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BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAIN MANAGEMENT IN THE CONTEXT OF AI-BASED SOLUTIONS

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Purpose: The purpose of the article is to emphasize the growing popularity of using tools based on artificial intelligence and blockchain technology in supply chain management, as well as to show the synergistic potential of using them together. Additionally, the author aims to present and discuss the concept of using both technologies for the purposes of constructing an ordering goods system in the supply chain based on AI tools supported by blockchain technology.
Design/methodology/approach: The purposes of the paper were achieved by analyzing literature, industry reports and online publications in the field of blockchain technology and artificial intelligence in supply chain management. The theoretical scope of the article is the description of application areas of both described technologies within the supply chain, their main characteristics and the potential for synergy in their combined use.
Findings: The author presented the results of the analysis of literature, industry reports and online publications, demonstrating the growing popularity of the use of blockchain technology and artificial intelligence-based tools in supply chain management, characterized key features of analyzed technologies, comparing them on the basis of opposites, and indicated their resulting synergistic potential. Drawing conclusions from this potential, the author indicated the possibility of using both technologies together as part of the blockchain-AI supported ordering system's concept. The article ended with the author's suggestions regarding the potential of future research aimed at concretizing the proposed concept and looking for opportunities to decentralize AI tools used so far based on their support with blockchain technology.
Practical implications: The use of blockchain technology and tools based on artificial intelligence in business shows measurable benefits, as shown by the submitted analysis of industry reports. Observed increasing adoption of both technologies contributes to cost decrease and revenue increase in many industries as shown in the paper.
Originality/value: The originality of the paper consists in comparing the opposites and drawing conclusions regarding the potential complementarity of the features of both analyzed technologies, and is also expressed in the proposed concept of Blockchain-AI supported ordering system.

Keywords: distributed ledger technology, blockchain, artificial intelligence, supply chain management.

Category of the paper: Research paper.

1. Introduction

The growing popularity of tools based on artificial intelligence usage has been clearly noticeable in recent months. Their popularity coincides with the growing importance of distributed ledger technology, with particular emphasis on blockchain technology. This article aims to outline the relationship between the development of tools using artificial intelligence and solutions based on blockchain technology and propose a concept of using both analyzed technologies for supply chain management. The advantages of blockchain technology seem to strengthen the potential of AI-based techniques that are increasingly used, also in the business activities of enterprises. Transparency and the elimination of the need for trust between market entities, which are the main benefits of using blockchain, enhance the opportunities arising from the use of AI tools in many areas of everyday life of people, but also in management in both the private and public sectors. The combination and synergy of two of the most trending modern technologies can result in the creation of modern solutions applicable in supply chain management. The article presents the results of literature research on the popularity of AI-based tools, the advantages of their use in business practice, the benefits of using blockchain technology, especially smart contracts, and the synergistic potential of both described technologies. This research was supported by the analysis of reports from leading analytical companies in the field of AI and blockchain. Conclusions from the literature research and analysis of solutions currently being developed in business led to the creation of the concept of using both technologies to improve the ordering of goods in the supply chain. In the course of research work leading to the creation of the article, a research gap was identified, four research questions were asked and, consequently, the objectives of the article were defined.

Research gap: To determine the synergistic potential of using blockchain technology and AI-based tools for goods ordering systems.

Research question 1: What are the areas of application of AI-based tools in supply chain management?

Research question 2: What is the popularity of the use of AI-based tools in supply chain management and what benefits does it bring to companies?

Research question 3: What complementary features do blockchain technology and AI-based tools have?

Research question 4: Is it possible to develop a goods ordering system that uses both blockchain technology and AI-based tools?

Main objective: To present and discuss the concept of using both technologies for the purposes of constructing an ordering goods system in the supply chain based on AI tools supported by blockchain technology.

Intermediate objective 1: To emphasize the growing popularity of using tools based on artificial intelligence and blockchain technology in supply chain management.

Intermediate objective 2: To present the synergistic potential of using both the blockchain technology and AI-based tools.
Article hypothesis: Is it possible to develop a goods ordering system that uses both blockchain technology and AI-based tools.

2. Materials and methods

A literature review - in particular bibliometrics - was carried out for research without the publishing time limitation on the topics of Blockchain technology and Artificial Intelligence in Supply Chain Management. The first step was to analyze publications included in the Scopus database. However, for a comprehensive study, the analysis was deepened to include the Web of Science database. The following queries were run on September 21st 2023:

Scopus:

- TITLE-ABS-KEY (“blockchain AND supply AND chain AND management”),
- TITLE-ABS-KEY (“artificial AND intelligence AND supply AND chain AND management”),
- TITLE-ABS-KEY ("AI AND tools").

