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KEY AREAS OF BLOCKCHAIN TECHNOLOGY APPLICATION IN LOGISTICS

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Purpose: The main purpose of the article is to present the current state of knowledge and business practice in the field of the use of Distributed Ledger Technology in logistics, with particular emphasis on Blockchain Technology, along with an indication of examples of its practical application in enterprises providing logistics services.
Design/methodology/approach: The article was mainly based on a thorough analysis of quantitative and qualitative data contained in documents made available by the European Union institutions and reports created by institutions aimed to analyze the development of the Blockchain Technology. The data is supported by modern scientific articles concerning the topic of Distributed Ledger Technology in logistics and supply chain.
Findings: The result of this article is an indication of the key areas of blockchain technology application, with numerous practical examples of its application. The set of practical applications, created on the basis of literature research and analysis of internet sources concerning individual applications, has been divided according to the criterion of the subject area of its application.
Originality/value: The originality of the article consists in analyzing modern solutions based on Blockchain Technology and creating a non-exhaustive collection of 26 applications based on Distributed Ledger Technology aimed to support modern logistic services. This collection has been divided into 4 groups according to area of application criterion.

Keywords: blockchain technology, Distributed Ledger Technology, Logistics 4.0, sustainable development, trust management, Internet of Things.

Category of the paper: general review.

1. Introduction

Due to increasing importance of information flows within various logistics systems, observed in recent years, it seems justified to constantly seek to optimize them (Hacker, 2007). Logistic information systems – consisting of numerous information streams connecting executive units of organizations with their management system – undoubtedly provide numerous benefits to entities interested in improving the effectiveness of logistics processes (Prajogo, 2018). It can be stated that, in today's logistics, the efficiency of material flows is largely dependent on the quality of information flow (Rajaguru, Matanda, 2013), while inter-organizational information systems are a key tool for shaping relationships in supply chains (Pereira, 2013). The continuous development of information technology, observed all over the world, suggests a series of analyses concerning the possibility of implementing the latest technological solutions in the context of information flow management, but also – in some cases – material and financial flows. Undoubtedly, possibilities of streamlining these flows fit into the scope of logistic interest (Nowakowska, Nowakowska, 2012). One of the technologies, that can be used in the management of logistics systems, is blockchain technology (Queiroz, Fosso Wamba, 2019). As it is increasingly considered a next-generation information tool, it is argued that the use of blockchain in logistics can affect the efficiency and growth of partnerships in the supply chain, thus affecting its performance (Kim, Shin, 2019).

In broadly understood logistics activities, the use of blockchain technology can reduce delays in orders, damage to goods, errors and duplication of data (Tijan et. al., 2019). In addition, blockchain technology appears in almost all lists of the most trending technologies in recent years, in the context of their application in logistics. According to the PwC report, published in 2019 (PwC, 2020), the Distributed Ledger Technology (DLT) was among the five key forces leading to the transformation of the logistics and transport market, indicating that they are applicable in all segments of logistics activity analyzed by PwC. On the other hand, the "Global Blockchain Survey" annual report, published by Deloitte, suggests that, in 2019, the discussion about blockchain in enterprises changed from: "Will blockchain work?" to: "How can we make blockchain work for us?" (Pawczuk et. al., 2019). The report also points out that organizations clearly see blockchain as their top priority, as indicated by 55% of respondents (an increase from 53% in 2019 and 43% in 2018). The group of respondents to the above-mentioned survey included 1,488 senior managers and management practitioners familiar with the operation of DLTs from different regions of the world. In addition to recognizing the priority of using blockchain technology for the current management of organizations, literature on the subject contains numerous references to the issue of sustainable development in the supply chain management. Currently, ensuring the sustainable development of supply chains is considered in three basic dimensions: economic sustainability, social sustainability and environmental sustainability, which – for many years – have been referred to as the Triple Bottom Line (Elkington, 1998). Among the main problems of modern supply chains regarding the aspect of economic sustainability, the following can be distinguished: insurance claim (Klibi, Martel, 2010), supply chain procurement contracts (Ghosh, Shah, 2015), high overseas financial transaction fees (Niepmann, Schmidt-Eisenlohr, 2017), loss due to discrepancy in information sharing among the supply chain stakeholders in real-time (Dubey, 2020) and cost of monitoring sustainability (Kshetri, 2018). Problems related to the aspect of social sustainability are: child labor, employee wages, sourcing from local communities and public health, or food traceability. On the other hand, the last aspect – environmental sustainability – is related to such issues as: supply chain wastage, pollution issues, footprint, illegally traded animal parts or plants (Giannakis, Papadopoulos, 2016). It is anticipated that the use of blockchain technology may contribute to solving the above problems, thanks to the use of smart contracts, ensuring transparency of information flow, invariability of records in databases, easy access to data by stakeholders and broadly understood traceability (Chandan, Potdar, 2019).

