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DETERMINING THE IMPACT OF BLOCKCHAIN TECHNOLOGIES ON THE GRAIN SUPPLY CHAIN TRACKING SYSTEM IN THE EU

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The object of this paper is blockchain technology in the tracking system of grain supply chains.

The current study considers the task of determining the impact of blockchain technology introduction on the tracking system of grain supply chains.

The key problems in the system of grain supply chains have been identified and the tasks to solve them have been proposed. The characteristics of key technologies in the implementation of blockchain in the system of grain supply chains have been defined, such as smart contracts, the Internet of Things (IoT), interplanetary file system (IPFS), contactless tags (RFID), Ethereum platform (identified as the best for supply chain tracking). The influence of factors on the introduction of blockchain technologies into the grain supply chain tracking system was determined using a SWOT analysis. Strengths include transparency, increased trust, automation of processes and protection against falsification. Weaknesses include high implementation costs, difficulty scaling, and the need for staff training. Opportunities that open up through the use of blockchain include attracting new partners, increasing competitiveness, and developing new markets. Threats include legal difficulties, technical failures, high energy costs, and resistance from market participants. An assessment of the investment attractiveness of introducing blockchain technology into the grain supply chain tracking system was carried out by calculating such indicators as economic effect; net present value (NPV) of implementing blockchain technologies; payback period of investments. According to the results of analysis, the following data were obtained: NPV (150439 a.u.) >0, the payback period of investments is 2.8 years, which is acceptable for large agricultural holdings. Prospects for development have been determined, in particular, the unification of agricultural holdings for the joint implementation of blockchain technologies in the tracking system of grain supply chains, which would be a strategically beneficial solution for all participants in the supply chain

Keywords: blockchain technologies, supply chains, grain industry, automation, document flow, economic effect, investment return

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1. Introduction

Grain is an important source of minerals, dietary fiber, and other nutrients that are necessary for the human body [1]. One of the priority areas of development in certain countries is the increase in grain exports with EU countries. Under the conditions of the war, the grain industry shows instability, there are significant fluctuations in gross receipts. The most difficult problem was the blockade of the Black Sea ports of Odesa and Chornomorsk. It was through these cities that almost all grain exports were carried out, in particular, as of May 2023, more than 30 million tons of grain were exported through the Black Sea Grain Initiative. More than half of the cargo was corn, which was the most affected by the closure of granaries. Although the Black Sea Grain Initiative contributed to the restoration of sea transportation and the establishment of grain exports, the implementation of this humanitarian corridor had many shortcomings. Among them, the fact that the agreement did not provide for liability in case of violation of the essential terms of the agreement, and the transportation process itself was very complex and risky [2], as one of the world's largest grain exporters, continues to seek alternative methods to improve the process of the grain supply chain, taking into account the problems and risks under war conditions.

Tracking the grain supply chain using blockchain technologies is a solution to a number of key tasks faced by agricultural holdings. Blockchain provides transparency, reliability, and security in the management of grain supply chains. With the help of blockchain, it is possible to register all transactions through a chronologically ordered structure of blocks. With the help of cryptography technology, it is possible to protect data and generalize them into a peer-to-peer network. The introduction of blockchain technologies into the grain supply chain tracking system will affect the efficiency of agricultural holdings by transforming their operational, management, and strategic processes. In part, this problem is based on a study that revealed the ability of blockchain to optimize logistics operations and reduce costs associated with supply chain processes [3].

Also, blockchain technologies contribute to solving a number of key tasks in the agricultural sector, improving transparency, productivity, and trust between all participants in the value chain. Blockchain technology will secure the grain supply chain, giving all participants access to a single system that will ensure transparency, security, and end-to-end monitoring of grain supply [4].

In view of the above, the chosen topic of our study is relevant; it involves research into assessing the economic impact of the introduction of blockchain technology into the tracking system of grain supply chains.

2. Literature review and problem statement

The grain supply chain to the EU countries is a rather complex process, covering numerous stages, such as collection, storage, and primary processing; logistics, transportation, customs control, distribution across EU countries [5]. There are a number of challenges in the grain supply chain system, which are related to the transparency and traceability of grain supply, inventory management, losses due to product spoilage, fraud risks, data privacy and security, and high dependence on the human factor.

These tasks can be solved with the help of automation and digitization of logistics processes. Industry 4.0 is characterized by intensive digitalization, integration of logistics processes, and the use of "smart" objects such as products and machines. Its development emphasizes the need to transform production systems in the direction of "smart" management [6] and create "smart" supply chains. This ensures comprehensive and systematic implementation of digital technologies in the entire ecosystem of the supply chain [7]. However, along with the advantages, there are disadvantages, namely the privacy and security of the data of participants in the grain supply chain.

To solve the above tasks, it is advisable to introduce blockchain technology into the system of grain production chains as one of the newest breakthrough technologies. Paper [8] reports a comparative analysis of the fundamental concepts of the blockchain in three main areas: health care, business, and the automotive industry. However, there remains the problem of introducing blockchain technologies into the data tracking system during grain emergence. In study [9], the task related to the possibility of introducing blockchain technology in supply chain management was solved. However, there is a lack of information on the technological capabilities of blockchain, which should be applied during its implementation at each stage of the grain supply chain.

The feasibility of introducing blockchain technology into the supply chain system is confirmed by studies aimed at studying the suitability of blockchain technology for solving the problems of tracking, trust, and accountability in the food industry [10]; addressing tasks of introducing blockchain technologies in finance, logistics, and security management systems [11]. However, the issue of the possibility of tracking transactions in the grain supply chain system using blockchain technologies has not been resolved.

Paper [12] demonstrates how organizational theory can be applied to explore the relationship between blockchain and supply chain. However, there are still unsolved problems in determining the economic impact of the introduction of blockchain technologies on the grain supply chain system. In particular, it is appropriate to determine the possible economic effect, to determine the level of time savings, to analyze the return on investments from the introduction of blockchain technology into the tracking system of grain supply chains.

This gives reason to claim that a study aimed at determining the impact of the introduction of blockchain technology on the system of grain supply chains is appropriate.

3. The aim and objectives of the study

The purpose of our work is to determine the impact of the introduction of blockchain technology into the tracking system of grain supply chains. This could reduce operational costs due to time savings, reduce the level of fraud, increase data transparency, logistics efficiency, and competitiveness of agricultural holdings.

To achieve the goal, the following tasks were set:

– to define the problems and tasks of agricultural holdings in the tracking system of the grain supply chain;

– to outline the characteristics of blockchain technology in the grain supply chain tracking system;

– to determine the influence of factors related to the introduction of blockchain technologies on the tracking system of grain supply chains;

– to assess the investment attractiveness of introducing blockchain technology into the tracking system of grain supply chains.

