

DIGITAL TECHNOLOGIES IN THE OIL AND GAS INDUSTRY: TECHNOLOGY SELECTION, ADVANTAGES AND RISKS

F. F. Yusifov

Institute of Information Technology, Ministry of Science and Education, Baku, Azerbaijan

ABSTRACT

Currently, the widespread use of digital technologies (DTs) in the oil-gas industry is shaping an environment referred to as digital oil-gas ecosystems. The key digital solutions used in the oil and gas sector include artificial intelligence, machine learning, the Internet of Things, cloud computing, smart materials, digital twins, robotics, drones, blockchain, and other emerging technologies. The article main aims to research the existing condition of digital transformations in oil and gas sector, analyze utilization capabilities of DTs and potential risks. The literature review shows that digital transformation is widely used to effectively organize oil and gas industry activities and increase management effectiveness. Despite the implementation of DTs, determining the next steps to be taken due to technological changes remains one of the key challenges. The article studies the directions of digital transformation in the oil and gas industry and analyses development strategies in this direction in thematic research and case studies. The reasons for the effectiveness of DTs include increasing production efficiency, lower production costs, faster management decision-making, improving the quality of applied solutions, and so on. The article reviews selection of DTs in oil-gas sector based on a multi-criteria decision-making method and conducts experimental evaluation. Risks caused by digital transformation are studied, advantages and disadvantages of development of DTs in oil and gas industry are demonstrated. Considering the findings of existing studies, along with the associated advantages and potential risks, there is a clear need to further explore the application of DTs in complex fields such as the oil and gas industry.

Keywords: digital transformation; digital technology; oil-gas industry; artificial intelligence; internet of things; digital platform.

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1. Introduction

The need to use digital technologies is directly related to the potential of oil and gas production. Technavio forecasts that the oil and gas market will grow to \$59 billion in 2027 [1]. International Energy Agency forecasts that expected growth in oil production will reach 105.7 million barrels per day globally by 2028 [2]. Leading companies apply digital technologies to different production chains due to these reasons [3, 4]. At all times in the oil and gas industry, there has always been a need to reduce risks and uncertainty in the process of oil and gas production, especially in the final stages of processing, field development and management decisions. In general, if it is possible to make such a classification, digital technologies in the oil and gas industry are mainly aimed at solving two problems: increasing oil production and reducing operating costs as much as possible [5, 6].

While a positive trend is observed related to digital transformations in leading companies of the oil-gas industry globally and in Azerbaijan, several unsolved problems remain that complicate the formation of digital platforms.

Dependence of the industry on external technologies, equipment, software and investments delay the application of digital technologies especially in many oil-exporting countries, including Azerbaijan. On the other hand, there is a need for special platforms that test new technologies for digital projects, but such implementation of such experiments requires large financial resources and industrial institutions are usually not interested in this issue [7-9]. In many cases, absence of a necessary number of staff with certain competencies, competitiveness and digital development strategy and priorities for implementation of such digital projects are among main reasons. From this perspective, there is a need for specialists in big data analytics, robotics, drone technologies, programming, 3D-modelling, as well as emerging fields related to digitalization [4, 8]. Lack of a single standard in use of Internet of Things (IoT) technologies, multiple challenges in digital transformation of existing production processes are important factors [4, 10].

Based on reports, digitalization level of oil-gas sector will annually grow 16.56% on average during the period from 2022 to 2027 [1]. Main digital solutions used in oil-gas sector include artificial intelligence (AI), machine learning (ML), IoT, cloud computing (CC), smart materials, big data, digital

twin, robotization, drones, blockchain and other digital ecosystems [1, 11]. According to Gartner's 2021 research results, AI will continue to rapidly strengthen its position in the oil and gas sector [12]. Currently, BP, Shell and ExxonMobil are considered leaders in the application of intelligent technologies in the oil and gas industry.

Currently digitalization is considered the main trend of modern economic development. Although digital transformation is seen as a factor of increasing responsibility and income, high-tech products and technologies are not only designed to facilitate work processes and communication between people but are also directly aimed at increasing production efficiency. From this standpoint, study of digital transformations (DT) in oil and gas sector is one of the relevant issues. Literature analysis shows that, digitalization and digital transformation problems are widely studied from different aspects. Besides, there is a need to study application issues of digital technologies especially in oil-gas industry.

2. Related works

Noticeable significant dynamic in the application of digital technologies (DTs) in the oil and gas economy forms the environment called digital oil and gas ecosystem. In this regard, the digital ecosystem in the oil and gas sector reflects the spatial-temporal structure of economic relations between providers and users of services/goods in the oil and gas sector [13-16]. This system processes large volumes of geodata in real-time mode. This sector covers all fields and steps from collection of geological data to goods manufacturing, transportation, and storage. Development and application of novel innovative technologies, including AI and fiber optic sensors are an important part of this process. This allows to collect, transmit, store and process large volume of data, which in its turn, allows to increase effectiveness of manufacturing and increase competitiveness in local and foreign markets. Digital information also opens new doors for scientific research. Multiple research papers study application capabilities of DTs in oil-gas sector, tendencies, advantages and disadvantages in this field [17]. The study [18] researches the impact of DTs on the energy sector, summarizes existing tendencies and new technologies. Conducted studies demonstrate that DT have the potential to significantly improve the efficiency, sustainability and durability of the energy sector.