2. Multidisciplinary nature of blockchain technology and its place in the concept of Logistics 4.0

Financial services and fintech companies continue to lead the way in blockchain technology development, but other sectors – in particular government, life science and health care, as well as technology, media and telecommunications – are also developing blockchain initiatives (Pawczuk et. al., 2019). Undoubtedly, today, blockchain – as one of the breakthrough innovations – significantly affects the functioning of the economy. Every logistic system is an element of this economy, and the Deloitte report shows that:

- 88% of respondents believe that blockchain technology is widely scalable and will eventually reach widespread use (86% in 2019 and 84% in 2018),
- 86% of respondents believe that the executive team of enterprises they manage say, that there are convincing business arguments for using blockchain technology in the organization (83% in 2019 and 74% in 2018),
- 85% of respondents agree that suppliers, customers and/or competitors are discussing or working on blockchain solutions for current value chain challenges, that will serve the organization (82% in 2019 and 77% in 2018),
- 83% of respondents believe that an organization or project will lose their competitive advantage if they do not use blockchain technology (82% in 2019 and 77% in 2018).

The Deloitte report shows that blockchain technology is perceived by practitioners of supply chain management as an extremely important technology for the operation of companies implementing logistic processes, and great efforts are made to adapt it.

2.1. Blockchain Technology basics

While some of the principles contained in blockchain technology had already been described in earlier cryptography work, the foundations of the technology used today were first published in October 2008. The article was titled “Bitcoin: A Peer-to-Peer Electronic Cash System” and was published by the author or group of authors under the pseudonym Satoshi Nakamoto (Nakamoto, 2008). Blockchain, in the simplest terms, can be defined as a transaction book that allows registration and tracking of every operation carried out within it, and which is scattered over the Internet in the form of non-modifiable copies (Biedrzycki, 2018). It is, therefore, a decentralized register of transactions, but it should be mentioned here, that it does not apply only to financial transactions, as could be inferred from the Bitcoin perspective. Blockchain makes it possible to describe the implementation of a given project from the perspective of information exchange (Casino, 2019). Taking into account the structure formed by blocks containing information about transactions, blockchain technology is, therefore, a system of elements used to store and transmit information about transactions, which are arranged as successive data blocks (Zhang, Xue, Liu, 2019). Each transaction is saved in the ledger as a block containing data about its value and conclusion time. Such a block is added to the previous ones and, together, they form an inseparable chain (Biedrzycki, 2018). Blockchain uses cryptographic solutions, such as one-way hashing functions or asymmetric cryptography (Dikariev, Miłosz, 2018). The system constructed in this way guarantees security and eliminates the problem of distrust – with no need for any central supervisory institution. Unauthorized changes to the ownership or value of assets are practically unfeasible, as all the previous blocks preceding the transaction would have to be changed. Currently, by far the best-known example of the use of this technology is the Bitcoin cryptocurrency, but this is only a small part of the possible applications (Grzywacz, 2018). In addition to applications within cryptocurrency markets, blockchain technology can also be widely used to transfer value, while ensuring a high level of security. For the purposes of this article, the issues of cryptocurrencies and technical details of blockchain technology are not analyzed. The article focuses on the possibilities of using blockchain in logistics, with particular emphasis on the area of information flows. A review of blockchain definitions appearing in the literature and in the message shaped by units involved in its use (e.g. cryptocurrency exchanges) is presented in Table 1.