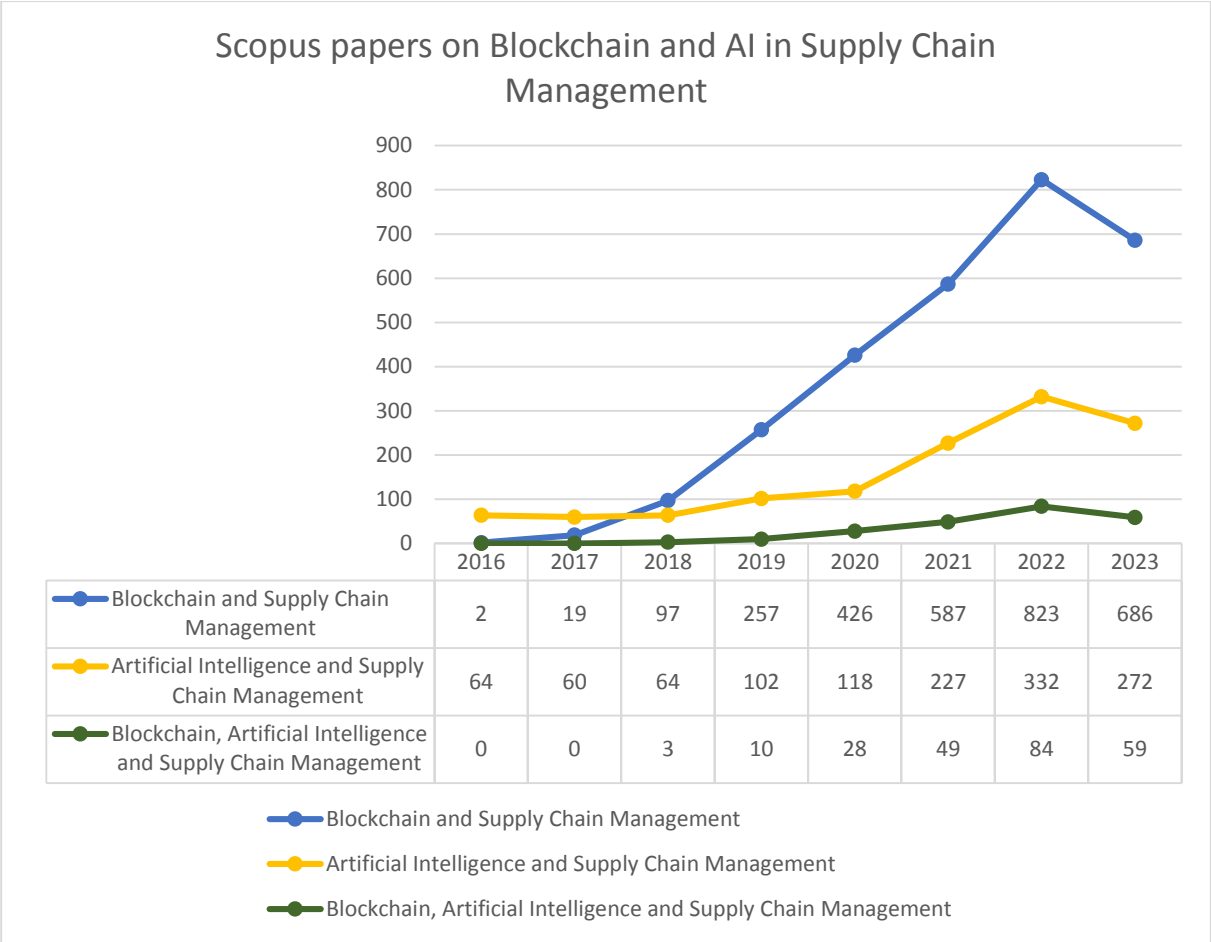
Web of Science:

- TOPIC: ("blockchain supply chain management"); Indexes: SCIEXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCREXPANDED, IC.
- TOPIC: ("artificial intelligence supply chain management"); Indexes: SCIEXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCREXPANDED, IC.
- TOPIC: (“blockchain artificial intelligence supply chain management"); Indexes: SCIEXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCREXPANDED, IC.

The search results showed given numbers of publications in subject areas:

- Blockchain in Supply Chain Management: Scopus – 2895, WoS – 2661,
- Artificial Intelligence in Supply Chain Management: Scopus – 1812, WoS – 1926,
- Blockchain and Artificial Intelligence in Supply Chain Management: Scopus – 233, WoS – 253.

Figure 1 and Figure 2 show the number of publications on analyzed topics since 2016 in both analyzed databases.



	2016	2017	2018	2019	2020	2021	2022	2023
Blockchain and Supply Chain Management	2	19	97	257	426	587	823	686
Artificial Intelligence and Supply Chain Management	64	60	64	102	118	227	332	272
Blockchain, Artificial Intelligence and Supply Chain Management	0	0	3	10	28	49	84	59

Figure 1. Scopus papers on Blockchain and Artificial Intelligence in Supply Chain Management. Source: own elaboration.