The research paper [19] reviews the analysis of modern approaches in digitalization of oil and gas industry. Current applications of traditional technologies used in oil industry are studied and application potential of innovative digital tools and systems that can increase the operational efficiency and reduce expenditure, risks and environmental impact are explored. Application potential, advantages and risks of any DTs including internet of things, robotics, drones and Unmanned aerial vehicle (UAV), big data analysis etc. are studied in detail. The study [20] focuses on the digital transformation of the oil and gas industry, highlighting how technologies like automation, IoT, big data analytics, AI, and ML are revolutionizing operations. These innovations enhance efficiency, reduce costs, and support real-time monitoring and predictive maintenance across exploration, drilling, production, and maintenance. DTs such as digital twins and AI-driven analytics play a critical role in extending asset lifespan, strengthening safety protocols, mitigating operational risks, and boosting overall productivity. Despite

these advancements, several challenges persist, including outdated infrastructure, cybersecurity vulnerabilities, and organizational resistance to change. Nevertheless, addressing these obstacles presents valuable opportunities for innovation and competitive differentiation. The successful implementation of digital transformation strategies will be essential for companies seeking to navigate complex market dynamics, meet sustainability objectives, and maintain a competitive edge in an increasingly dynamic global environment. The study [21] examines application strategies of digital transformation and DTs in European gas and oil companies. The reviewed study shows several stages of digital transformation that promise new advantages to the studied firms and enable them to rise to market-leading positions in new and digital business areas, albeit on a small scale. In study [22] covers the study of DT, opportunities and current challenges in the oil and gas industry. In this study, the digital transformation trends of the oil and gas supply chain, as well as initiatives taken by the Norwegian oil refining company Equinor, were analyzed. The presence of a targeted strategy, successful implementation of digital solutions at the global level will reshape the market dynamics (in terms of demand and supply, investment) as well as the way energy networks are managed. In research [23] reviews the issues related to evaluation of digitalization and digital transformation level of oil-gas industry of the Russian Federation. The examined research paper conducts an analysis for assessing the level of digitalization and digital transformation by systematizing international and local methods, methodological approaches, and methods, and determines their positive and negative aspects. Comparative analysis between «Lukoil», «Rosneft», «Gazprom» and other leading local companies in the oil and gas field demonstrated an insufficient dynamic of digitalization and digital transformation processes in local oil-gas industry.

The study [24] interprets the multifaceted advantages of the synergy of edge computing and cloud integration in the oil and gas industry through a literature review and a review of thematic studies. The study [25] examines cloud and edge computing for application of digital twins in the oil and gas industries. Based on the review results, it was determined that application of cloud and edge computing in the oil and gas industry will be possible later than in other industries due to security and data confidentiality concerns. In research [26] examines digital transformation, digitalization and automation issues in oil and gas wells. Advantages of application of DTs in oil-gas sector are demonstrated and existing approaches are analyzed. Application of the virtual twin model for virtual planning and simulation of wells, as well as utilization potential of autonomous drilling systems and smart technologies are examined. The study [27] evaluates the impact of digital transformation on the economic sustainability of the energy industry in the context of AI. The proposed forecasting model can be used for energy industry analysis and economic stability forecasting. The research paper [28] reviews the issues of risk assessment and management in the oil and gas industry with the application of ML and DTs. The effectiveness of ML algorithms for risk modeling and forecasting, the advantages of applying IoT and blockchain technology for data collection and processing were demonstrated, and results related to the use of DTs for risk management were presented.

Summary of related works demonstrates that digital transformation is widely applied for effective organization of oil and gas industry operations and increasing the management effectiveness. DTs are used in multiple operations of industrial fields (drilling, monitoring, control, exploitation etc.). Despite the introduction of DTs, there is no consensus on the next steps to be taken in near future considering technological changes. However, more research needs to be done to achieve digital transformation in the oil and gas industry. For example, determining the economic efficiency of various DTs applied in oil and gas industry, impact of technology and ensuring the data confidentiality, possibilities of transferring knowledge and experience gained through traditional methods, coordinating advantages of the digital platform, etc. It can be considered that initiatives such as innovation brought by DTs, ecology, climate change, provision of employee health and safety will completely change the oil and gas ecosystem.

