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MULTI-CRITERIA ANALYSIS TECHNIQUES TO ASSESS THE EFFICIENCY OF USING BLOCKCHAIN IN LOGISTICS

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Introduction. In complex areas of supply chain management and logistics, there is a need to use innovative solutions to improve economic efficiency, which is particularly important in the context of evolving digital technologies. The solution to the supply chain management problem is based on the use of multicriteria analysis methods to assess the efficiency of implementing modern information technologies in purchase procedures, such as blockchain technology, on the flexibility of the supply chain.

Aim and tasks. The study aims to examine the effects of blockchain to the adaptability of supply chains, its transparency, and the trust levels among its participants.

Results. The developed multi-criteria analysis tool provides the ability to specify weighting coefficients individually for each of the evaluated criteria, making it possible to consider a particular company's priorities within the framework of the optimised process. A survey of experts who knew the subject area under study was conducted to obtain the data necessary for analysis. This can provide expert opinions to assess the feasibility of certain alternatives when making decisions. The assessment conducted by experts revealed three main effects of blockchain and smart contracts on business: increasing the reliability of stored information, increasing the integrity of stored information, and integrating various information flows into a single information system.

Conclusions. The developed multi-criteria analysis tool allows for the specification of weighting factors, or “preferences”, for each of the examined criteria. This feature allows for considering a company’s priorities within the context of the process being improved. Blockchain and smart contracts offer key benefits in streamlining logistics procedures, primarily by bolstering the trust and dependability of the data storage system by creating local copies of data for each participant in the chain and improving data quality by integrating data from various sources into a single blockchain platform. In addition, it increases data security and minimises the risk of falsification because of the impossibility of making unauthorised changes to the database (at the current stage of system development) and the high degree of information integrity ensured by its distributed storage.

Keywords: multi-criteria analysis, supply chain, blockchain, logistics, management, purchase procedures.

1. Introduction.

Logistics and supply chain management involve many steps, from the delivery of raw materials to production to the consumer's receipt of the final product. At each stage, companies participating in the supply chain must solve many problems, including those related to increasing the efficiency of logistics processes.

The problem is that these studies were aimed at finding a solution in a specific area and did not imply the creation of a universal approach to solving problems of increasing efficiency, which is especially important in the current constantly changing conditions when new digital technologies appear every day that can change established business processes (Qulmatova et al., 2022). Therefore, methodological tools that allow managers to make decisions quickly based on the advisability of using these digital technologies are very relevant for managers (Korolchuk et al., 2021).

A potential approach to evaluating how modern information technologies contribute to the purchase process involves employing multi-criteria analysis techniques. The search for a solution when using these methods is based on forming a set of procedures with many acceptable alternatives as a result of the analysis of which many rational (best) alternatives are identified. The basis of multi-criteria analysis methods is the constant refinement (additional definition) of criteria and performance indicators in the tasks under study (Gunasekaran 2017; Kiker et al., 2005). To obtain the data necessary for analysis, when using these methods, a survey of experts who know the subject area under study well and can provide their expert opinion in assessing the feasibility of certain alternatives when making decisions is conducted.

Based on the information from experts, a search was conducted for the best options for solving the issue under study. From the challenges mentioned above in implementing new digital technologies by assessing efficiency based on multi-criteria analysis, the following research question is proposed: Can the multi-criteria analysis method provide valuable assessment results for using blockchain technology?

2. Literature Review.

The Fourth Industrial Revolution, also called Industry 4.0, is primarily associated with the emergence of new information technologies, allowing for higher production efficiency. The technologies emerging in this industry can also impact the social, environmental, and other aspects necessary for the sustainable development of companies. At the same time, the scientific and technical literature needs to contain a sufficient number of recommendations for their use in various industries. Bai (2021) explores assessing the potential applications and impacts of Industry 4.0 technologies on company operations in terms of their effectiveness. Bai (2021) implemented a set of metrics for evaluation aligned with the UN Sustainable Development Goals and devised a blended decision-making approach for analyzing multiple scenarios and criteria. According to Bai (2021), this approach should be used to evaluate the progress of Industry 4.0 based on data on productivity, sustainability and practical applicability..

Industry 4.0 technologies include additive manufacturing, artificial intelligence, big data and analytics, blockchain, cloud solutions, industrial Internet of things, and integrated modelling systems Bai (2021). These technologies offer substantial potential for fostering innovation, thereby enhancing companies' competitiveness in both domestic and global markets while also enhancing the sustainability of current industrial systems. An examination of literature evaluating the effectiveness of employing information technologies to gain competitive edges in logistics and supply chain management, presented in Gunasekaran (2017), is as follows.