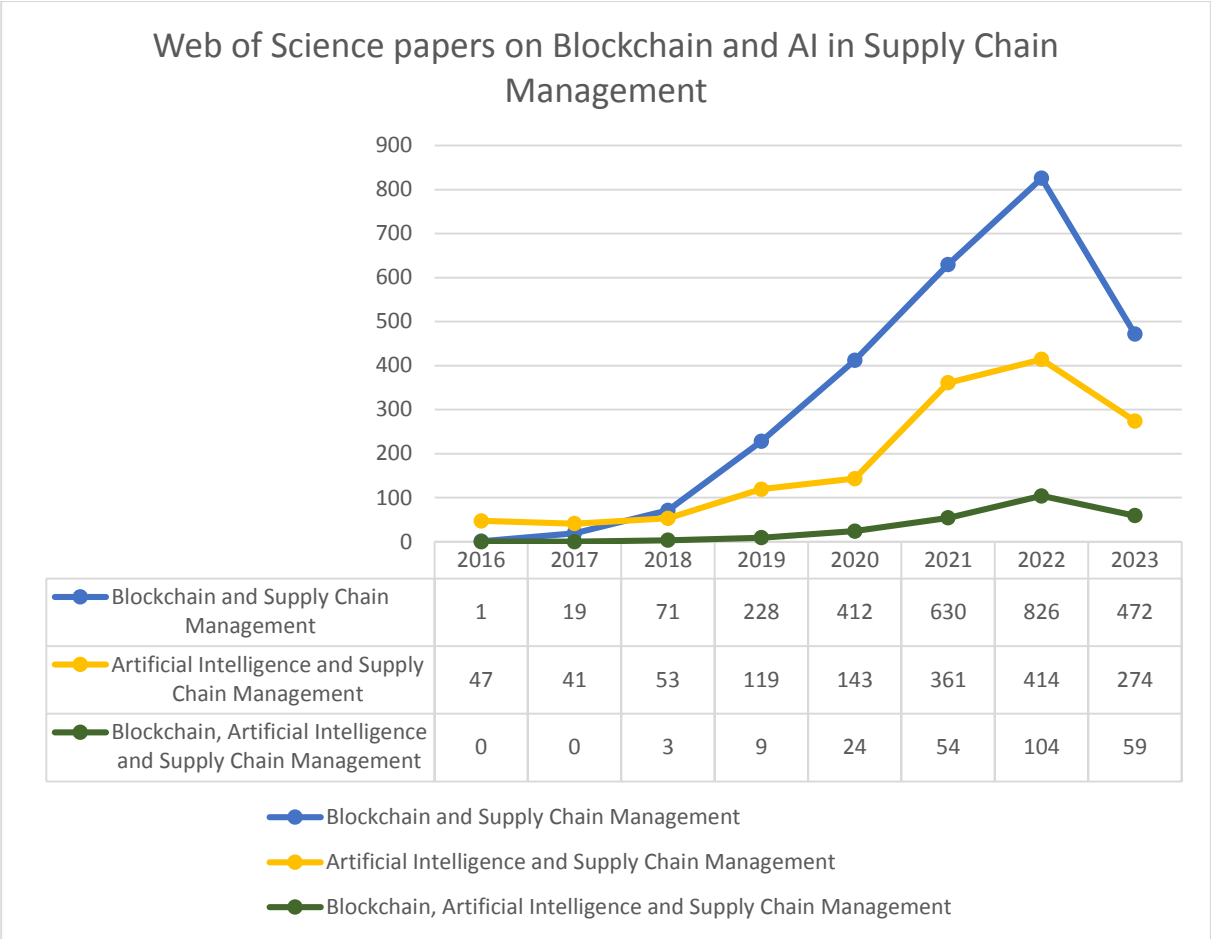


Figure 2. Web of Science papers on Blockchain and Artificial Intelligence in Supply Chain Management.

Source: own elaboration.

The search results including indicate a relatively small number of publications (Scopus – 233, WoS – 253) embedding the topic of both blockchain technology and artificial intelligence in the field of supply chain management, which confirms the author's assumptions about the legitimacy of in-depth analyzes in this area. During the preparation of this article, the literature review resulting from the above bibliometric analyzes was supplemented with a review of industry reports and reports of analytical and consulting companies.

3. AI-based solutions in supply chain management

During the fourth industrial revolution, which is characterized by the use of a fusion of breakthrough technologies, it is necessary to search for and use modern solutions, such as systems based on artificial intelligence (Sahai, Rath, 2021). Conventional management, production or provision of services has been largely modified over the last decade by the use of unprecedented amounts of data (data-driven management), cyber physical systems and the

Internet of Things (Lee, Azamfar, Singh, 2019; Rüßmann et. al., 2015). These solutions significantly strengthen the efficiency and productivity of supply chains and increase its visibility (Ben-Daya, Hassini, Bahroun, 2019). A special place among disruptive technologies is occupied by the extensive use of artificial intelligence offering interoperability and analytical capabilities (Baryannis et. al., 2019). AI is generally understood as the use of computers for reasoning, pattern recognition, gathering knowledge from the experience of working with data and developing forms of problem solving in search of optimal solutions (Min, 2010). Its use in supply chain or enterprise management can radically modify current business practices and ways of performing managerial tasks.