4. The study materials and methods

The object of our research is blockchain technology in the tracking system of grain supply chains.

The hypothesis of the study assumes that the introduction of blockchain technology into the tracking system of grain supply chains would affect the improvement of the efficiency of agricultural holdings.

The introduction of blockchain technologies into the tracking system of grain supply chains could significantly increase the efficiency of agricultural holdings and optimize their business processes. This innovative technology is driving transparency, automation, and cost reduction in supply chains, creating a competitive advantage for agribusiness. The introduction of blockchain technology into the tracking system of grain supply chains is evidence of the serious transformational potential of entered data at all stages of transportation.

There are reasons to assume that blockchain technology will become one of the most important components of modernizing the system of management and functioning of agribusiness, including grain supply chains. Its implementation ensures transparency, trust, and efficiency in the interaction among market participants, which are key conditions for the sustainable development of the industry.

Ukrainian grain meets the needs of a large part of the EU countries, playing a key role in guaranteeing food security in the region. Owing to favorable climatic conditions and large cultivated areas, Ukraine is one of the leading grain exporters in the world. Public statistical data, financial data of agricultural holdings, and publications on this topic were selected as input data for the analysis of the dynamics of Ukraine's grain exports to EU countries.

A set of general scientific methods of cognition was used to conduct the research. The theoretical analysis, comparison, generalization, and synthesis methods were employed to study the theoretical provisions and current state of blockchain and its application in the tracking system of grain supply chains, justifying the expediency of using this technology in the activities of agricultural holdings. Empirical methods were applied to determine the economic impact of introducing blockchain technology into the system of grain supply chains, including observation and questionnaires. Economic and statistical methods were exploited to assess the investment return on the introduction of blockchain technology into the grain supply chain tracking system.

5. Research results related to building a grain supply chain tracking model based on blockchain technology

5. 1. Problems and tasks of agricultural holdings in the grain supply chain tracking system

One of the main priorities of individual countries is the development of the grain sector, which depends on the quality and standard of living of its population. The military conflict in Ukraine significantly affected the supply of grain in EU countries, as Ukraine is one of the key suppliers of grain on the world market, including the EU. The consequences of the impact were a disruption of supply chains, an increase in grain prices, a change in supply routes, and a strategic reorientation.

The key problems of the export and logistics of Ukrainian grain to the EU are the destruction of the infrastructure, in particular the damage to ports, railroad hubs, and transport routes as a result of military operations. There are also logistical delays, due to increased delivery times when reorienting land and river routes such as rail, road, and Danube ports. In addition, there is limited border capacity, high cost of transportation, security risks, uneven distribution of demand.

One of the important ways for solving such problems is the introduction of blockchain technologies into the tracking system of grain supply chains, which makes it possible to ensure transparency and speed of operations; using big data and predictive tools to optimize routes.

The application of blockchain technologies in the system of grain supply chains is a global challenge today for agricultural holdings, which has especially intensified after the full-scale invasion. Agricultural holdings are important participants in the Ukrainian grain market, providing a significant part of exports to international markets.

Among the largest agricultural holdings in 2022–2023, we can highlight the following: Kernel, Louis Dreyfus Company, and Cargill. The largest exporter is the Kernel company with a share of 8 %; it has a large network of elevators, its own port terminals, and ships. Second place was taken by Louis Dreyfus with a 7 % share, which has its own processing plants to create value-added products. The top five also included Cargill, Nibulon, and ADM. Fig. 1 shows the structure of the ten largest agricultural holdings that exported the most Ukrainian grain to EU countries in 2022–2023.

Starting from 2021, Ukraine, which is one of the largest exporters of grain crops in the world, has faced a negative trend of reducing the volume of grain exports. This situation is caused by a number of internal and external factors affecting the agricultural sector and supply chains. Initially, the reasons for this were COVID-19, and then Russian aggression had an extremely negative impact.

At the moment, individual countries have a limited number of railroad and road routes that lead to the borders of EU countries. These routes are often congested, causing delays in grain transportation. Delays in transportation lead to violations of delivery terms, loss of grain quality, increased storage costs, and additional logistics costs. The military conflict affects the safety of grain transportation, infrastructure destruction, restrictions on the use of seaports on the Black Sea, and also increases risks for logistics operations. Violations of transport routes, increase in costs for security and insurance of cargoes are carried out on a permanent basis, which leads to a reduction in the export possibilities of agricultural holdings. Grain prices and exchange rates are extremely volatile, which affects the financial condition of agricultural holdings. Exchange rate risks increase due to unpredictable changes in grain markets. Sudden changes in prices and exchange rates can lead to financial losses, which complicates supply planning and contract management.

Also, the grain supply process is complicated by the interaction between legislative norms, logistics problems, the presence of officials, providers, and forwarders. The situation is no less simple at the stage of customs clearance and paperwork associated with permits and cargo declarations [14].

The involvement of different government structures in many countries with their own standards for accounting and documentation systems makes grain transportation much more complex. Thus, the costs of logistics, in particular the processing of documents, reach half of the transport costs for the delivery of goods.

Thus, the key problems in the system of grain supply chains are increased costs, unforeseen losses, large time losses, and insufficient transparency of data (Fig. 2).

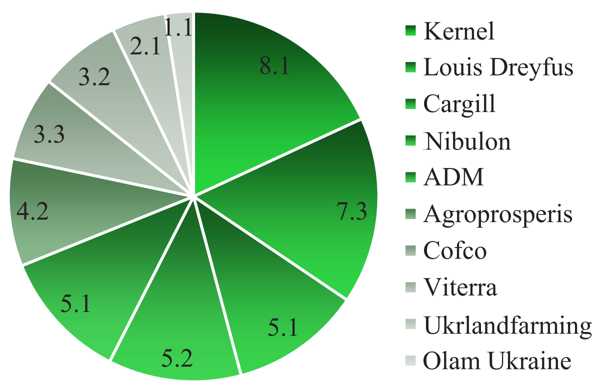

Fig. 1. The structure of the ten largest agricultural holdings that exported the most Ukrainian grain to EU countries in 2022–2023, %

Source: compiled by Author using [13]