1. To conduct an assessment using indicators of supply chain adaptability, consistency, and flexibility by surveying or questioning professional supply chain participants. Moreover, such measures must be adapted to research goals and objectives.

2. It is necessary to consider the impact of different groups of indicators when evaluating the influence of information technology across diverse contexts such as strategy, capabilities, innovation, outsourcing, logistics, and productivity.

3. Since quantitative approaches are cross-cutting and only partially reflect the impact of information technology on firm performance, research should employ them for data collection and analysis, and longitudinal and qualitative methods should reflect the impact of information technology on company performance over time.

Colin et al. (2015) assessed the efficiency of integrating information and communication technologies (ICT) into the activities of enterprises. This study shows that entrepreneurs use ICT to manage records, documents, and information pertaining to business operations. Entrepreneurs also use these tools to coordinate suppliers and interact with customers to manage their supply.

The efficiency of these businesses is not guaranteed by their use of ICT in their operations, as it depends not only on the technology employed but also on how well it is used and how well it is adapted to business demands. It is critical to note that the use and integration of any technology solution, especially supply chain management, requires an assessment of factors, such as the ability to collaborate and negotiate with suppliers and purchasing businesses. A primary obstacle faced by ICT in supply chain management involves enhancing the efficacy of current trading agreements with suppliers and customers.

This can only be achieved by improving the quality of data management, on the one hand, and reducing the costs and time required to transfer information, on the other. The correlation increases in the case of ICT use and the approaches enterprises take in supply chain management (correlation = 0.735).

Consequently, the achievement of operational efficiency and financial sustainability of organisations depends, to a large extent, not only on the use of ICT, but also on the extent to which a specific implementation of ICT is aimed at achieving the strategic goals of the organisation and contributes to achieving competitive advantages (Colin et al., 2015). Tippayawong (2010) compares two groups of firms with different intensity levels when using new technologies.

The LSC system (logistics scorecard) was used as the data collection tool.

The combined information from the high-tech and low-tech categories was contrasted for each evaluation aspect. This study found that the mean scores of the comparison groups differed significantly in most areas. The study found that the group exposed to high-intensity exercise performed noticeably better than the low-intensity exercise group. Factor analysis revealed differences in the elements influencing the efficiency of supply chain operations, which are concentrated in the aspects of flexibility and responsiveness of management, depending on the degree of use of ICT.

Soltany et al. (2018) examined the relationship between organisational culture and the utilisation of information technology within supply chains and its correlation with organisational culture was explored by researchers. Findings revealed a distinct relationship between IT adoption and organisational culture. The study suggests that the organisational culture of large entities impacts their distributors and suppliers within the shared supply chain. IT infrastructure and the ability to use new technologies significantly impact firm performance. At the same time, the study remains open to the relationship between the costs and benefits of using information systems.

Daneshvar (2020) demonstrated that the adoption of cutting-edge information technology enhances the efficiency of supply chains. These results extend the findings of Colin (2015) and Cheung (2018) findings and confirm that ICT integration into supply chains aims to enhance and fortify current trade agreements with suppliers and customers. By utilizing modern technology, information can be transferred quickly, efficiently, at a lower cost, and in less time.

Improving the entire supply chain performance with appropriate ICT in cooperation with suppliers requires sharing universal standards and updating organizations on new information and capabilities.

Therefore, a survey of enterprise managers was conducted, assessing the results based on the Cochrane methodology and a random sample listed by Huo (2012), in which a Likert scale from 1 – “too little” to 5 – “too much” was used.

Assessing the impact of information technology, Gu et al. (2021) use comparable measures and research approaches to obtain comparable results.

Kim (2019) indicated that various indicators could be used to assess the efficiency of technological development. However, economic indicators are predominantly utilised and are the most critical metrics for evaluating a company's performance. Economic indicators must be generalised to measure the efficiency of new technologies. This is because the success of new technologies is influenced by unrelated factors, making it difficult to determine the efficiency of various relationships, primarily through profit and sales metrics alone.

Most of the reviewed studies argued that the emphasis is on the analysis of objective indicators, including measuring the effectiveness of technological development, but keeping in mind the importance of subjective indicators. However, research has focused only on financial indicators and has calculated estimated indicators through the separation of financial and non-financial indicators. These indicators include successful sales outcomes, time savings, cost reductions, research and development (R&D), productivity, technological innovation and technical excellence, customer satisfaction, and product and technology competitiveness.