Regarding the areas of application of AI tools in supply chain management, Sharma et al. indicated that these include: supplier selection, inventory planning, Green Supply Chain Management, Supply Chain Network Design, Healthcare and demand forecasting (Sharma et al., 2022).

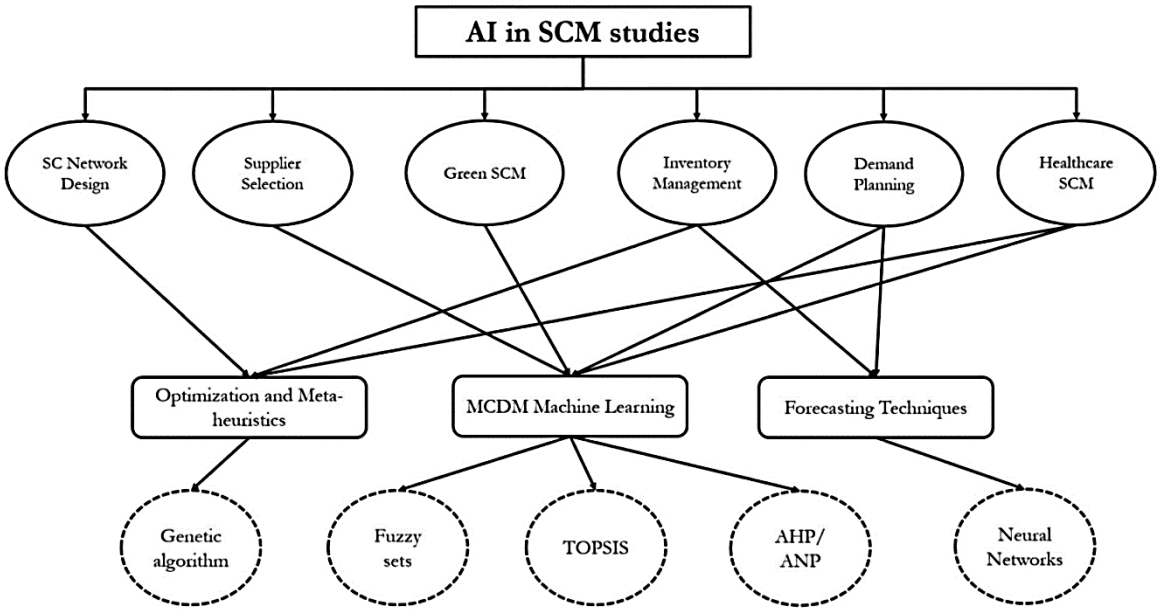


Figure 3. AI-based tools' areas of application and basic AI techniques.

Source: Sharma et. al., 2022.

Figure 3 illustrates the connections between the areas of application of AI tools in SCM and specific AI techniques (which are not directly the subject of this article). According to the McKinsey & Company Survey 2022 report, the use of AI tools, according to respondents, contributes to reducing costs and increasing revenues of enterprises, which is shown in Figure 4. The greatest savings are noticed by respondents in the SCM area (52% of respondents).

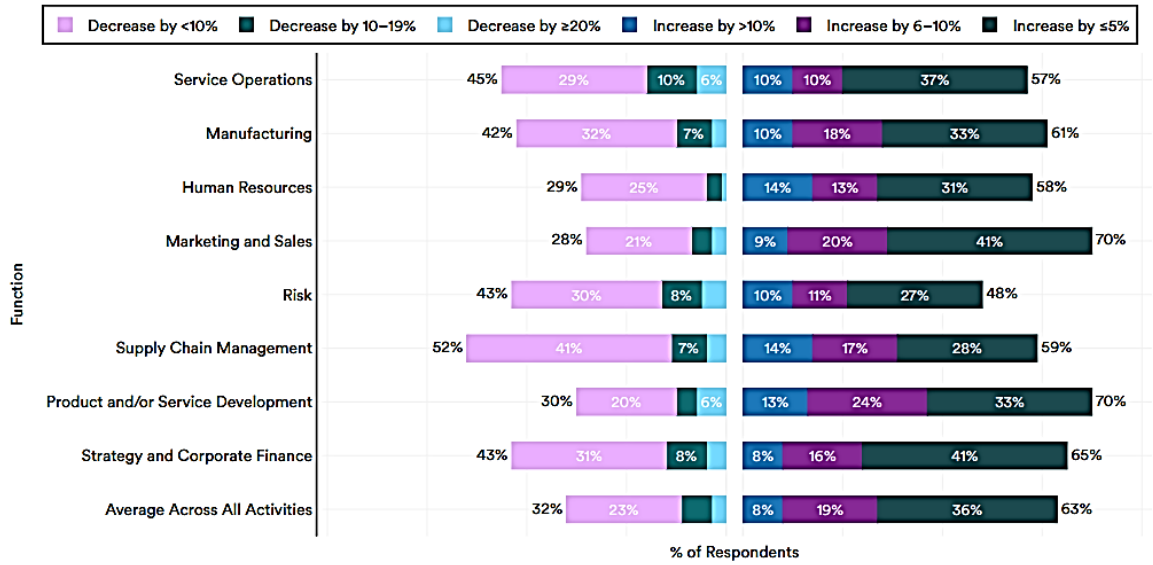


Figure 4. Cost decrease and revenue increase from AI adoption by function in 2021.
Source: McKinsey, 2022.