Table 1.
A review of blockchain definitions

Source	Definition
(Coinbase, 2020)	A distributed, public ledger that contains the history of every bitcoin transaction.
(Oxford Dictionaries, 2018)	A digital ledger, in which transactions made in bitcoin or another cryptocurrency are recorded chronologically and publicly.
(Stroud, 2020)	A type of data structure that enables identifying and tracking transactions digitally and sharing this information across a distributed network of computers, creating – in a sense – a distributed trust network. The distributed ledger technology offered by blockchain provides transparent and secure means for tracking the ownership and transfer of assets.
(Sultan, Ruhi, Lakhani, 2020)	A decentralized database containing sequential, cryptographically linked blocks of digitally signed asset transactions, governed by a consensus model.
(Quiniou, 2019)	A distributed ledger based on a data structure, in which transactions are stored in blocks that are chained to each other. A block contains, in addition to transactions, the hash of the previous block. The modification of a transaction, therefore, modifies not only the block to which it belongs, but all the blocks that follow it. The blockchain structure gives the distributed ledger its immutability.

Cont. table 1.

(Natarjan, Krause, Gradstein, 2017)	A particular type or subset of the so-called distributed ledger technology. DLT is a way of recording and sharing data across multiple data stores (also known as ledgers), each of which has the exact same data records and which are collectively maintained and controlled by a distributed network of computer servers, called nodes. Blockchain is a mechanism that employs an encryption method known as cryptography and uses (a set of) specific mathematical algorithms to create and verify a continuously growing data structure – to which data can only be added and from which existing data cannot be removed – that takes the form of a chain of "transaction blocks", which functions as a distributed ledger.

The first two presented definitions focus on the narrow application of blockchain technology in relation to the cryptocurrency market, but the next two suggest a wider use of it. All the definitions indicate the fact that blockchain is a technology focused on improving not only information flows, but also other types of flows, including material flows. The last two definitions emphasize the fact that the blockchain technology is the part of a broader technology – Distributed Ledger Technology. Solutions based on DLT are expected to find its application in very broad scope of economics (Swan et. al., 2019).

2.2. Multidisciplinary nature of blockchain technology

The multidisciplinary nature of blockchain technology, suggested in some of the definitions, is visible in literature, as well as business practice of enterprises from various industries. As a confirmation of the above claim, Figure 1 may be used to show potential areas of blockchain application in different economic branches (Zhang, Xue, Liu, 2019). On the other hand, Figure 2 aims to position the potential areas of blockchain technology application in a matrix, taking into account two dimensions: blockchain access and blockchain scope (Sultan, Ruhi, Lakhani, 2018). As shown in Figure 2, blockchain technology is used in a wide spectrum of areas of the economy, and there are many confirmations for this state in the literature (Bansod, Ragha, 2020; Zheng et. al., 2018; Mohamed, Al Jaroodi, 2019). The "access" dimension, indicated in Figure 2, is characterized on the basis of the answer to the question whether the basic function of blockchain is data processing (application) or its presentation (service); while the "scope" dimension is based on the question: is the access to a given blockchain public or private. Therefore, for the purposes of further considerations, it is necessary to distinguish two basic types of blockchains, according to the criterion of database access rights: private and public chains. A public data ledger (public blockchain) is available to everyone and allows all entities to analyze (read) ongoing transactions, as well as to submit transactions for writing within the network, while a private data ledger (private blockchain) is available only to selected participants, who have the right to inspect (read) the transactions made or can submit transactions to be placed in the block (EPRS, 2020). Therefore, as shown in Figure 2, the use of blockchain technology in relation to SCM requires the creation of a private blockchain, focused on data processing, which seems obvious from the perspective of the functioning of supply chains as structures operating dynamically and requiring continuous monitoring of flows inside it. The main features of blockchain can be very useful for supply chain applications: public availability makes it possible to trace products from the place of origin to the end customer, decentralized structure enables the participation of all parties in the supply chain and its invariable nature – based on cryptography – guarantees security (Tijan et. al., 2019).