Meidute-Kavaliauskiene (2021) examined the influence of blockchain technology on the adaptability of supply chains, their transparency, and the level of trust among involved parties. Currently, the growing popularity of blockchain technology does not inspire confidence in companies to invest in this technology, and it is considered risky. Owing to the need to demonstrate the benefits of blockchain to companies in the future, it is crucial to identify factors (transparency, flexibility, and trust) for supply chain management.

Olah (2018) surveyed 284 logistics providers to assess the impact of information technology on their income and profit. The author points out that the data provided in the responses of 51 respondents provided a representative sample for conducting the analysis and formulating general and specific conclusions on the analysed indicators.

From the presented analysis, most studies devoted to evaluating the efficiency of employing information technologies utilise identical methods and information systems for data analysis (Miglierina et al., 2008). Simultaneously, the results obtained, as a rule, are presented as correlations. These findings need to be more precise in determining the exact contribution of information technologies to business growth. However, the conclusions of all the analysed studies indicate the importance of their use in improving operational efficiency and gaining competitive advantages. This finding indicates a need for further research in this area.

Subsequent studies on blockchain technology in a specific context (Azimov, 2020; 2021) suggested creating an original model. To improve further the efficiency of logistics and supply chain management processes, the primary attention of researchers should focus on their automation and digitalisation, as well as the development of analytical models and methods, including technologies for processing big data, as well as other promising technologies implemented (planned for implementation) in the industrial (industrial) Internet of things, including blockchain technologies and smart contracts.

Among all the modern information technologies described above, when carrying out logistics procedures, the most appropriate is the use of blockchain technology and smart contracts (Kouhizadeh et al., 2021; Wang et al., 2014; Manupati et al., 2020; Saberi et al., 2019; Nykyforov et al., 2020). Researchers are studying the impact of blockchain technology and smart contract contracts on supply chains and logistics. According to Kamble (2020), Pournader (2020), and Petrova et al. (2022), blockchain technology, along with smart contracts, is poised to enhance the efficiency of supply chains and logistics.

Despite a number of advantages, blockchain technology and smart contracts also need help. These include lack of regulation by the state, the impossibility of terminating already concluded contracts, the complexity of correcting errors in systems based on this technology, and restrictions on the number of transactions (Azimov et al., 2022).

However, blockchain technology continues to develop actively, and new application opportunities appear in various fields every day. There are promising prospects for adopting blockchain and smart contracts in the purchase processes, and companies are keen to integrate blockchain as swiftly as possible. Using blockchain technology and smart contracts in the future will reduce costs, increase work efficiency between counterparties (Hofmann et al., 2018).

3. Methodology.

The novelty of the combined method lies in the combination of the verbal analysis of solutions based on the theory of fuzzy sets using an experimental design. When conducting an expert survey, a parametric fuzzy measure was created to quantify the preferences of decision-makers regarding the criteria for achieving the goal. In essence, the assessments of decision makers are based on production rules that consider only the extreme values of certain indicators that represent a reference scenario.

These estimates were then processed using experimental design methods.

To apply multi-criteria analysis to evaluate the efficacy of modern information technologies in purchase procedures, it is imperative to establish a comprehensive set of indicators and criteria (criteria functions) to gauge the efficiency of the process under examination. To do this, it is necessary to conduct an expert survey or analyse the information published in this area.

As an illustration of conducting such an analysis, the researchers selected the process of executing purchase procedures by utilising blockchain and smart contracts. The criteria, as well as the corresponding criterion functions, were determined based on the analysis of information about systems and platforms implemented based on blockchain technology with smart contracts (including the analysis of data on the effects obtained from the use of this technology).

Table 1 presents a list of the criteria (criterion functions).

Table 1. Criteria (criteria functions) for assessing the efficiency of the purchase process.