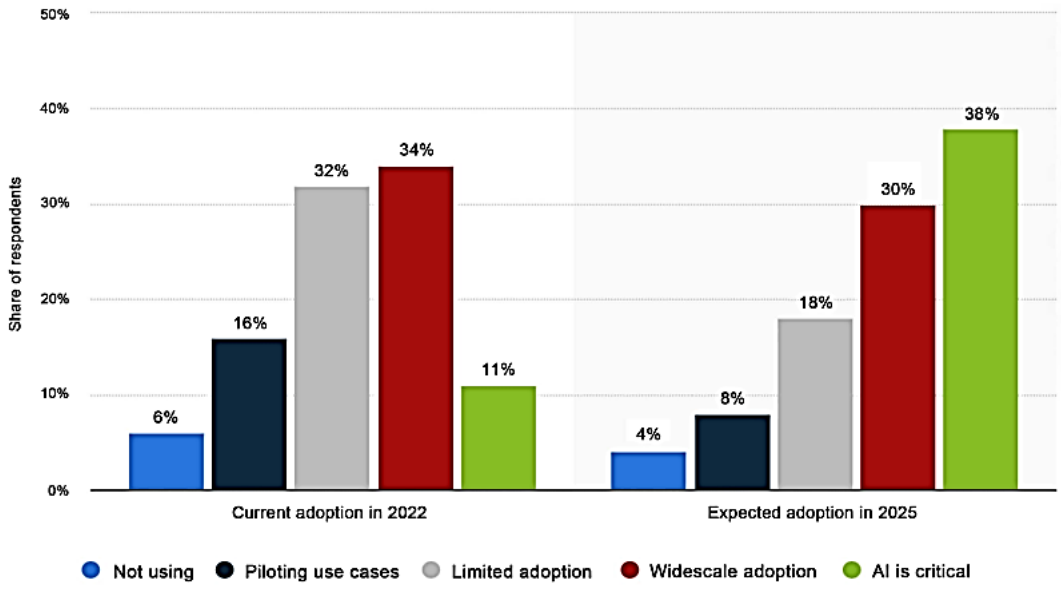


Figure 5. Global AI adoption rate in supply chain and manufacturing businesses (2022 and 2025).
Source: Statista, 2022.

According to a report by Statista, the global adoption of AI solutions in the supply chain and manufacturing industry should increase significantly over the next few years (Fig. 5). On the other hand, the NetBase Quid report (Fig. 6) shows that global corporate investments in the development of AI have recorded a huge increase over the past few years. While the readings for 2022 are slightly lower than those for 2021, the trend remains upward, with the record year 2021 being spent in the order of $276 billion.

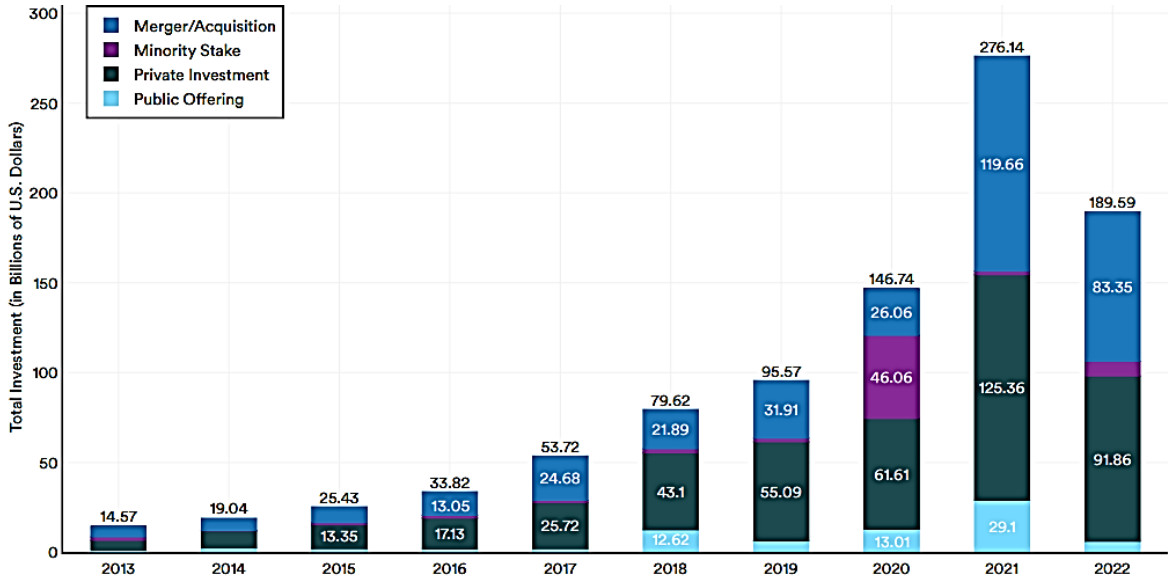


Figure 6. Global corporate investment in AI by investment activity.