3. Directions of digital transformation in oil-gas industry

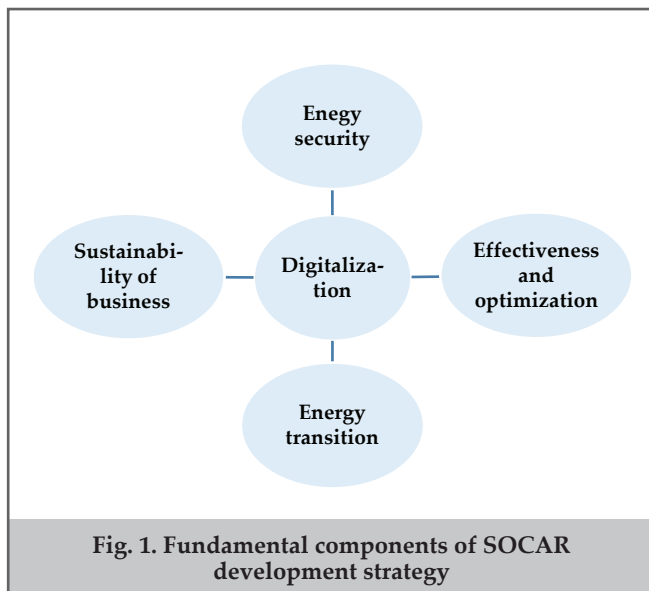
Increasing the efficiency of oil-gas enterprises with the assistance of digital transformation is considered as a relevant issue; however, it is fundamental in two contradictory trends for development of this field. On one hand, increasing demand for oil and gas also increases the demand for energy carriers. On the other hand, enterprises working in this field are constantly developing in a competitive field and constantly facing different crises and decreasing energy prices globally. From this standpoint digital transformation can be viewed as a factor of increasing the competitiveness of oil-gas industry enterprises. It must also be considered that the oil and gas sector is the largest consumer of high-tech products in the world. It is known that many technologies of the information technology industry were initially developed based on the orders from the oil and gas industry enterprises and later became available to a wider audience of users. Currently, DTs for the oil and gas industry are continuously develop-

ing at a rapid pace. Expanding cloud applications, big data analysis, intelligent data analysis methods, IoT applications, etc. are focused on gathering and processing information, ultimately allowing more effective solutions to be developed. Table 1 demonstrates the directions of digital transformation in the oil and gas industry.

According to the forecasts of the World Economic Forum held in 2017, by 2025, the digital transformation of oil and gas enterprises could generate profits of 1.6-2.5 trillion US dollars for the industry, its customers and society as a whole [29]. The heads of more than 200 oil and gas enterprises surveyed by the consulting company Accenture consider the digital transformation of the enterprise to be the most important component of maintaining competitiveness. Analytics of BrilaSoft company working in DTs have demonstrated possible results of digital transformation in the studied sector in their reports. Based on calculations, effective digital transformation of oil and gas enterprises will allow to decrease exploitation expenses by 12-20 % and production efficiency by 8-12 % [30]. In addition, it is predicted that there will be an increase in indicators such as productivity, labor protection and environmental protection in parallel. According to «Digital strategy» forecast of McKinsey, using only openly available technologies in oil and gas field can allow the industrial enterprises to earn 240-529 billion US dollars annually [11]. According to the survey results conducted among IT managers of international oil-gas companies, AI and IoT solutions determine future development directors of the companies [1, 11].

Growing demand for oil requires processing of energy resources, improvement and optimization of existing technologies, which is practically impossible without application of DTs. In current conditions, digital solutions become priority fields in increasing the operational effectiveness of the companies. Nowadays almost all leading global oil and gas companies form their development strategy based on the use of digital transformation.

Directions of digital transformation in oil-gas industry	
Title of the direction	Description
Smart platform	AI, digital twins, IoT technologies allow to decrease equipment repair expenses
Digital field	AI, digital twins, IoT technologies, cloud technologies allow to collect and process big data, synchronize data, minimize risks, ensure safety of the employees
Remote service	AI, ML, data analytics, CC, IoT and other tools expand service potential
Optimizing production fields	Digital twins shorten information retrieval time by up to 30% and data exchange time by up to 70%, improve document approval efficiency by up to 25%, IoT reduces consumption and emissions throughout the entire service process
Diagnostic service	Preventative service technologies are used for unplanned breaks and can reduce the break period up to 20%
Pipeline monitoring	Monitoring of leaks in pipelines using IoT
Increasing production volume, reducing expenses	AI tools, robotized mechanism allow to increase the effectiveness of exploration works and reduce the expenses to a minimum
Optimizing business processes	Data analytics, big data analysis, increased data processing speed, less time spent on software development
Effective decision-making	AI, blockchain allow to increase the efficiency of important decision-making and spend less time on drilling works
Optimization of software	Tools such as AI and CC allow to optimize drilling schedule algorithms
Digital prototype	Optimizing design technology using 3D models