Criterion (criteria function)	Description of the criterion (criteria function)
Reliability	A system is considered reliable if the area of data exchange between system users includes at least three independent participants. The reliability of a database implemented on the basis of a distributed registry increases in proportion to the number of participants.
Sophistication of business logic	The system meets the criterion if: a well-developed system solution scheme; there is regulatory and normative documentation for the automated business process; when using blockchain technology and smart contracts as a mechanism for process integration and maintaining business logic, an unambiguous set of rules for processing and converting information is used.
Information integrity	The system guarantees the integrity of information in cases where there are no breakpoints in processes and/or information flows within the analyzed application area. Blockchain technology makes it possible to eliminate gaps in information flows due to the presence of mechanisms to guarantee the preservation of the integrity of the structure and the immutability of the contents of information flows and the information field as a whole.
Process transparency	Processes are considered transparent when all participants have equal access to information, and a digital algorithm guarantees its immutability (all attempts at unauthorized changes will be entered into a public register). There is a potential for conflicts to arise within the interactions between supply chain participants. Blockchain and smart contract technology allow us to minimize this risk since it has a mechanism that guarantees compliance with consensus between the chain participants.
Integrability	The system ensures data integrability if there are connectors for transmitting and receiving data between internal and external software products. Participants use various information systems that ensure the fulfilment of their information needs. Blockchain and smart contract technology allow for effective integration of processes in disparate information solutions through a combination of technology integration tools (API) and smart contracts as a universal tool for managing process logic.

Source: based on Korhonen (2012); Gregory et al. (2012).

The combined method of multi-criteria analysis used in this case implies that a certain set of criterion functions can be associated with $R = \{R_1, R_2, \dots, R_m\}$ as indicators, calculated on the basis of expert assessments. Each R_i indicator can take values from "short", "below average" and "average", to "above average" and "high". To calculate the resulting R_{res} indicator, the linguistic variable $T(R_{res})$ is used, which can take the values "short", "below average", "average", "above average", "high". Indicators obtained on the basis of expert assessments $R = \{R_1, R_2, \dots R_m\}$ reflect the relationships between the values of partial criterion functions and the resulting indicator R_{res}.

These relationships can be described by the following logical expression. If $R_1 = B_{1j}$ and $R_2 = B_{2j}$ and $R_m = B_{mj}$, then:

$$R_{res} = B_{jres}, B_{ij} \in T(R_i), B_{jres} \in T(R_{res}) \quad (1)$$

where B_{ij} and B_{jres} are the units of measurement of the corresponding linguistic variables.

To move from qualitative to quantitative assessment of R_i indicators, the scale $[-1, 0, +1]$ is used, in which units of measurement can be defined utilizing fuzzy numerical values (L-R), as shown in Fig1.

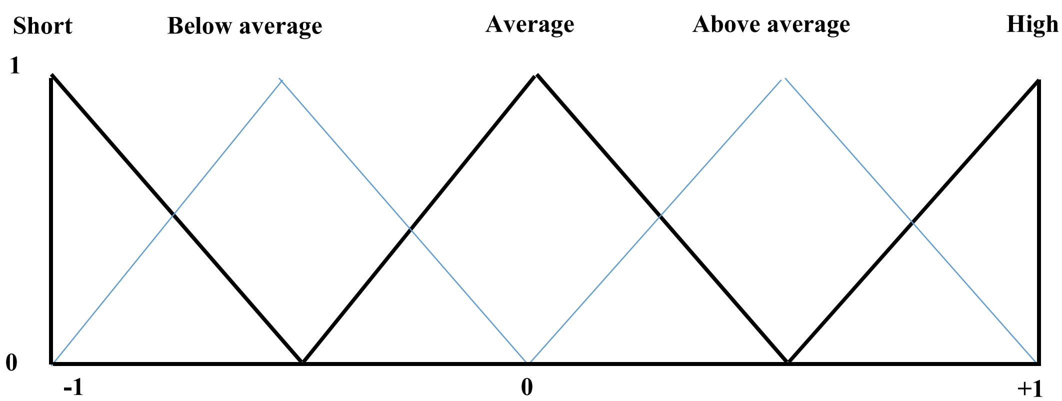

Fig. 1. Units of measurement of a linguistic variable.

By the method of multicriteria analysis proposed above, the minimum and maximum values of the linguistic variable R_i correspond to the values "-1" and "+1". The resulting indicator R_{res} is calculated based on data obtained during an expert survey regarding the values of indicators $\{R_1, R_2, \dots, R_m\}$.

An example of the results of an expert assessment carried out using this method is presented in Table 2.

Table 2. Expert survey results.