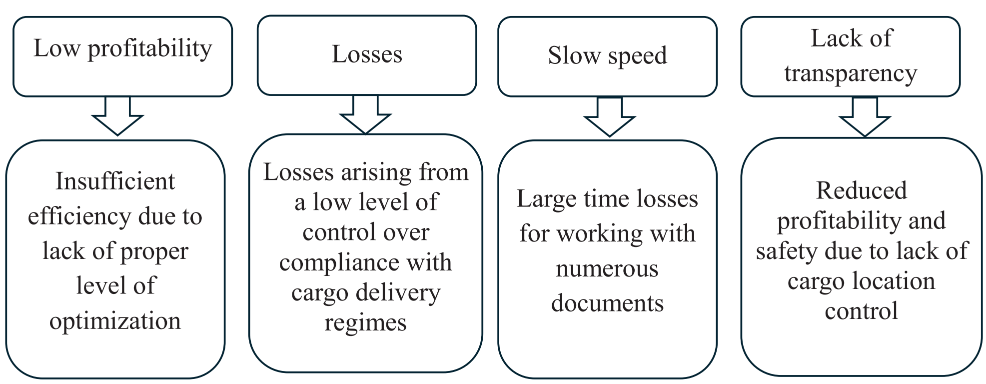

Fig. 2. Key problems in the grain supply chain system

Given the above, transparent tracking of grain supply chains is extremely important, especially under wartime conditions. In the grain supply chain system, agricultural holdings have a number of problems in terms of monitoring, security, countering theft and fraud, logistics management, and contract fulfillment [15].

Blockchain technology is designed to solve these problems, it is an innovative technology called the "stone of trust" [16]. The specified problems can be solved with the help of the set tasks of agricultural holdings when introducing blockchain technology. Among the key tasks, the following are highlighted: grain supply monitoring; ensuring transport safety; prevention of theft and fraud; effective management of logistics; execution of contracts; support for the stability of the grain sector.

Given the above, Table 1 summarizes the key tasks of agricultural holdings in the tracking system of grain supply chains, in particular to EU countries.

Table 1

Main tasks of agricultural holdings in the tracking system of grain supply chains

Task		Characteristics
Monitoring of grain supply	Inventory control	Tracking the supply of grain makes it possible to control the level of stocks and avoid food shortages, especially in the regions
Monitoring of grain supply	Forecasting needs	Supply monitoring helps agricultural holdings predict future grain needs, plan humanitarian aid and avoid crisis situations
Ensuring the safety of transport	Routing and scheduling	Tracking makes it possible to determine safe routes for transporting grain, avoiding dangerous zones where there are active hostilities or mined territories
Ensuring the safety of transport	Warning of risks	Timely information on the state of roads, bridges and infrastructure allows for prompt decisions to be made regarding route changes or delivery delays until the security situation improves
Prevention of theft and fraud	Protection against theft	In wartime, the risk of theft and smuggling of grain increases, tracking supplies helps prevent grain theft
Prevention of theft and fraud	Transparency and trust	Ensuring transparency in grain supply chains helps maintain trust with international partners
Effective management of logistics	Cost optimization	Supply tracking makes it possible to optimize logistics processes, reducing grain transportation and storage costs
Effective management of logistics	Monitoring resource consumption	Tracking systems help control fuel consumption, vehicle utilization, and human resources, which is important in resource-constrained environments
Execution of contracts	Compliance with terms of supply	Supply tracking helps ensure the fulfillment of grain supply contracts, which is important for maintaining the reputation of suppliers and avoiding sanctions or fines
Execution of contracts	Customs control and compliance	Tracking systems help ensure compliance with customs and regulatory requirements as goods cross borders and pass through checkpoints
Support of sustainability of the grain sector	Analysis and planning	Supply data help agricultural holdings analyze current trends, identify problems, and adapt to new conditions
Support of sustainability of the grain sector	Reduction of losses and waste	Tracking grain supply allows minimizing grain losses during transportation, which is critically important in conditions of limited access to food resources

Source: summarized by Author using [15, 17].

Thus, the tracking mechanism of grain supply chains requires constant monitoring, analysis, and management decisions. The use of blockchain technologies will significantly improve the process of tracking grain supply chains, ensure accurate and unalterable data storage, increase transparency and data security, reduce the need for intermediaries and costs for document circulation, and increase trust between all participants in the process.

5. 2. Characteristics of blockchain technology in the grain supply chain tracking system

Solutions based on blockchain technologies automate the preparation of numerous documents required for logistics operations. This is due to several key capabilities of blockchain technologies, namely automation of processes through smart contracts, digital documents as a result of transactions, ensuring the authenticity of documents [18].

The use of blockchain technology can provide authorized participants in the logistics process with an effective tool for managing the quality and current stage of cargo delivery. It can provide an effective tool for managing the current stage of freight and freight transportation. Tracking information from various devices is stored in a reliable source and does not change, which makes it possible to control the quality of delivered goods.

Platforms that are built on blockchain technologies provide free access to the necessary data based on access rights that depend on the role of the participants in the process, their geographic location, and others. This significantly increases the safety of cargo transportation, reduces the level of errors and potential theft, eliminates losses during cargo transportation, and also reduces and eliminates the need to hire additional specialists.

Smart contracts are an important component of the contract level in the blockchain architecture, which is a piece of code stored on the blockchain. As soon as the pre-set conditions in the contract are met, the program is automatically executed without human intervention [19].

Current applications of blockchain-based smart contracts in the supply chain include contract security, smart contract design, and parallelism transaction efficiency. The consensus mechanism is the core of the entire blockchain, which ensures that each node confirms the compatibility of the system in a distributed environment and determines the operational efficiency of using blockchain technology [20].

In the system of grain supply chains based on blockchain technology, many different transactions can take place, in particular for the purchase and supply of grain, transportation and logistics, customs clearance, between participants of the supply chain, at the stage of sale and final delivery, etc.

With the implementation of blockchain technologies, each transaction involves identification and control. The proposed algorithm for carrying out transactions in the system of grain supply chains based on blockchain technology is illustrated in Fig. 3.

As you can see, at the first stage, the transaction is initiated (starting the process). An order is created, where the supplier initiates a transaction by creating a grain delivery record in the blockchain system, where all the details are indicated: quantity of grain, type, place of origin, date of collection, terms of delivery, etc. Also at this stage, the buyer or the next participant in the chain to whom the grain will be transferred is determined.