Source: NetBase Quid, Stanford HAI, 2022.

Therefore, the fact that AI is increasingly widely adopted and used in the day-to-day operations of entities that are part of modern supply chains does not raise any doubts. AI can and should be used in cooperation with other modern technologies noticed in the concept of Industry and Logistics 4.0. One of them is undoubtedly distributed ledger technology, and especially blockchain technology.

4. Synergistic potential of blockchain and AI-based solutions for SCM

The use of AI is therefore gaining importance in managing business entities, including SCM. In search of synergistic relationships between AI and blockchain, this article indicates the basic advantages of blockchain technology, which may translate into strengthening the benefits of using AI. The integration of AI and blockchain as part of various types of solutions should result in their increased security, efficiency and productivity (Saxena, Gayathri and Kumari, 2023). Blockchain is an open, decentralized, distributed and public ledger in which transactions are recorded on multiple computers, which ensures that it cannot be modified backwards (Sarmah, 2018). Thanks to the use of cryptography and proof of work consensus, the fact of immutability of records in the blockchain is achieved, which eliminates the need to trust entities responsible for entering data into various systems. Each block chain node has access to the data contained in it.

One of the most important mechanisms using blockchain technology is a smart contract. It is a computer program that is executed automatically when predefined conditions are met. A smart contract contains arbitrarily constructed logic and can be used in various types of

applications where users or events can trigger their execution (Ante, 2021). Smart contract is also being defined as a piece of computerized transaction protocol that satisfies contractual conditions such as payment terms, confidentiality or enforcement, reduces exceptions and minimizes the need for trusted intermediaries (Ante, 2021). In supply chain management, it can be used to automate transactions between its participants. That way, a specific event taking place in reality is recorded on the blockchain in real-time (e.g. recording a material flow using an IoT sensor) and triggers a financial and information flow (generating and sending documents) directly using a smart contract without the need for any human activities.

Blockchain technology therefore shows great potential for data sharing in the form of decentralized, secure and reliable records. The basic advantages of blockchain are indicated and characterized in Table 1.

Table 1.
Blockchain technology advantages

Blockchain technology advantages	Description
Immutability of blockchain	A knowledge record or its details cannot be changed until they are processed or added to the blockchain as a block. Nothing can ever change the data stored in a blockchain; it has an indestructible place there.
Decentralization	Due to its ability to provide digital independence to a single consumer, the entire blockchain network can be decentralized. In the network, no organization has control over every other user. Each node functions individually.
Flexibility	To protect transactions, the blockchain network uses sophisticated encryption techniques. Users of the blockchain can safeguard and maintain their privacy.
Security	Blockchain chains include information records that are encrypted using cryptography, which ensures that hackers cannot change or modify those data. All blocks on the blockchain are connected by encrypted hash functions, making it unlikely for theft or illegal transactions to take place there.
No intermediaries	Because of the blockchain network's point-to-point architecture, transactions between two nodes take place without the need for a middleman. To facilitate transactions between two parties, there is no requirement for an intermediary like PayPal, any bank, Visa, Western Union, etc.
Transparency	All or any individuals who are a neighborhood of the network disposes transparency thanks to the digital distributed ledger system. In a network, each node has a copy of the ledger and the ability to check transactions. Because of this, no one can keep their transactions and personal information a secret from other users, ensuring fair commerce.
Fewer transaction costs	The transaction costs are reduced because there are no middlemen involved in transactions on the blockchain network. One's entire transaction cost rises if there are middlemen because they charge a significant fee.
Consensus-based	The blockchain concept is totally built on consensus, meaning that each transaction between two nodes during a blockchain is accompanied by an invitation for its verification sent to all or some of the opposing nodes. In any scenario, after a transaction has been verified by the nodes, it is added to the memory pool and forms a replacement block. There are many such validated transactions stored in the memory pool.

Source: Saxena, Gayathri, Surya Kumari, 2023.

AI-based tools in supply chain management, on the other hand, are used in many areas. It can support sales and distribution inventory in the field of communication in the supply chain and management of sales teams; enable real-time performance tracking (through forecasting, inventory replenishment scheduling and order generation, as well as advice based on expert

knowledge implemented in the AI tool); provide smart reporting (by generating reports in various areas of activity); ensure supply chain transparency (by transforming data into suggestions for carrying out work, optimizing transportation solutions and proactively detecting disruptions); creating forecasts of demand for goods, or early detection of errors in ongoing processes (Kashem et al., 2023).

Certain features of both considered technologies (artificial intelligence and blockchain) seem to be contradictory, which does not exclude the possibility of seeking synergistic effects resulting from their combination on the basis of complementary technologies. Selected features of blockchain technology and AI-based solutions are summarized on the basis of opposites in Table 2.