4. SOCAR digital development strategy

DTs expand opportunities for improving operations in large enterprises, ensuring economic efficiency, environmental and labor safety. SOCAR as a global brand of Azerbaijan, is already considered one of the leading energy companies. In recent years, SOCAR's achievements within the framework of large-scale projects in Azerbaijan have been made possible primarily by using DTs in the energy sector. In 2020, together with McKinsey company, a new development strategy of SOCAR Azerbaijan covering the period until 2035 was developed [31]. The main principles of the development strategy include sustainable development of the company, implementation of an effective management system, increasing social and environmental responsibility, assessment of the country's fuel and energy demands, and ensuring the company's profitability, as well as debt management. The goal was to improve the company's management model, centralize functional management, achieve flexibility of business operations, eliminate bureaucratic obstacles and simplify management processes. «SOCAR Corporate Strategy 2035» was approved in 2021 by the Supervisory Board of SOCAR. The need for continuation and intensification of targeted activities toward Industry 4.0 challenges is more relevant today. In accordance with requirements of Industry 4.0 ecosystem, digitalization of production cycle, increasing investment volume allocated for innovation and venture projects, optimization of staff potential through re-skilling and professional development allows for more stable operation of the company. One of the fundamental goals of the strategy is to contribute towards general regional development by ensuring sustainable development of Azerbaijan. The strategy is based on five core components (listed in fig. 1) [31].

Digitalization refers to enhancing operational effectiveness by digitizing segments of the value chain within a unified digital transformation program. In addition to the strategic objectives set for its core operational areas, SOCAR has identified the following areas and approaches as key directions that will support its long-term sustainable development, collectively referred to as new horizons [31]:

Digitalization – this approach emphasizes enhancing efficiency and flexibility through the effective implementation of digital technologies across SOCAR's local, regional, and

international operations, and has been identified as a key strategic direction.

Energy Transition – in light of climate change and broader global challenges, SOCAR intends to reevaluate its engagement in low-carbon sectors such as green energy, biofuels, biopolymers, and hydrogen, drawing on its extensive expertise in the oil and gas sector to inform its future development and growth strategies.

Innovations and venture capital investments – SOCAR aims to enhance its internal innovation ecosystem by fostering the adoption of innovative practices within oil and gas operations and by establishing a structured framework that enables employee participation through their creative capabilities. To reinforce business resilience, SOCAR will also initiate venture capital investment activities, targeting promising opportunities across local, regional, and international markets that align with its strategic business profile. Additionally, SOCAR will contribute to the development of the national start-up ecosystem as part of its broader innovation-driven vision.

Furthermore, SOCAR will adopt proactive measures to optimize its business portfolio, with an emphasis on future market trends, the financial and economic performance of its portfolio companies, and other relevant factors. Throughout this process, SOCAR will uphold its unwavering commitment to the effective utilization of human resources and the fulfillment of its social employment responsibilities. To ensure the successful execution of its strategy, SOCAR will implement functional excellence initiatives across various areas, including human resources, finance, risk management, health and safety, and corporate social responsibility.

Currently SOCAR is successfully implementing digitalization in all operation fields from expedient exploration of deposits, transportation of hydrocarbons to final processing. SOCAR is improving the oil and gas production operations by starting the Digital Field project. SAP UFAM (Upstream Field Activity Manager) combines production processes in one system and will be integrated into the digital core of the enterprise SAP ERP. A consolidated team from SOCAR, Caspian Innovation Center, SAP Digital Business Services and OIS are creating a single data source in staged phases, which will allow for integrated planning, modelling, analysis and monitoring of all oil production processes. In the first stage, it developed solutions for the main business processes, data and its integration with SOCAR measurement source systems, corporate data storage and SAP ERP digital core. The solution was implemented in the system of consistent algorithms and has been tested at two production departments of SOCAR. It demonstrated the functionality of the platform for selection of geological and technological measures, analysis of wells operations, integrated modeling and planning of the production process. Launching the platform for industrial exploitation will enable SOCAR to achieve the following goals:

- a standardized approach to planning will ensure performance record of all production services affecting the output, which will significantly reduce intraday shortages;
- a permanent asset model will be realized in the integrated modeling subsystem to support decision-making and calculating the pattern of static and dynamic constraints;

- all business facilities (well, pipeline, ground equipment, energy facilities, etc.) will be displayed on the map of monitoring panel in real mood with a presentation of their passport, target, and current operation parameters.

Application of integrated modelling technologies allows to use the full potential of the field and is implemented in all its segments from exploration to product sale. There are over 240 «digital field» projects worldwide, including 27 in Russia and 1 in Azerbaijan [32]. BP, Shell and Exxon Mobile are among global leaders in production intellectualization. Clearly, the application of intellectual technologies is accompanied by certain challenges. In particular, this includes expensive equipment and software, personnel training, equipping the production process with a network and data server, conservative approach of the management, remoteness of deposits, etc.

«Intellectual field» technology in oil-gas enterprises is based on technological, management and information fields of decision-making. Application of this technology includes selection of effective solutions that will assist in improving the information flow.

Rapidly increasing the demand for oil, gas, processing and chemical products in the region and globally, as well as steadily increasing the share of Azerbaijan in regional and global energy security, as always, is one of the fundamental strategic goals. Nowadays renewable energy is preferred globally and transformation processes in this direction are supported. Considering the perspective of this direction, stimulation of low carbon emission business, circular economy and ecologically clean operations are among important goals.