R_0	R_1	R_2	R_3	R_1 R_2	R_1 R_3	R_2 R_3	R_1 R_2 R_3	R_1 R_2 R_3.... R_m	R_{res}
1	1	-1	-1	1	1	1	-1	-1	B_{1res}
1	1	-1	-1	-1	-1	1	1	1	B_{2res}
1	-1	1	-1	-1	1	-1	1	1	B_{1res}
1	1	1	-1	1	-1	-1	-1	-1	B_{3res}
1	-1	-1	1	1	-1	-1	1	-1	B_{2res}
1	1	-1	1	-1	1	-1	-1	-1	B_{4res}
1	-1	1	1	-1	-1	1	-1	-1	B_{3res}
1	1	1	1	1	1	1	1	1	B_{5res}
λ_0	λ_1	λ_2	λ_3	λ_{12}	λ_{13}	λ_{23}	λ_{123}	$\lambda_{123\dots i}$	

The values of the R_i indicator required to calculate R_{res} can be represented by fuzzy triangular sets (Figure 2). Then, the expert assessment can be interpreted as follows: "If the R_1 indicator is "short", the R_2 indicator is "high", the R_3 indicator is "average", and then the resulting R_{res} indicator will be assessed as "average".

In this case, to calculate the resulting F_{res} indicator, you can use the formula:

$$R_{res}=\lambda_0+\sum_{i=0}^{m}\lambda_0 R_i+\sum_{i=1}^{m}\sum_{\substack{j=1 \\ j\neq i}}^{m}\lambda_{ij} R_i R_j+...+\lambda_{12...m}R_1...R_m \quad (2)$$

The resulting indicator takes into account the influence of both individual partial indicators λ_i and the influence of sets of indicators of two (λ_{ij}), three (λ_{ijk}) and so on sets.

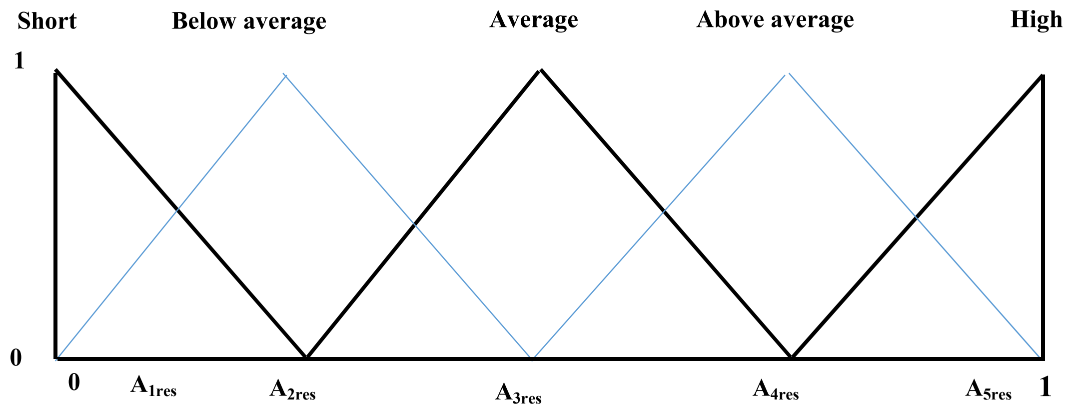

Fig. 2. Scale for assessing the resulting indicator F_{res}.

The experimental design theory's guiding principles are applied to compute these indicators. This entails multiplying the vector of F_{res} values by the averaged scalar products of the corresponding columns in the expert survey results matrix (Table 2). For instance, the following formula is used to determine the coefficient λ_2 value:

$$\lambda_2=\frac{-B_{1res}-B_{2res}+B_{1res}+B_{3res}-B_{2res}-B_{4res}+B_{3res}+B_{5res}}{8} \quad (3)$$

Thus, the proposed method for solving the problem of selecting the best alternatives consists of the following steps.

Step 1. The formation of a set of linguistic variables for each of the initial criterion functions Fi and the resulting indicator R_res, after which the resulting R_i indicators are transferred to scale [-1, +1].

Step 2. Conducting an expert survey and generating a table with its results.

Step 3. Calculation of the resulting quality indicator R_{res}.

4. Results

Based on the above methodology, to calculate the resulting quality indicator F_{res}, an expert survey was conducted, in which 12 experts in the field of implementation of blockchain technology and smart contracts took part. All interviewed experts worked in large Uzbek companies in the oil and gas and financial sectors in information technology (IT) departments, had at least 5 years of experience in the IT field (3 experts had more than 10 years of experience) and, at the time of the survey, were involved in resolving issues related to the implementation of blockchain technology and smart contracts in the supply chain for at least one year.

Experts assessed the impact of using blockchain technology and smart contracts in the information systems presented for each of the criterion functions specified in Table 1. The assessment was carried out on a five-point Likert scale from low to high level of influence (Figure 1).

The experts answered the question: "How do you assess the impact of blockchain technology and smart contracts in the *XX* system according to the *YY* criterion". The results of the expert survey on compliance criteria (SS) are shown in Table 3. The calculation of the coefficients λ for the resulting indicator R_{res} for one of the blockchain systems under study is presented in Table 4.