Table 2.
Complementary features of blockchain technology and AI-based solutions

Blockchain technology features	AI-based solutions features
Deterministic	Probabilistic
Permanent	Changing
Algorithms and cryptography to record reality	Algorithms to guess the reality
Immutable	Data ingestion
Decentralized	Centralized
Secure	Moderately secure
Consensus-based	Learning process-based

Source: own elaboration.

While blockchain technology is based on a deterministic approach, AI-based solutions use a probabilistic approach (Antonopoulos, 2014). Blockchain, thanks to its structure, ensures the immutability of data registers, and AI shows considerable variability in generating solutions based on available knowledge. The algorithms that constitute the blockchain are aimed at recording reality, and AI aims to predict its future states. The immutability of blockchain-based registers contrasts with the changing behavior of AI as new data arrives, and the decentralized structure of blockchain (Alzahrani, Bulusu, 2018) contrasts with the centralization of currently used AI-based tools (Brynjolfsson, Ng, 2023). The issue of cybersecurity in relation to blockchain is beyond doubt and is one of its greatest advantages, while in relation to the security of AI tools there are many reservations Attkan, Ranga, 2022). The blockchain is built and updated based on the consensus of the nodes that constitute it (Chaudhry, Yousaf, 2018), and the AI tools are controlled by the learning process (Fahle, Prinz, Kuhlenkötter, 2020).

The apparent contradiction observed in the features of blockchain technology and AI-based tools may suggest the potential of their joint use as complementary technologies. Therefore the use of smart contracts and other blockchain technology mechanisms supplemented with AI-based tools seems to offer enormous opportunities to improve the functioning of modern supply chains.

5. The concept of implementing AI-based solutions and blockchain technology in SCM

The nature of smart contracts as self-enforcing mechanisms offers significant opportunities to enhance the benefits of AI. AI models combined with smart contracts offer the potential to, for example, detect the need to replenish stocks (using AI) and automatically order delivery from an external supplier (using a smart contract) (Chainlink, 2023). The combination of blockchain technology and AI is also able to improve supply chain transparency and minimize the impact of counterfeits by digitizing document flow and ensuring real-time tracking of goods in the supply chain. The use of predictive analysis supported by AI in the company of automated flow of information (and finances) via blockchain can provide enterprises with the ability to view and analyze patterns, optimize warehouse management and make data-based decisions, and consequently reduce costs. GMDH Streamline (a company creating platforms for modern support for S&OP processes for supply chains based on AI and blockchain) CEO, noticed that a few years ago inventory management processes were carried out manually. The pandemic experience and the continuous development of modern solutions made entrepreneurs look for more robust solutions (Forbes, 2023). Today, supply chains face the problems of unpredictability, lack of historical data, or numerous supply chain disruptions. They must be able to adapt to changes in the environment at a very fast pace. According to Streamline CEO, the use of AI tools has at least several significant advantages over traditional methods: reducing the number of manual processes, reducing the number of errors resulting from the complexity of the supply chain, supporting the determination of the amount of ordered materials over time. Supply chain managers often use Excel to manage data from ERP systems. This is extremely time-consuming and often causes individual participants in the supply chain to rely on expired data. Blockchain-based solutions integrate data from many sources in near-real time, and based on AI mechanisms, it is possible, for example, to forecast the amount of ordered materials at a given point in time. Other significant problems facing modern supply chains are the issues of forecasting sales volumes, required inventory levels in warehouses, or simply reliable data on the current inventory throughout the supply chain, current status and the possibility of delays in transit. Thanks to the use of blockchain technology, the data held by the participants of the supply chain is up-to-date and cannot be changed retrospectively by any of the actors, making it fully reliable. Each flow of materials within the supply chains is recorded in the blockchain, and knowledge about this flow and the current state of the supply chain is in the hands of all participants in the supply chain in real time.

AI-based tools, on the other hand, can, based on reliable data (provided by blockchain) and recognition of historical patterns or seasonal changes visible in them, make advanced forecasts of future demand for materials. Artificial intelligence is also able to assign tasks to individual employees or issue instructions to implementers of manufacturing processes based on data

whose veracity is beyond doubt (thanks to blockchain). What's more, AI can also improve the process of planning transport routes thanks to machine learning mechanisms and be much more effective in this respect than a human. Among the areas where the use of AI in the supply chain is particularly useful, the following are listed: predictive analytics, production planning, customer response, warehouse management, route efficiency and optimization (Pournader et al., 2021). A hypothetical example of the synergistic operation of systems based on AI and blockchain technology is the concept of the goods ordering process proposed by the author of this article based on available historical data and with the support of the technologies described in this article. A decision-maker (manager) in ordering goods from suppliers in an enterprise based on AI and blockchain could be significantly relieved thanks to the use of technology, both in terms of analytical processes necessary to determine the delivery volume and time of placing an order, as well as the execution activities related to the physical order. In the layer of analytical and decision-making activities, support would be provided by AI techniques, while in the execution layer, blockchain technology (smart contract) would provide support. The proposed structure of the described solution is shown in Figure 7.