5. Selection of digital technologies based on fuzzy TOPSIS method

Currently multi-criteria decision-making (MCDM) factors are widely applied in nearly all fields, including selection of projects, staff, resources, equipment etc. Various development strategies on the Industry 4.0 platform and the ever-increasing international competition force companies to implement digitalization projects of industrial enterprises. From this standpoint, there is a need to develop special models for selection of DTs in implementation of projects. Multi-criteria evaluation that considers industry characteristics is preferred in project implementation, as DT require multi-criteria approach. Literature analysis demonstrates a very limited number of studies, due to complex nature of technology selection in industrial fields [33-43]. Literature analysis demonstrates many studies dedicated to application of fuzzy MCDM methods [33, 36, 39, 40, 42, 44]. Fuzzy MCDM methods are widely used for evaluation of solution alternatives characterized with a fuzzy value by considering multiple criteria.

This paper reviews selection of DTs in oil-gas industry based on TOPSIS method. TOPSIS method allows to calculate the integral index for alternatives considering multiple criteria and ensures ranking of alternatives for option selection procedure with participation of the decision maker [41, 44, 45]. Modified models of fuzzy TOPSIS method are used for alternatives' selection and decision-making [41, 44-47].

Let's review selection of DTs to be used in oil-gas industry based on fuzzy TOPSIS method.

Consider a scenario that, n number of alternative sets T_i ,

$i=1,2,\dots,n$ must be assessed by a group of D decision makers $DM_k (k=1,2,\dots,D)$ based on m number of criteria $C_j, j=1,2,\dots,m$. The criteria are assumed to be independent, hold equal importance, and can be assessed.

Each decision maker DM_k , performs the evaluation to construct the decision matrix $A^k = \|a_{ij}^k\|, i=1,2,\dots, n ; j=1,2,\dots, m ; k=1,2,\dots,D$.

In this case fuzzy TOPSIS method consists of following stages (as shown in fig. 2).

Stage 1. Design a decision matrix. Decision matrix A^k is built as following: $A^k = \|a_{ij}^k\|$, here a_{ij}^k – is evaluation of T_i alternative in relation to C_j criteria by DM_k decision maker.

Stage 2. Choose of linguistic variables based on criteria. The decision maker prefers to express their opinion through linguistic variables due to uncertainty. The linguistic variable is the variable linguistic term value. Each linguistic value can be described with fuzzy numbers that can be assigned to a membership function. Fuzzy numbers have different shapes, with triangular fuzzy numbers (TFNs) being more popular among them. It is a fuzzy number, represented with three points with the following order: $s_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$, where m_{ij}^k – is the most assessment value, l_{ij}^k and u_{ij}^k accordingly are the lower and upper values for reflecting the fuzziness of the evaluation, $l_{ij}^k \leq m_{ij}^k \leq u_{ij}^k$. This representation is explained as a membership function as following:

$$\mu_{s_{ij}^k}(s) = \begin{cases} 0, & s < l_{ij}^k \\ \frac{s - l_{ij}^k}{m_{ij}^k - l_{ij}^k}, & l_{ij}^k \leq s \leq m_{ij}^k \\ \frac{u_{ij}^k - s}{u_{ij}^k - m_{ij}^k}, & m_{ij}^k \leq s \leq u_{ij}^k \\ 0, & s > u_{ij}^k \end{cases}$$

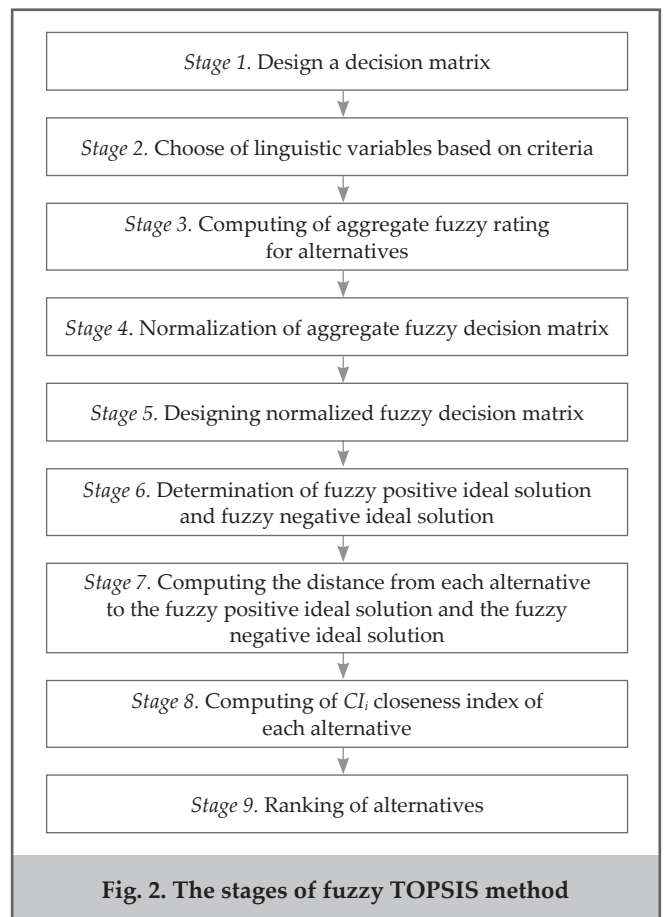


Fig. 2. The stages of fuzzy TOPSIS method

Stage 3. Computing of aggregate fuzzy rating for alternatives.