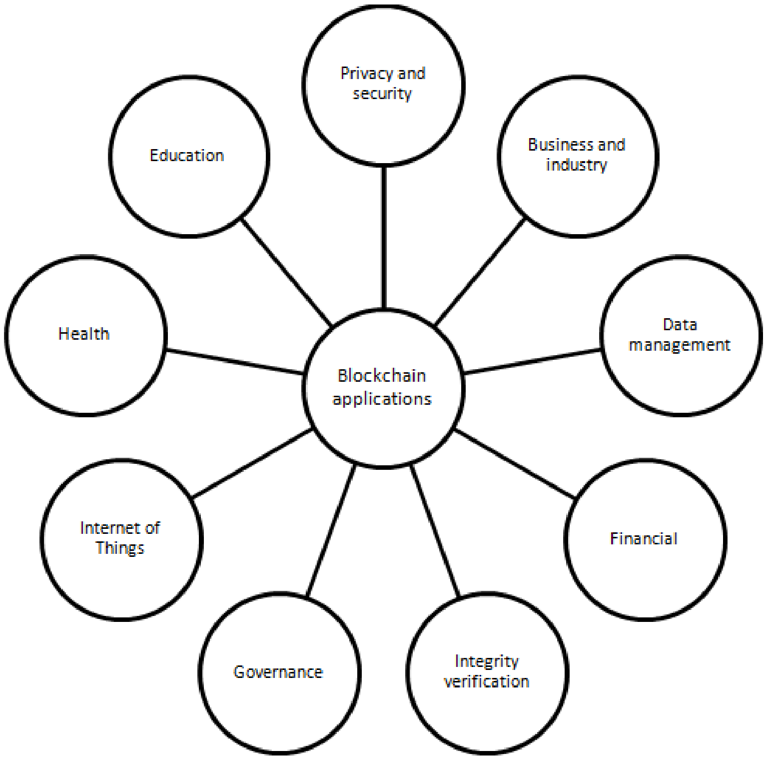

Figure 1. The areas of blockchain implementation in economics.

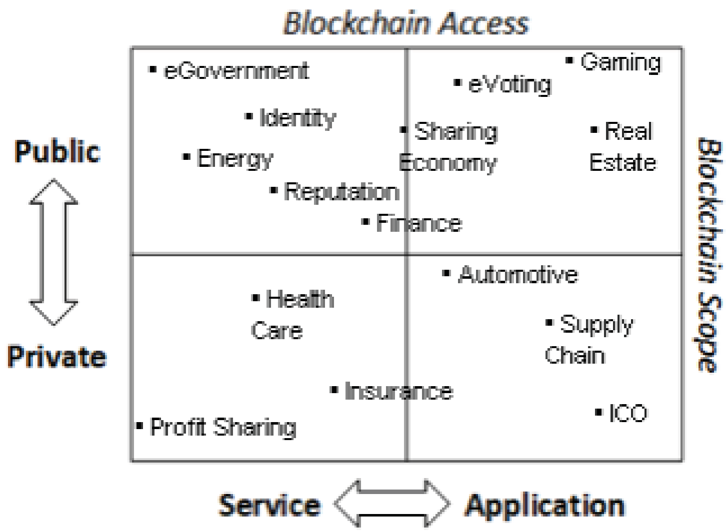

Figure 2. Blockchain Access vs Blockchain Scope matrix. Adapted from: (Sultan, Ruhi, Lakhani, 2018).