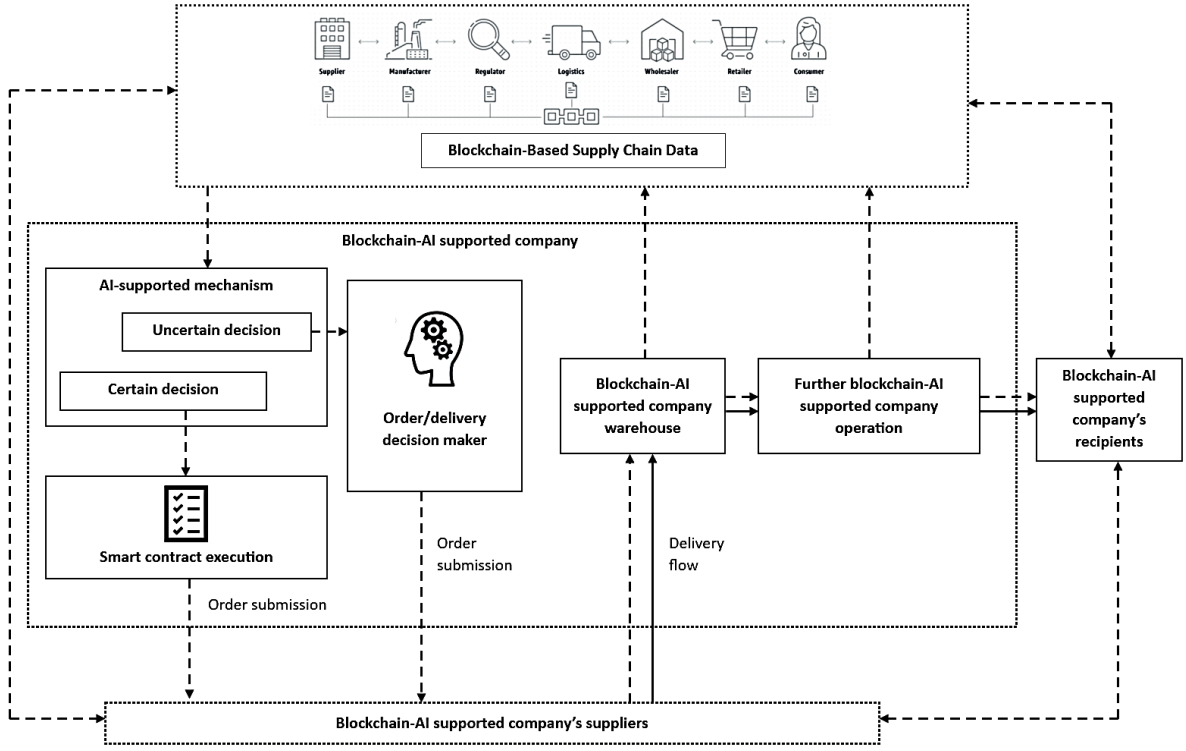


Figure 7. Blockchain-AI supported ordering system concept's structure.
Source: own elaboration.

All data necessary to make a purchase decision would come from the blockchain (providing access to knowledge about the current state of the entire supply chain in real time), and their initial analysis would be carried out using AI tools. In the case of a standard situation (certain decision), which has often occurred in the past, without any deviations from past purchasing situations, the implementation of a smart contract would allow the order to be placed (and even

paid for) directly by the AI itself, which significantly minimizes (even eliminates) manual work. In the case of an unusual situation (uncertain decision), not previously observed and occurring as a result of disruptions in the supply chain, the AI tool would interact with the decision-maker, suggesting potential management options. The final decision would then be made by a human. The system constructed in this way has enormous potential for savings for the company, resulting from a significant reduction in the workload of people responsible for analytical and management activities.

6. Conclusion

This article demonstrates the broad potential of using AI tools and blockchain technology in modern supply chain management. Both technologies described have many seemingly contradictory features, which enhances the impression of their complementarity. Using the advantages of AI and blockchain as part of coordinated solutions provides new opportunities in supply chain management. This was illustrated in the form of the concept of blockchain-ai supported ordering system, which was presented at a high level of generality. Among the limitations of the proposed solution, it is worth noting the low level of adoption of blockchain technology, and therefore the small number of smart contract developers specializing in their implementation in the field of supply chain management, as well as the high investment costs required to implement the proposed solutions. The direction of further research suggested by the author of this publication should be aimed at concretizing the proposed solution at the technical level, taking into account specific AI techniques for forecasting and analyzing the demand for materials in the supply chain and the programming issues of blockchain-based smart contracts enabling the automation of financial flows. Another direction of future scientific considerations proposed by the author is the decentralization of AI-based tools using blockchain technology, leading to the creation of systems that operate on consensus among multiple nodes, instead of relying on a single central authority, which leads to a more secure, transparent and trustworthy alternative to traditional AI systems. As indicated, the integration of two technologies based on different features and having different advantages is a wide research field for researchers, and as previous research indicates - their separate use in supply chain management provides many measurable benefits for the entities implementing them. The synergistic effect resulting from integration should contribute to increasing the benefits while minimizing the negative aspects of their separate use.

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