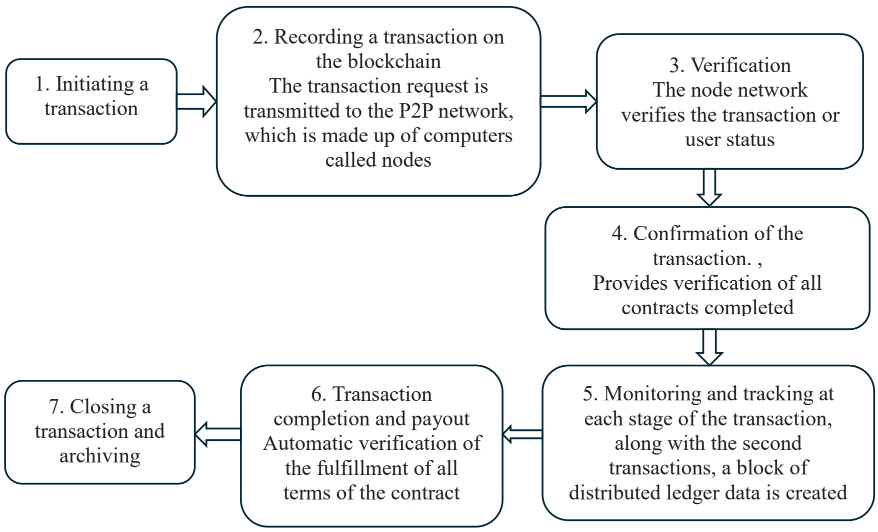

Fig. 3. Algorithm for carrying out transactions in the system of grain supply chains based on blockchain technology

Source: summarized by Author using [19, 20]

At the second stage, an entry in the blockchain is automatically generated, information about the transaction is automatically generated and recorded in the blockchain, each block contains information about the previous and next stage.

At the third stage, the transaction is verified, where the blockchain technology automatically verifies the data, checking whether the necessary conditions for the execution of the transaction are present.

At the fourth stage, data is confirmed through smart contracts, where after a transaction is created and recorded in the blockchain, a smart contract is activated, which automatically checks whether all the terms of the agreement have been met. Smart contracts fully automate the process of document circulation, information exchange, data transfer, and their processing, making it more efficient, transparent, and secure.

In the fifth stage, there is monitoring and tracking at each stage of records of all stages of the supply chain, in particular, at each stage of the supply chain (storage, transportation, processing), information is automatically recorded in the blockchain. This enables all members of the chain to track the current status of the supply and to perform real-time verification.

At the sixth stage, the transaction is completed and paid out, where after the grain reaches the final recipient, the smart contract automatically checks that all terms of the agreement have been met. If all conditions are met, the system automatically makes payment to the supplier or farmer, through confirmation of the transaction in the blockchain. Payment can be automated through smart contracts, which avoids delays.

In the seventh stage, the transaction is closed and archived, after all conditions are met, the transaction is recorded in the blockchain as completed, and all supply data becomes available for analysis and verification in the future. All stages of the transaction are stored in a public registry, which allows for audits of the supply chain, verification of data on each batch of grain and ensures transparency for control or certification bodies.

The advantages of the proposed algorithm for carrying out transactions in the system of grain supply chains based on blockchain technology are: transparency and control (access to information for all process participants); automation (automatic execution of smart contracts, which reduces time and error risks); protection against fraud (the impossibility of changing data, which provides a high degree of protection against forgery and falsification); speed and efficiency (reducing the need for intermediaries and optimizing all stages of supply makes it possible to reduce the time and costs of executing transactions).

Such an algorithm will significantly increase the efficiency, security, and transparency of grain supply chain processes, providing better control at every stage of tracking.

When tracking grain chains, it is important to read quality and safety data, so the use of contactless cards (RFID) is recommended. RFID technology is a technology of automatic identification of objects using radio frequency tags and readers. It allows contactless data exchange between tags and readers via radio waves [20].

The conceptualization of tracking grain supply chains based on blockchain technologies involves the collection, processing, storage, and management of data, which is proposed to be carried out with the help of Internet of Things (IoT) technology. Such a concept will provide a description of the network of all participants in the process by exchanging data over the Internet [21].

IoT devices have a number of advantages: the ability to exchange data; interaction with other systems; collection of data about the state of the object; data transfer to servers (cloud). Along with this, they will help create integrated solutions for various tasks by automating all processes of tracking grain supply chains [22].

Fig. 4 depicts the data collection, storage, processing, and management system in the IoT-based grain supply chain tracking system.

An IoT system can collect information from various devices installed on a vehicle, container, or cargo. Data on the location, temperature, humidity, quality of grain on the blockchain platform are available to participants in the grain supply chain. This makes it possible to quickly respond to problems, promptly monitor deviations that occurred during transportation.

Blockchain has the characteristics of a distributed ledger; when it is applied to track grain supply chains, there is an issue of high data storage pressure. Therefore, it is necessary to optimize and reduce pressure on the data storage of the blockchain platform. In order to optimize data storage, storages that include multi-chain architecture and a combination with the Interplanetary File System (IPFS) are recommended [18].

The Interplanetary File System (IPFS) is a distributed file system designed for storing and sharing files on the Internet. IPFS uses blockchain technologies and the principles of peer-to-peer networks to create a distributed and reliable file system, where data is not stored on a single server but distributed among users.

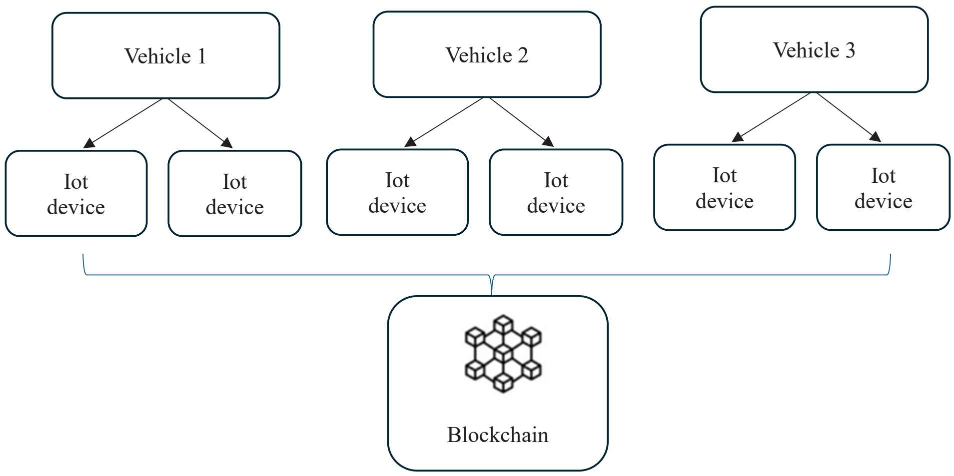

Fig. 4. Scheme of data collection, storage, processing in the tracking system of grain supply chains based on IoT
Source: summarized by Author using [18, 20, 21]

Features of IPFS operation:

– addressing by content, the system uses hashes of files to identify them, means that files are accessible not by address, but by a unique identifier formed on the basis of the file content;

– a distributed network, the system works using peer-to-peer technology, where each user can be both a client and a server. Users can upload and share files without the need for centralized servers;

– constant access to data, the system makes it possible to ensure reliable access to data even in case of disconnection of certain servers or networks;

– versioning, the system makes it possible to save not only the current versions of files but also their previous versions, which provides the possibility of data recovery and easy access to the history of changes.