If fuzzy rating of all decision makers is determined as TFNs $s_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$ and decision makers are equally important, then aggregate fuzzy decision matrix $\tilde{S} = [\tilde{s}_{ij}]$, $\tilde{s}_{ij} = (\tilde{l}_{ij}, \tilde{m}_{ij}, \tilde{u}_{ij})$ can be defined using arithmetic average operator as following

$$\tilde{l}_{ij} = \frac{1}{D} \sum_{k=1}^D l_{ij}^k, \quad \tilde{m} = \frac{1}{D} \sum_{k=1}^D m_{ij}^k, \quad \tilde{u} = \frac{1}{D} \sum_{k=1}^D u_{ij}^k, \\ i = 1, 2, \dots, n, \quad j = 1, 2, \dots, m$$

Stage 4. Normalization of aggregate fuzzy decision matrix. Fuzzy decision matrix denoted by $Y = [y_{ij}]$ is determined as following:

$$y_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \left(\frac{\tilde{l}_{ij}}{\tilde{u}_j^+}, \frac{\tilde{m}_{ij}}{\tilde{u}_j^+}, \frac{\tilde{u}_{ij}}{\tilde{u}_j^+} \right) \text{ and} \\ \tilde{u}_j^+ = \max_{i=1, 2, \dots, n} \{ \tilde{u}_{ij} \} \text{ (for benefit criteria)} \\ y_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \left(\frac{\tilde{l}_j^-}{\tilde{u}_{ij}^-}, \frac{\tilde{l}_j^-}{\tilde{m}_{ij}^-}, \frac{\tilde{l}_j^-}{\tilde{l}_j^-} \right) \text{ and} \\ \tilde{l}_j^- = \max_{i=1, 2, \dots, n} \{ \tilde{l}_{ij} \} \text{ (for cost criteria)}$$

Stage 5. Designing normalized fuzzy decision matrix. Normalized fuzzy decision matrix $Y = [y_{ij}]$, $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$ is created.

It must be noted that, y_{ij} is a TFNs represented with $y_{ij} = (l_{ij}, m_{ij}, u_{ij})$

Stage 6. Determination of fuzzy positive ideal solution and fuzzy negative ideal solution. Fuzzy positive ideal solution A^+ and fuzzy negative ideal solution A^- are determined based on normalized values as following:

$$A^+ = (a_1^+, a_2^+, \dots, a_m^+)$$

where $a_j^+ = (u_j^+, u_j^+, u_j^+)$ and $u_j^+ = \max_{i=1, 2, \dots, n} \{ u_{ij} \}$

$$A^- = (a_1^-, a_2^-, \dots, a_m^-)$$

where $a_j^- = (l_j^-, l_j^-, l_j^-)$ and $l_j^- = \min_{i=1, 2, \dots, n} \{ l_{ij} \}$

Stage 7. Computing the distance from each alternative to the fuzzy positive ideal solution and the fuzzy negative ideal solution. Calculation distance for each alternative $T_i = (y_{i1}, y_{i2}, \dots, y_{im})$ from fuzzy positive ideal solution $A^+ = (a_1^+, a_2^+, \dots, a_m^+)$ based on Euclidean distance using the calculation of the distance between two fuzzy numbers:

$$D_i^+ = \sqrt{\sum_{j=1}^m (dist(y_{ij}, a_j^+))^2}$$

In the same manner, distance of each alternative $T_i = (y_{i1}, y_{i2}, \dots, y_{im})$ from fuzzy negative ideal solution $A^- = (a_1^-, a_2^-, \dots, a_m^-)$ can be calculated as following:

$$D_i^- = \sqrt{\sum_{j=1}^m (dist(y_{ij}, a_j^-))^2}$$

Accordingly, $dist(y_{ij}, a_j^+)$ distance between two $y_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $a_j^+ = (u_j^+, u_j^+, u_j^+)$ TFNs and $dist(y_{ij}, a_j^-)$ distance two $y_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $a_j^- = (l_j^-, l_j^-, l_j^-)$ TFNs are calculated as following

$$dist(y_{ij}, a_j^+) = \sqrt{\frac{1}{3} [(l_{ij} - u_j^+)^2 + (m_{ij} - u_j^+)^2 + (u_{ij} - u_j^+)^2]} \\ dist(y_{ij}, a_j^-) = \sqrt{\frac{1}{3} [(l_{ij} - l_j^-)^2 + (m_{ij} - l_j^-)^2 + (u_{ij} - l_j^-)^2]}$$