2.3. Blockchain technology and Logistics 4.0

The blockchain technology is also part of the currently discussed Logistics 4.0 concept, which is a concept supporting Industry 4.0 processes, from processing market requirements and production planning to delivering products to end users (Radivojevic, Milosavljevic, 2019). The solution to these problems is, in the opinion of the authors of the concept, digitization of activities and logistics processes. The main features of digitization of logistics systems are (Kayikci, 2018):

- Cooperation – digitization enables the creation of virtual logistic associations (clusters), through which companies exchange data and information.
- Connectivity – digitization enables horizontal and vertical integration in supply chains and visibility of information in all links of the chain.
- Adaptability – the connected digital assets system is flexible, as it can respond to various changes in the market (requests, users, suppliers etc.).
- Integration – in the digital world, the integration of logistics systems is the process of physically or functionally linking different computer systems and applications to ensure coordination of logistic flows.
- Autonomy of objects – smart objects are increasingly appearing in the logistic systems, which have the ability to communicate and make independent decisions based on processing of their own data, as well as environmental characteristics.
- Cognition – the use of devices and systems to automate tasks requiring human skills, knowledge, perception and cognitive abilities (planning, reasoning and learning).

Most of the above-mentioned features are related to the blockchain technology, which – within the concept of Logistics 4.0 – is recognized as one of its key components and technologies. In addition to blockchain, elements such as wireless sensor networks, the Internet of Things, AGV systems, 3D printing, drones, cloud computing, Big Data, robotization and process automation, as well as augmented reality are mentioned in this context (Radivojevic, Milosavljevic, 2019).

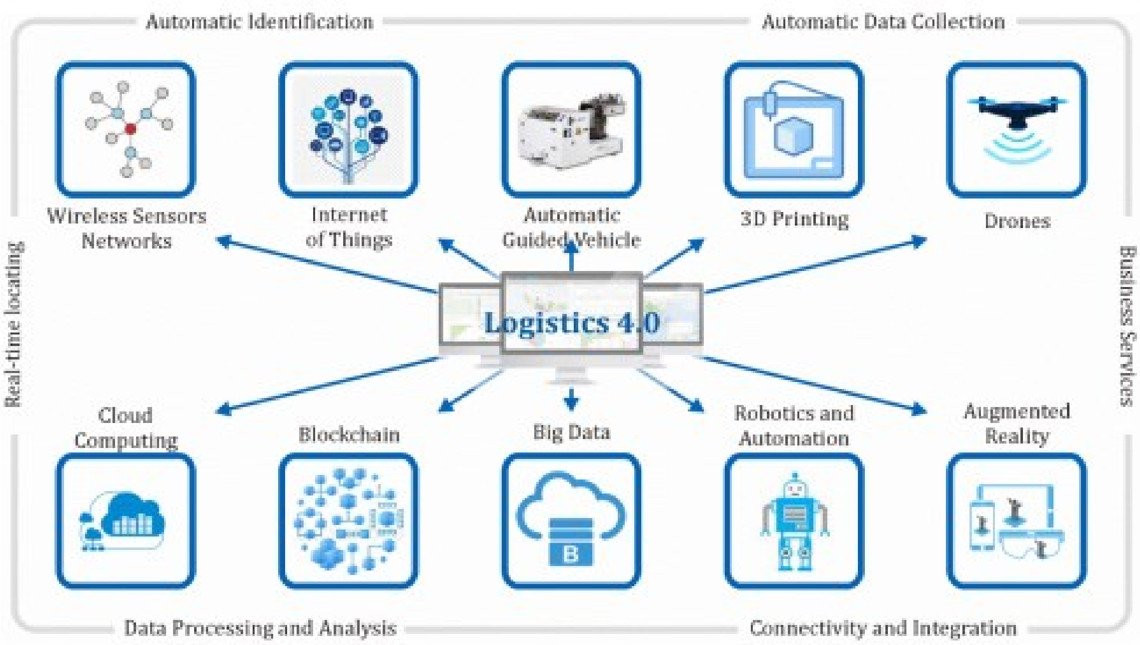

Figure 3. The place of blockchain technology in the concept of Logistics 4.0.