The implementation of blockchain technology involves the selection of a suitable platform. There are many platforms for developing and using blockchain technologies. They have different capabilities and tools; among the most modern and powerful platforms, it is appropriate to single out Ethereum and Hyperledger. These platforms have their own characteristics, capabilities, features, and cost of use.

Table 2 gives a comparative description of the use of modern Ethereum and Hyperledger platforms for blockchain development and implementation.

Analyzing the obtained data, we can conclude that the cost of using the Ethereum and Hyperledger platforms is practically the same, but they have key differences in terms of characteristics: Ethereum is a public platform that is intended for use by many participants who are connected to it. Hyperledger is a private/consortium platform that allows the creation of private or consortium blockchain networks where access is limited and controlled by specific participants.

Table 2

Comparative characteristics of the use of modern Ethereum and Hyperledger platforms for blockchain development and implementation

Platform ID	Network type	Consensus	Smart contracts	Privacy	Approximate cost, incl.
Ethereum platform	A public blockchain platform, all transactions are available for verification and confirmation by participants	Uses Proof of Stake (PoS) and Proof of Work (PoW) mechanism is the main mechanism to update, requiring large computing resources to confirm transactions	Smart contracts are written in Solidity and run through the Ethereum Virtual Machine (EVM)	Is a public network where all transactions are available to any user	Approximate cost, include: 1. Development and launch of a smart contract: from 50,000 a.u. up to 100,000 a.u. (depending on the complexity). 2. Transaction Fees: Varies, but for an active platform you can expect costs from 1,000 up to 10,000 a.u./month. 3. Audit and security: 5,000 a.u. to 50,000 a.u./month. 4. Infrastructure and hosting: use of API services or Infura-type platforms — from 100 a.u. up to 1000 a.u./month. The total cost of implementing and operating blockchain technologies on the Ethereum platform is approximately 100,000 to 500,000 a.u. for larger or more complex solutions
Hyperledger platform	Private/Consortium Blockchain: Allows the creation of private or consortium blockchain networks where access is limited and controlled by specific participants.	Uses consortium-supported consensus mechanisms such as Practical Byzantine Fault Tolerance (PBFT) or Raft. Such mechanisms are for private networks where participants trust each other	Smart contracts are called Chaincode and can be written in Go, Java, or JavaScript. Chaincode allows you to perform data operations, verify conditions, and process transactions within private or consortium networks	Aimed at private or consortium blockchain networks, it provides higher privacy and allows control of data access	1. Development and launch of a smart contract: from 50,000 a.u. up to 200,000 a.u. (depending on the complexity). 2. Transaction Fees: Varies, but for an active platform you can expect to spend from 10,000. up to 50,000 a.u./month. 3. Audit and security: 20,000 a.u. up to 100,000 a.u./month. 4. Infrastructure and hosting: use of API services or Infura-type platforms — from 1000 a.u. up to 10,000 a.u./month. The total cost of implementation and operation of blockchain technologies on the Hyperledger platform is approximately from 100,000 to 500,000 a.u. for larger or more complex solutions

Source: summarized by Author using [23].

In view of the above, it is recommended to use the Ethereum platform, which is ideal for public decentralized applications, where openness and trust between participants are important, for the implementation of blockchain technologies in the tracking system of grain supply chains.

In summary, it is appropriate to schematize blockchain technologies on the Ethereum platform in the grain supply chain tracking system (Fig. 5).

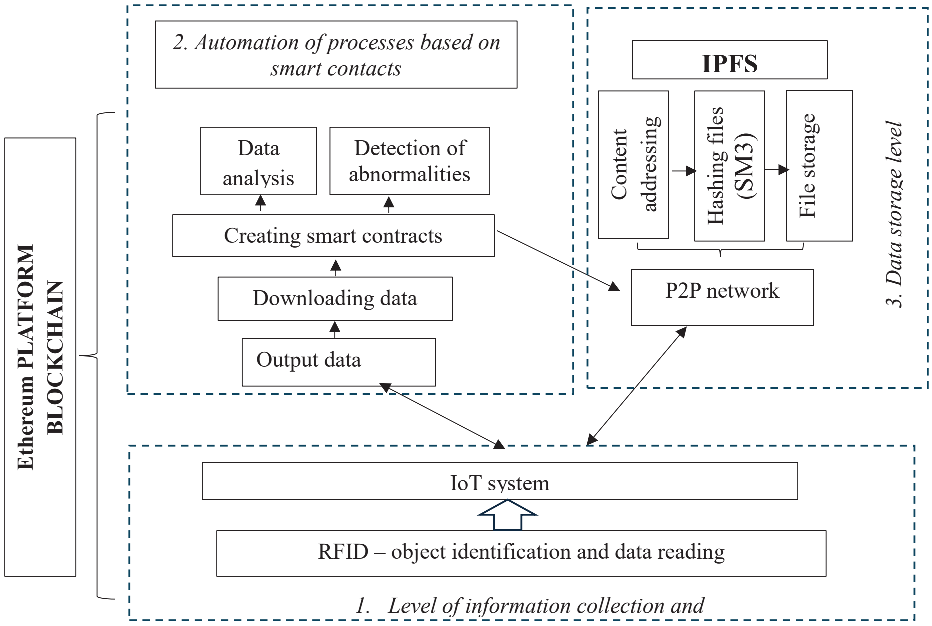

Fig. 5. Schematization of technologies on the Ethereum blockchain platform in the grain supply chain tracking system

As you can see, the schematic mechanism of using blockchain technologies on the Ethereum platform can be divided into three blocks, namely:

Block 1. This block provides for the implementation of such tasks as collection and processing of information; identification of objects (orders); order management. In the developed model, the following actions are proposed to be carried out with the help of technological systems: RFID (identification of objects);

Block 2. Automation of processes based on smart contacts. At this level, data processing and analysis of deviations is carried out using smart contracts.

Block 3. The data storage level is proposed to be organized using IPFS technology, which will ensure efficient distribution of files, ensure the reliability, indisputability and confidentiality of data that were processed in the process of tracking grain supply chains from the conclusion of the contract to its execution.

At each stage of supply chain tracking, grains are collected using connected IoT devices and transmitted to the business layer through a unified data exchange interface.

5. 3. Influence of factors regarding the introduction of blockchain technologies into the tracking system of grain supply chains

To make a decision on the introduction of blockchain technology into the tracking system of grain supply chains, it is advisable to use the strategic tool SWOT analysis, which makes it possible to assess the influence of internal and external factors in terms of strengths and weaknesses, opportunities, and threats). Using a SWOT analysis, you can get a clear picture of the internal and external factors that influence the implementation of blockchain technologies in the tracking system of grain supply chains.