Stage 8. Computing of CI_i closeness index of each alternative. The closeness index CI_i represents the distance until fuzzy positive ideal solution A^+ , as well as fuzzy negative ideal solution A^- . The closeness index CI_i for each T_i is computed as following:

$$CI_i = \frac{D_i^-}{D_i^- + D_i^+}, \quad i = 1, 2, \dots, n$$

Based on $D_i^+ \geq 0$ and $D_i^- \geq 0$, it is evident that the value of CI_i lies between 0 and 1. The higher the value of CI_i , the better performance of the alternatives.

Stage 9. Ranking of alternatives. Alternatives T_i are ranked in descending order based on CI_i value and the alternatives with the highest values CI_i are selected.

6. Application of Fuzzy TOPSIS method and ranking

Assume that the selection and application of DTs is intended to increase the effectiveness of the oil and gas company due to digital transformation. Various technologies and approaches are used for digital transformation of the oil and gas company [19]. Suppose that in accordance with priorities and development strategy of oil-gas company, selection and application of following is required: T_1 –0robotics and UAV, T_2 –internet of things; T_3 –cloud services; T_4 –artificial intelligence and machine learning; T_5 –big data analytics; T_6 –blockchain; T_7 –3D printing; T_8 –virtual reality; T_9 –modelling and simulation; T_{10} –smart sensors and measurement tools; T_{11} –cybersecurity; T_{12} –predictive maintenance.

Criteria used for selection of digital technology: C_1 –increasing operational effectiveness; C_2 –reducing expenses; C_3 –reducing risk and environmental impact; C_4 –effective management of cyber-physics systems; C_5 –personnel safety.

Let us consider the assumption that, in this case, 12 alternative sets $T_i (i=1, 2, \dots, n)$ are evaluated based on 5 criteria $C_j (j=1, 2, \dots, m)$ by 10 groups of decision makers (experts) DM_k .

Relevant linguistic variables are determined for evaluation of alternatives in relation to each criterion. Decision makers use TFNs provided in table 2 to evaluate alternatives based on criteria [45, 48].

Suppose that according to stage 1-3, the aggregate fuzzy decision matrix is shown in table 3.

According to stages 4-5, the normalized aggregate fuzzy decision matrix for the benefit criterion is designed. The results of numerical experiment, stages 6-9 of fuzzy TOPSIS method, T_i ranks the alternatives based on the values CI_i closeness index as shown in table 4 [48]. According to stage 6, fuzzy positive ideal solution A^+ and fuzzy negative ideal solution A^- are determined according to the normalized values.

Table 2

Linguistic variable for evaluation of digital technologies	
Linguistic variables	TFNs
Very high	(8, 9, 10)
High	(6, 7, 8)
Average	(4, 5, 6)
Weak	(2, 3, 4)
Very weak	(1, 1, 2)

The aggregate fuzzy decision matrix															
	C ₁			C ₁			C ₁			C ₁			C ₁		
	(l, m, u)			(l, m, u)			(l, m, u)			(l, m, u)			(l, m, u)		
T ₁	5.17	6.00	6.83	3.50	4.33	5.17	0.83	0.83	1.67	3.33	4.17	5.00	3.50	4.33	5.17
T ₂	3.00	3.83	4.67	5.50	6.17	7.00	3.33	4.17	5.00	0.83	0.83	1.67	5.17	6.00	6.83
T ₃	6.00	6.83	7.67	3.92	4.67	5.50	1.58	2.33	3.17	5.00	5.83	6.67	4.17	5.00	5.83
T ₄	2.58	3.33	4.17	1.67	1.83	2.67	4.25	5.00	5.83	6.17	7.00	7.83	3.17	4.00	4.83
T ₅	3.00	3.83	4.67	1.50	2.17	3.00	1.58	1.83	2.67	3.17	3.83	4.67	3.17	4.00	4.83
T ₆	5.42	6.17	7.00	3.92	4.67	5.50	1.75	2.50	3.33	4.50	5.33	6.17	4.00	4.83	5.67
T ₇	1.67	2.50	3.33	0.83	0.83	1.67	4.67	5.50	6.33	6.08	6.83	7.67	2.83	3.67	4.50
T ₈	3.33	4.17	5.00	1.67	2.50	3.33	1.08	1.17	2.00	3.17	4.00	4.83	2.67	3.50	4.33
T ₉	1.67	2.50	3.33	0.83	0.83	1.67	5.00	5.83	6.67	6.67	7.50	8.33	2.83	3.67	4.50
T ₁₀	3.33	4.17	5.00	1.67	2.50	3.33	0.83	0.83	1.67	3.33	4.17	5.00	1.83	2.67	3.50
T ₁₁	1.67	2.50	3.33	0.83	0.83	1.67	5.00	5.83	6.67	6.67	7.50	8.33	2.00	2.83	3.67
T ₁₂	3.33	4.17	5.00	1.67	2.50	3.33	0.83	0.83	1.67	3.33	4.17	5.00	1.67	2.50	3.33

$$A^+ = \{ 1.000, 1.000, 1.000, 1.000, 1.000 \},$$

$$A^- = \{ 0.217, 0.217, 0.119, 0.125, 0.100, 0.244 \}$$

In table 4, DTs are ranked in (T_i) order. As seen from obtained results, in this case several solutions are offered through use the of cloud services (T_3) in digitalization of oil-gas industry in accordance with selected criteria based on expert opinion.