All of the solutions presented in Figure 3, which are components of the Logistics 4.0 concept, focus on issues such as: real-time location of goods, data processing and analysis, business services, automatic identification of goods or automatic data collection (Wang, 2016). The above-mentioned issues are the starting point for considerations contained in the further part of the article focusing on the areas of application of blockchain technology in logistics and SCM.

3. The areas of blockchain technology application in logistics

A logistic system, perceived as a comprehensive set of mutual relations between numerous stakeholders – such as producers of goods, importers, exporters, logistic companies, financial market authorities, operators of infrastructure hubs, government and territorial administration bodies or, finally, consumers of goods – is characterized by a huge spectrum of information flowing through this system and, thus, a huge amount of documentation is produced within it (EPRS, 2020). The vast majority of it is created and processed at individual stages of the flow within the supply chain – manually (Skiba, 2020). The use of blockchain technology could significantly automate these processes, while also maintaining a high level of security for their implementation (Szewczyk, 2019). Storing data on transactions between the links of the supply chain in a dedicated, private blockchain would provide full transparency of activities performed within the supply chain for its participants. The actors in a given supply chain would, thus, gain access to transaction data and the stage of its execution in real time. Other current problems, faced by modern supply chains, are indicated on the basis of (UNECE, 2019) in Table 2.

Table 2.
Modern key problems of supply chains

Problem	Explanation
Proving the origin of goods	Today, many transactions are made on the basis that the delivered goods are of the declared quality or origin. Currently, buyers do not have a cost-effective way to verify the authenticity of supplier's claims. This increases the dependence on long-term and large-scale contracts with established players and creates natural entry barriers for new and smaller suppliers – and this, in turn, harms real competition.
Customs delays	Customs and excise officials at each border rely on the provided information while making decisions. The ability of unscrupulous actors to alter or fabricate information increases the risk and distrust of the process. This risk and distrust then become delays, costs and uncertainties for all actors in the supply chain, who do not know whether they are good or bad players.
Poor transparency in supply chains	Some of the biggest inefficiencies in many supply chains are the time and effort required to gather accurate information on the location, condition and estimated time of arrival (ETA) of goods in the supply chain.
Supply chain resilience	When a supply chain breaks, it is often very difficult to recreate it in order to understand the root cause of problems. Being able to prevent and intelligently respond to these incidents has a huge impact on the costs and performance of enterprises, even outside the supply chain.
Errors in payments processing and auditing	Sometimes, an audit may not identify all potential discrepancies in the financial flows of the involved links in the supply chain.
Data-driven scams	Even the most detailed audits can overlook the signs of fraud hidden in thousands of data files. However, blockchain technology already enables today's supply chain players to reduce and more easily identify fraud attempts.
Dispute resolution	As with the supply chain resilience discussed above, disputes that arise due to time, quantity or quality could be more easily resolved, if reliable data on these (for example time and date of delivery) were recorded on the blockchain. In theory, some disputes could also be avoided by using a set of smart contracts that self-execute based on terms pre-agreed by all parties, thus reducing administrative costs and legal bills.
Information flow that ends at the point of sale	Under current supply chain arrangements, with the limited exception of warranty items, the supply chain ends at the final consignee. Contact with the product is lost and important information about its use is not recorded.

The above-outlined problems in the logistics environment seem to suggest the statement that it is possible to use the described technology for SCM in order to reduce the impact of identified problems on supply chains. Among the applications of blockchain in logistics and SCM, some sources indicate (Litke, 2019):

- Recording the flow of resources through individual links in the supply chain.
- Tracking orders, receipts, invoices, payments and any other official documents.
- Tracking digital assets (such as warranties, certificates, copyrights, licenses, serial numbers, barcodes) in a standardized way and in parallel with physical assets.
- Sharing information on the production process, delivery, maintenance and consumption of products between suppliers and sellers, introducing new opportunities for cooperation on complex assembly lines with the use of IoT.