Among the strengths of the implementation of blockchain technologies in the tracking system of grain supply chains, it is advisable to highlight transparency and availability of data; ensuring the quality and authenticity of products; reducing costs and increasing the efficiency of improving risk management; improving security and trust; auditing and compliance with standards.

Weaknesses of the implementation of blockchain technologies in the grain supply chain tracking system include high initial implementation costs; difficulty in scaling; challenges in integration with other technologies; the need for training and changing cultural approaches; regulation and legal issues; increase in energy consumption; limited acceptability among participants.

Table 3 summarizes the strengths and weaknesses of introducing blockchain technologies into the grain supply chain tracking system.

In order to further make a management decision regarding the introduction of blockchain technologies into the tracking system of grain supply chains, it is advisable to identify opportunities and threats.

The possibilities of introducing blockchain technologies into the tracking system of grain supply chains include:

– attraction of new partners and investors, introduction of innovative technologies can improve the image of the company, which will help attract new partners and investments;

– increasing competitiveness, using blockchain to track grain supply chains can become a competitive advantage in the market;

– the development of new markets, the use of blockchain can open up new opportunities for expanding sales markets due to increased trust in products;

– environmental initiatives, the use of blockchain to monitor environmental standards in the production and transportation of grain can contribute to greater environmental responsibility.

Among the threats of the introduction of blockchain technologies into the tracking system of grain supply chains, it is reasonable to include:

– normative and regulatory restrictions, the lack of regulatory regulation of the application of blockchain technologies can lead to legal problems, especially in conditions of changing or limited legislative norms;

– technical malfunctions, technological failures or software vulnerabilities may lead to data loss or delays in transaction processing;

– high energy costs, depending on the consensus mechanism used, blockchain can be energy-intensive, which increases energy costs;

– doubts about the technology, some market participants may doubt the effectiveness and security of blockchain, which may lead to resistance to implementation.

Table 3

Strengths and weaknesses of introducing blockchain technologies into the tracking system of grain supply chains

Strengths	Characteristic	Weaknesses	Characteristic
Transparency and availability of data	Blockchain allows for full transparency of all stages of grain supply, which ensures greater trust among chain participants. Data on all transactions is available in real time	High initial implementation costs	The costs of developing and implementing a blockchain infrastructure can be significant, especially in the early stages. The need for specialized software, data storage infrastructure and hardware
Ensuring the quality and authenticity of products	Thanks to the fixation of all stages of supply in the blockchain, it is possible to guarantee the quality of the grain, the data is authentic. Protection against falsifications and forgeries	Difficulty in scaling	Blockchain can be difficult to scale, especially in large supply chains with many participants, which can lead to bandwidth issues
Cost reduction and efficiency improvement	Automation of processes through smart contracts allows to reduce administrative costs and reduce the need for intermediaries, automation of document flow	Challenges in integration with other technologies	Integrating blockchain with other existing supply chain management systems can be complex and require additional resources
Improving risk management	Detection and rapid response to problems in the supply chain, ease of detection of malfunctions or violations	The need for training and changing cultural approaches	The need to train staff and supply chain participants. Companies may face cultural barriers, in particular, mistrust of new technologies or changes in organizational processes
Improving security and trust	Blockchain technology guarantees a high level of security thanks to the use of cryptography	Regulation and legal matters	The use of blockchain in agribusiness may be limited by existing regulations that do not correspond to the distribution and use of this technology. Legal issues can create legal uncertainty
Auditing and Compliance	All members of the chain have access to the same data. Simplification of the audit process, as all transactions are available for review	Increase in energy consumption	Support for the blockchain system involves the use of resource-intensive algorithms, which can lead to high energy costs
		Limited eligibility among participants	For the successful operation of the blockchain system, all chain participants must agree to use the technology

Source: summarized by Author using [24].

In view of the above, the implementation of blockchain technologies in the tracking system of grain supply chains has many strengths, such as transparency, increased trust, automation of processes and protection against counterfeiting. However, there are also weaknesses, such as high implementation costs, difficulty in scaling, and the need for staff training. Opportunities opened up by the use of blockchain include attracting new partners, increasing competitiveness, and developing new markets. However, there are also threats, in particular, legal difficulties, technical failures, high energy costs and resistance from market participants.

However, taking into account all the analyzed aspects, the introduction of blockchain technology into the tracking system of grain supply chains has significant potential for increasing the efficiency, transparency, and security of agricultural holdings.

5. 4. Assessment of the investment attractiveness of introducing blockchain technology into the grain supply chain tracking system

Decentralization of platforms based on new technologies will lead to simplification of accounting of financial flows and transactions, regardless of the form of interaction. Blockchain technology can solve problems in the supply chain system, such as tracking the movement of goods on all chain blocks, transportation dynamics, transparent document flow, etc.

In solutions based on blockchain technology, smart contract algorithms provide full automation of document flow from the conclusion of contracts to their execution. Such actions will lead to a reduction in the time for processing such documents and a reduction in operational costs in the system of grain supply chains, which leads to an economic effect. It is appropriate to determine the economic efficiency of introducing blockchain technology into the tracking system of grain supply chains.

In the literature, there are various methods for evaluating the economic efficiency of projects, among the main ones it is advisable to distinguish two main types: financial and mixed. Financial shows the level of profitability from the implementation of the project (financial return), and a mixed approach that includes a combination of financial and non-financial factors [25]

The financial and economic effect of the introduction of blockchain technology in the tracking system of grain supply chains can be calculated according to the following formula (1):

$$PEe = \sum Pr - \sum Pc, \quad (1)$$

where PEe is the possible economic effect from the introduction of blockchain technology into the grain supply chain tracking system;

$\sum Pr$ – expected revenues (possible revenues) from the introduction of blockchain technology into the grain supply chain tracking system;

$\sum Pc$ – expected costs (possible costs) from the introduction of blockchain technology into the grain supply chain tracking system.

To calculate the likely economic effect of the introduction of blockchain technology into the tracking system of grain supply chains, it is reasonable to calculate the reduction of the time period for performing operations related to document flow in the grain supply chain system.

The time savings can be calculated using formula (2):

$$Slc = T * Ahw, \quad (2)$$

where Slc is the possible saving of labor costs for 1 employee;

T – possible time saving by 1 employee of an agricultural holding when introducing blockchain technology into the tracking system of grain supply chains per year, hours/year;

Ahw – average hourly wage of 1 employee of an agricultural holding, a.u. per hour.