Table 3. Results of the expert survey.

№	Blockchain systems	SS 1	SS 2	SS 3	SS 4	SS 5
1	Cyber wallet	1	1	1	-1	-1
2	NotaryLedger	1	1	1	1	1
3	IBM-Maersk blockchain-based platform	1	1	-1	-1	1
4	Hyperledger Fabric	1	-1	1	1	1
5	BlockchainX	1	1	1	1	1
6	MYGOV.UZ	-1	1	-1	1	-1
7	South Korea Smart Government	1	1	1	1	1
8	Pillyze healthcare platform	-1	-1	1	-1	-1
λ		0.51	-0.24	0.46	0.31	0.34

Table 4. Calculation of coefficients λ.

№	λR_1R_2	λR_1R_3	λR_1R_4	λR_1R_5	λR_2R_3	λR_2R_4	λR_2R_5	λR_3R_4	λR_3R_5	λR_4R_5	$\lambda R_1R_2R_3R_4 R_5$
1	-0.7	0.7	-0.7	-0.7	-0.7	0.7	0.7	-0.7	-0.7	0.7	-0.7
2	-1	1	1	1	-1	-1	-1	1	1	1	-1
3	0.8	-0.8	-0.8	0.8	-0.8	-0.8	0.8	0.8	-0.8	-0.8	0.8
4	-0.9	0.9	0.9	0.9	-0.9	-0.9	-0.9	0.9	0.9	0.9	-0.9
5	-1	1	1	1	-1	-1	-1	1	1	1	-1
6	0.7	0.7	-0.7	0.7	0.7	-0.7	0.7	-0.7	0.7	-0.7	0.7
7	1	1	1	1	1	1	1	1	1	1	1
8	-0.6	-0.6	0.6	0.6	0.6	-0.6	-0.6	-0.6	-0.6	0.6	-0.6
λ	-0.21	0.49	0.29	0.66	-0.26	-0.41	-0.04	0.34	0.31	0.46	-0.21

5. Discussion.

The developed multi-criteria analysis tool provides the ability to specify weighting coefficients ("preferences") individually for each of the evaluated criteria, which makes it possible to consider the priorities of a particular company within the framework of the process being optimised. In the example presented in, the weighting coefficients are set based on the results of the expert survey and the obtained coefficients λ.

According to the calculation results, the highest resulting *Rres* indicator was obtained for Hyperledger Fabric despite a negative assessment according to the elaboration of the business logic criterion.

This demonstrates the extent of the impact of blockchain technology on the business operations of the system and the potential for improving the efficiency of the procurement process of enterprises.

Three main advantages for organizations resulting from the implementation of blockchain technology and smart contracts were identified based on the findings of the expert evaluation:

1. Increasing the trustworthiness of storing data obtained during purchase procedures minimises the risk of its lesion or dropping of third parties due to potential business breaking or fiscal, time, and reputational losses.

2. Increasing the level of honesty of the stored information maximises the scale of its security and minimises the risk of fabrication. Honesty implies the technologically guaranteed impossibility of changing stored data without participants' knowledge in the chain and unequivocal identification of falsification.

3. Integrating different data flows into an information system based on blockchain and smart contracts increases the speed of interaction between producers and the quality of data used for further analysis of events, including the purchase process.

The benefits that showed the most minor relevance included the following:

1. Sophistication of business logic reduces operational costs (employee labour costs) by optimising and automating business processes implemented within the blockchain system.

2. Increasing the transparency of processes, minimising the likelihood of conflicts between participants in the supply chain and the procedure of purchasing commodities and services, and the possibility of end-to-end control at all supply chain stages.

6. Conclusions.

Based on the analysis proposed in the study of possible models and techniques used to assess the efficiency of logistics procedures, the use of normal approaches, models, and techniques for assessing the efficiency of business procedures during purchasing does not ensure the required degree of validity and safety when assessing the efficiency of blockchain and smart contracts during the purchase process. To carry out such an assessment, the design of agent systems using simulation design tools is necessary.

The key advantages of blockchain and smart contracts in digitalising the process of purchasing are growing the trustworthiness of the data storage system by creating local copies of data for each participant in the chain, improving data quality by integrating data from various sources into a single blockchain platform, increasing data security and minimising the risk of falsification due to the impossibility of making unauthorised changes to the database (at the current stage of system development) and the high degree of information integrity ensured by its distributed storage.

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