifying crisis phenomena, and market uncertainties, including those related to Russian-Ukrainian war

and COVID-19, are inhibitory factors that require careful consideration. Therefore, effective IT industry management is crucial to achieving strategic goals and maintaining financial stability. To support decision-making under conditions of uncertainty and risk, decision support systems are becoming increasingly important. Fuzzy decision support systems, which use methods and models of fuzzy logic, are proving to be effective and gaining popularity as an instrumental base for decision support in these conditions.

To improve the operation of IT industry, the use of fuzzy DSS FuzzyKIDE has been proposed. This application offers a modified mechanism of fuzzy inference that accelerates the process and reduces the time needed for expert consultations. The effectiveness of the fuzzy DSS has been demonstrated by performing forecasts of Ukraine IT industry functioning dynamics under various circumstances. The study also highlights the benefits of updating the knowledge base frequently and the ability to consult with minimal dependence on precise data. While the proposed approach has demonstrated promising results, there are some limitations that should be considered, such as the subjectivity of knowledgebase filling, which can lead to conflicting inputs from different users. Additionally, the method currently does not support the combination of fuzzy and clear computations, which may impact its applicability in certain scenarios.

Decision support systems are considered a reusable tool, and their effectiveness in management improves with the enrichment of knowledge and databases by incorporating new experiences. With the rapid growth of the IT industry and standardization of software development processes on a global scale, there is a strong foundation for the exchange, replication, and implementation of intelligent technologies that integrate fuzzy logic elements. Given these findings, it is recommended to utilize the fuzzy DSS approach when forecasting the performance of the IT industry in uncertain conditions.

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