In turn, the average hourly wage of 1 employee of an agricultural holding is calculated according to formula (3):

$$Ahw = \frac{Sw}{Tw}, \quad (3)$$

where Ahw is the average hourly wage of 1 employee of the agricultural holding;

Sw – salary of 1 employee of the agricultural holding for the n-period;

Tw is the number of hours worked by 1 employee of the agricultural holding for the n-period.

In order to determine the saving of the time spent, a survey was conducted among the employees of agricultural holdings, which ensured document flow in the system of grain supply chains. 100 specialists from various large agricultural holdings were among the respondents. The survey was conducted on the basis of a questionnaire, which included the following questions:

1. How long does it take to draw up a grain purchase and sale contract?
2. How long does it take to issue an invoice?
3. How long does it take to issue a payment order?
4. How long does it take to complete a customs declaration?

The experts' answers were divided, so it was appropriate to divide them by length of service to determine the average value. In particular, groups of experts were divided according to work experience: up to 1 year; from 1 to 3 years; from 3 to 5 years.

The results of the survey of experts are summarized in Table 4.

According to the above calculations, it can be stated that almost 10.5 hours are needed for the registration of documents in the supply chain system at the initial stage of registration. With the introduction of blockchain technology, the process of document circulation will be fully automated, everything will be done by uploading files and applying electronic digital signatures.

In order to calculate time savings for a month and a year in general, it is necessary to determine the number of contacts made by employees per month, to calculate the average hourly wage of 1 employee of an agricultural holding.

Table 5 gives possible cost savings from the automation of document flow with the help of blockchain technologies in the system of grain supply chains.

Table 4

Results of a survey of groups of experts on determining the time spent on processing documents

Question	Experts up to 1 year	Experts from 1 to 3 years	Experts from 3 to 5 years	Average
1. How much time is needed to draw up a grain purchase contract?	5 hours	4 hours	3 hours	4 hours
2. How long does it take to issue an invoice?	2 hours	1 hour	30 min	1.2 hours
3. How long does it take to issue a payment order?	2 hours	1 hour	30 min	1.2 hours
4. How long does it take to complete a customs declaration?	5 hours	4 hours	3 hours	4 hours
In total	14 hours	10 hours	7 hours	10.4 hours

It is possible to save money from the automation of document flow for a year using blockchain technology, it is advisable to calculate NPV (Net Present Value) using formula (4):

$$NPV = \sum_{t=1}^{n} \frac{CFi}{(1+r)^t} - Co, \quad (4)$$

where NPV – net present value of implementing blockchain technologies in the system of grain supply chains;

CFi – cash flow in period i;

r – discount rate;

n – total number of periods (intervals, steps)

t=0, 1, 2, ..., n for the entire investment term;

Co – initial investment (cash outflow in period 0).

Accordingly, the amount of costs required for the initial investment in introducing blockchain technology into the grain supply chain tracking system is calculated.

Implementing blockchain technology in grain supply chain tracking involves a variety of costs that can be divided into direct and indirect costs. Direct costs should include Technological costs, Licenses and commissions, equipment. Indirect costs include staff training, legal and organizational costs, ensuring cyber security (Table 6).

On the basis of the given data, the NPV of introducing blockchain technology into the grain supply chain tracking system was determined (Table 7).

As a result of the obtained data, it is possible to conclude that the obtained NPV (150439 a.u.)>0, which indicates the expediency of introducing blockchain technology into the grain supply chain tracking system.

The final stage of assessing the feasibility of implementing an investment project regarding the intro-

Table 5

Savings from the automation of document flow with the help of blockchain technologies in the system of grain supply chains

No. of entry	Indicator	Months						Total
		1	2	3	4	5	6	
		7	8	9	10	11	12	
1	Average number of hours for processing documents, h	10.5	10.5	10.5	10.5	10.5	10.5	–
		10.5	10.5	10.5	10.5	10.5	10.5	–
2	Average number of final contracts per month, unit	100	–	–	80	80	80	340
		90	105	115	110	90	95	605
3	Average hourly wage of 1 employee, a.u.	50	50	50	50	50	50	–
4	Savings of funds from the automation of document flow per month, a.u.	52,500	–	–	42,000	42,000	42,000	178,500
		47,250	55,125	60,375	57,750	47250	49875	317,625
5	Savings of funds from the automation of document flow per month, a.u.	99,750	55,125	60,375	99,750	89,250	91,875	496,125

duction of blockchain technology into the tracking system of grain supply chains is the calculation of the payback period of investment PPI, which is calculated by the ratio of the cost of attracting investments (CAI) and the average monthly recurring income of the company (MIS) according to formula (5):

$$PPI = \frac{CAI}{MIC}, \quad (5)$$

where *PPI* is the payback period of investments from the introduction of blockchain technology into the tracking system of grain supply chains;

CAI – the cost of attracting investments;

MIC is the company's income.

According to the results of the calculations, the payback period of the investments incurred for the introduction of blockchain technology in the grain supply chain tracking system is 2.8 years.

A promising direction of development is the unification of agricultural holdings for the joint implementation of blockchain technologies in the tracking system of grain supply chains, which can be a strategically beneficial solution. This approach makes it possible to distribute costs, increase the efficiency of technology, and create a standardized system for all participants in the supply chain.

Table 6

Direct and indirect costs of introducing blockchain technology into the grain supply chain tracking system

No.	Types of expenses	2022	2023	2024	2025	2026	2027
Direct costs							
1	Development and adaptation of the Ethereum platform, a.u.	250,000	–	–	–	–	–
2	Integration with existing systems, a.u.	40,000	–	–	–	–	–
3	Costs for smart contracts, incl.	30,000	–	–	–	–	–
4	Hosting and data storage, a.u.	10,000	–	–	–	–	–
5	Licenses and commissions, a.u.	15,000	–	–	–	–	–
6	Transaction costs, incl.	15,000	–	–	–	–	–
7	Servers and nodes, a.u.	20,000	–	–	–	–	–
8	IoT scanners and sensors, a.u.	20,000	–	–	–	–	–
Indirect costs							
9	Legal and organizational expenses, a.u.	30,000	–	–	–	–	–
10	Development of policies and standards, a.u.	20,000	–	–	–	–	–
11	Security audit, a.u.	10,000	10,000	10,000	10,000	10,000	10,000
12	Staff training, a.u.	20,000	20,000	20,000	20,000	20,000	20,000
13	Consultations and support, a.u.	20,000	20,000	20,000	20,000	20,000	20,000
Total costs, a.u.		500,000	50,000	50,000	50,000	50,000	50,000

Table 7

NPV from implementing blockchain technology in grain supply chain tracking system