7. Risk caused by digital transformations

The oil and gas industry are of strategic importance for the global economy as a whole and is the basis of the economy of individual countries. At the same time, the efficient development of this production area mostly depends on the application of modern technologies, especially DTs. Processes related to production, transportation, processing, and sale of energy resources, building business relations, management of oil-gas industry enterprises and human resources are highly labor intensive and increase the effectiveness of production and business processes in the studied field. Thus, digitalization plays a critical role in transformation of oil-gas industry by ensuring effectiveness, security and sustainability of production. The application of information technologies such as the IoT, CC, AI, and big data allow industrial enterprises to obtain more accurate information and analyze it in real time. It helps to optimize oil and gas extraction, production, processing, and transportation processes, as well as allows for quick response to changes in operating conditions, improved planning and forecasting.

In addition to advantages of DTs, ensuring information security and data confidentiality, infrastructure requirements and staff's professional development, the need to ensure the reliability and sustainability of new systems and technologies, etc. cause a number of problems and deficiencies. In particular, the development and application of AI systems in complex and potentially hazardous industries, such as the oil and gas industry, pose significant challenges and uncertainties. For example, emergencies and contingencies usually require a flexible and adaptive approach, which is difficult to use with existing AI systems. Mostly

Ranking of digital technologies		
Alternatives	CI_i	Rank
T ₁	0.45	8
T ₂	0.515	3
T ₃	0.583	1
T ₄	0.507	4
T ₅	0.337	9
T ₆	0.559	2
T ₇	0.469	7
T ₈	0.328	10
T ₉	0.491	5
T ₁₀	0.306	11
T ₁₁	0.475	6
T ₁₂	0.302	12

this can be explained by the fact that, as in all applications of AI, there is no clear boundary between AI and human interaction. This is particularly the case when it is necessary to solve problems quickly and accurately in unforeseen situations. In addition, development and implementation of reliable and accurate digital models that can be used in AI control systems is quite a complex task. This requires fundamental research and knowledge about the operation of hybrid systems that allow for the human factor, as well as algorithms for analyzing and solving problems. Most importantly, transformation from human management to AI management creates social, psychological, technological, ethical, and other problems that are complex to solve. This process can be complex and require considerable time and resources, especially considering that many functions currently performed by humans, i.e. decision-making, will be entrusted to AI.

Additionally, ethics and liability issues must be considered when discussing the application of AI in critical and potentially dangerous systems. Besides, there are several limitations and risks that are not critical but require different organization measures at the country and industry

scale. These include the need for competent, professional personnel, sanctions imposed on the export of technology and equipment in many cases in developed and developing countries, difficulties in managing complex technological

systems, technological and organizational problems, etc. It is important to note that issues such as DT and technology require significant investments and long-term efforts by the government and industry.

Conclusions

1. The article reviews the current state of digital transformations in the oil and gas sector, opportunities in using DTs, and analysis of potential risks. Literature review demonstrates that digital transformation is widely used to increase the efficiency of oil and gas industry activities, decision-making, and management. The article studies the directions of digital transformation in the oil and gas industry, reviews the literature references and analyzes development strategies in this direction in the experience of a specific country.
2. The study reviews selection of DTs in oil-gas industry and performs experiments evaluation based on fuzzy TOPSIS method. Criteria for increasing operational effectiveness, reducing expenses, reducing risks and environment impact, effective management of cyber-physics system and personnel security were determined, and empirical evaluation was performed. The study evaluates DTs to be applied in the oil-gas industry based on selected criteria. The article studies the risks caused by digital transformation, demonstrates advantages and disadvantages of development of DTs in oil-gas sector. Research results demonstrate the necessity for more detailed study of application of DTs in oil-gas industry with consideration of advantages and potential risks.
3. Lack of sufficient funding by companies and the government, lack of a sufficient number of qualified and competent personnel, lack of a single standard for the use of DTs, organization of activities according to the traditional mining principles, and several other problems can be listed among fundamental problems in application of intellectual technologies. This problem can be solved in many cases with sufficient funding of scientific research of oil fields' digitalization. Accordingly, development of appropriate polygons (fields) for development of technologies and implementation of experiments may grant obtaining more effective results. Looking at the experience of Western countries, clearly, this approach and method is effective for application of DTs and high-tech equipment in production.

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