Year	Discount ratio, %	Total costs including discount rate, a.u.	Projected revenues taking into account the discount rate, a.u.	Projected profit taking into account the discount rate, a.u.
2022	0.909	454,500	162256.5	–292,244
2023	0.826	41,300	147,441	106,141
2024	0.751	37,550	134,053.5	96,503.5
2025	0.683	34,150	121,915.5	87,765.5
2026	0.621	31,050	110,848.5	79,798.5
2027	0.564	28,200	100,674	72,474
Sum		626,750	777,189	150,439
Net present value, NPV				150,439

The main advantages of the association of agricultural holdings with regard to the introduction of blockchain technologies into the tracking system of grain supply chains include cost savings on the implementation of blockchain technologies, joint financing reduces the burden on each participant, reducing the cost of development, technical support, and maintenance. Standardization of data, creation of a single standard for information exchange between agricultural holdings, traders, and buyers. Broad market coverage, pool members gain access to more data, improving overall supply chain efficiency. A competitive advantage, a common platform can become an industry standard, which will increase the trust of international partners and access to premium markets. Risk sharing, which is associated with the introduction of a new technology, is shared among all participants in the supply chain.

6. Discussion of research results based on assessing the economic effect of the introduction of blockchain technology

The problems (Fig. 2) and tasks of agricultural holdings (Table 1) in the tracking system of the grain supply chain have been identified, which showed the need to introduce digital technologies, in particular blockchain, in their activities. Threats associated with the introduction of blockchain technologies, namely: technical, economic, organizational, and regulatory, need to be discussed.

Our paper summarizes the comparative characteristics of the technological properties of the Ethereum and Hyperledger platforms, in contrast to study [23], which outlines the technological capabilities of Hyperledger. Network types, consensus, smart contracts, confidentiality, average cost of integration are summarized (Table 4). A proposal regarding the expediency of using the Ethereum platform, which may depend on the specificity of agricultural holdings in terms of the scale of their activities, production capacity, and financial capabilities, needs discussion.

Identified factors that directly or indirectly affect the tracking system of grain supply chains (Table 3) need to be discussed since they do not have empirical studies in terms of their level of influence but are more based on assumptions.

Our work assesses the investment attractiveness of introducing blockchain technology into the grain supply chain tracking system. First of all, the definition of the economic effect (1), time savings (2), cost savings from the automation of document processing is proposed (Table 5). Based on the calculations of the indicators, the influence of the introduction of blockchain technology on the automation of document flow was determined, which showed the level of time savings from the automation of document flow in the grain supply chain system. To determine the time before and after the introduction of blockchain technologies, the method of surveying experts was used, the results are summarized in Table 4. To calculate the investment attractiveness, direct and indirect costs related to the introduction of blockchain technology into the tracking system of grain supply chains were determined (Table 6). The expediency of introducing blockchain technology into the tracking system of grain supply chains has been substantiated, calculated on the basis of the NPV indicator, which was 150,439 a.u. (Table 7). The payback period of investments PPI was calculated according to formula (5), with the help of which it was established that the payback period of investments incurred for the introduction of blockchain technology in the tracking system of grain supply chains is 2.8 years.

The study opens up opportunities for future researchers to solve further problems in terms of the technological challenges of the Industry 4.0 era, aimed at improving the tracking system of grain production chains using blockchain technologies.

This study has certain limitations; in general, it is the complexity of technology implementation, limited data for analysis, modeling, which can affect the accuracy, reliability and applicability of blockchain technology in the grain supply chain tracking system. The evaluation of the economic effectiveness of the introduction of blockchain technology is partially based on the assumptions of experts and the prediction of probabilities, possible results, which requires additional calculations in some cases.

The development of this research involves the possibility of combining blockchain technologies with artificial intelligence, which is especially relevant for grain supply chains.

7. Conclusions

1. Key problems in the system of grain supply chains have been identified, in particular destruction of infrastructure, damage to ports, railroad hubs and transport routes as a result of military operations; logistic delays, reorientation to land and river routes; limited capacity of borders, high cost of transportation, security risks, uneven distribution of demand; increased costs, unforeseen losses, large time losses and insufficient data transparency. Tasks for improving the system of grain supply chains have been defined, namely grain supply monitoring; ensuring transport safety; prevention of theft and fraud; effective management of logistics; execution of contracts; support for the stability of the grain sector.

2. The characteristics of key blockchain technologies, which are necessary for their introduction into the system of grain supply chains, have been outlined. Among the main ones, smart contracts are highlighted, which include the security of contracts, the efficiency of transactions, and full automation of document processing. An algorithm for conducting transactions in the system of grain supply chains based on blockchain technology has been developed, the advantages of which are accessibility of information to all participants in the process; automatic execution of smart contracts; impossibility of falsifying data; reducing the need for intermediaries and optimizing all stages of supply. The collection, processing, storage, and management of data when tracking grain supply chains based on blockchain technologies is proposed to be carried out using the Internet of Things (IoT) technology. Optimization of storage is proposed to be carried out with the help of storage, which includes a multi-chain architecture and a combination with the Interplanetary File System (IPFS). The use of contactless cards (RFID) has been proposed for tracking grain production chains and reading quality and safety data. For the implementation of blockchain technologies in the tracking system of grain supply chains, it is proposed to use the Ethereum platform, which is ideal for public decentralized applications where openness and trust between participants are important.

3. The influence of factors on the introduction of blockchain technologies into the grain supply chain tracking system has been determined using a SWOT analysis. It has been established that the implementation of blockchain technologies in the tracking system of grain supply chains has many strengths, such as transparency, increased trust, automation of processes and protection against counterfeiting. However, there are also weaknesses, such as high implementation costs, difficulty in scaling, and the need for staff training. Opportunities opened up by the use of blockchain include attracting new partners, increasing competitiveness, and developing new markets. However, there are also threats, in particular, legal difficulties, technical failures, high energy costs and resistance from market participants.

4. An assessment of the investment attractiveness of introducing blockchain technology into the grain supply chain tracking system has been carried out by calculating such indicators as economic effect; net present value (NPV) of implementing blockchain technologies; payback period of investments. The payback period for investments in the implementation of blockchain technologies in the system of grain supply chains has been determined, which is 2.8 years, which is acceptable for large agricultural holdings. Prospects for development have been defined; in particular, the unification of agricultural holdings has been proposed for the joint implementation of blockchain technologies in the tracking system of grain supply chains, which could be a strategically beneficial solution for agricultural holdings. Such measures will allow them to distribute costs, increase the efficiency of the technology, and create a standardized system for all participants of the supply chain.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The data are publicly available in a public repository that publishes datasets with DOIs.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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