In relation to other studies (Hackius, Petersen, 2017), 4 areas of blockchain technology application in logistics can be identified:

- Document processing/reduction of paperwork – global shipping of containers involves a lot of paperwork, which costs time and money. In addition, shipping documents are prone to loss, fraud and forgery.
- Identification of counterfeit products – counterfeit drugs are a growing problem in pharmaceutical supply chains. This is especially true in case of expensive, innovative drugs, such as cancer drugs. Pharmacies must sell the "right thing" to consumers.
- Facilitating traceability – food-borne outbreaks in the food supply chain are a challenge for retailers. They need to get a quick overview of where the food is coming from, as well as what other products were also involved in production and need to be removed from stores.
- Internet of Things support – logistics facilities are to be equipped with sensors that generate data in the supply chain – e.g. about the status of the shipment. This data must be stored in an unchanging, accessible way.

Documents summarizing the research conducted by the European Parliament Research Service (EPRS, 2020) indicate, in turn, four key areas of blockchain applications in relation to logistics:

- digitalization of resource exchange within the supply chain,
- cargo security in maritime transport,
- enforcement of trademarks and property rights,
- providing additional traceability and transparency in trade.

According to PwC report – Five Forces Transforming Transport & Logistics, PwC CEE Transport & Logistics Trend Book 2019 – the key applications of the discussed technology in transport and logistics include (PwC, 2019): automation of transport processes, product authentication, payment automation, tracking the flow of goods, digitization and automation of information flow. On the other hand, authors of a large-scale study focused on the implementation of blockchain technology in both the academic and business dimensions indicate that, in both of them, there are certain useful properties of blockchain technology or its application possibilities, such as traceability, anti-fraud capability, trust management, IoT transparency and integration (Gonczol et. al., 2020). As a result of the analysis of the currently developed projects, based on the blockchain technology, and referring to the areas indicated above, a list of 26 commercial applications was prepared (Table 3) with an indication of the areas to which they relate.

Table 3.
Selected commercial examples of logistics support applications based on blockchain technology

ID	Example of application	Main areas of application	Source
1.	Accenture	-Reduction of paperwork -Tracking the flow of goods -Trust management	https://www.accenture.com/_acnmedia/PDF-93 /Accenture-Tracing-Supply-Chain-Blockchain-Study-PoV.pdf
2.	Ambrosus	-IoT support - Tracking the flow of goods	https://ambrosus.com/assets/en/-White-Paper-V8-1.pdf
3.	CargoCoin	-Reduction of paperwork -Trust management	https://thecargocoin.com/docs/CargoCoin-Whitepaper.pdf
4.	Cargowise	-Tracking the flow of goods -Identification of counterfeit products	https://www.cargowise.com/
5.	CargoX	-Reduction of paperwork - Tracking the flow of goods - Tracking digital assets	https://cargox.io/CargoX-Business-Overview-Technology-Bluepaper.pdf
6.	ePhyto certificate in the Port of Antwerp	-Reduction of paperwork -Tracking the flow of goods -Security of cargo	https://www.wto.org/english/res_e/reser_e/session_2b_1_nico_de_cauwer_v2.pdf
7.	Everledger	-Tracking the flow of goods -Identification of counterfeit products -IoT support	https://www.everledger.io/industry-applications
8.	Guardtime	-Identification of counterfeit products -Tracking the flow of goods -IoT support	https://guardtime.com/health/ef_cient-supply-chain-management
9.	Insurwave	-Trust management -Reduction of paperwork	https://insurwave.com
10.	Medildger	-Tracking the flow of goods -Security of cargo	https://assets. chronicled.com/2018-MediLedger-Progress-Report.pdf
11.	Modum	-IoT support -Reduction of paperwork -Tracking the flow of goods	(Bocek, 2017)
12.	NextPakk	-Trust management -Tracking the flow of goods	https://s3.amazonaws.com/nextpakk-assets/docs/pakka- icowhitepaper.pdf
13.	OriginTrail	-Trust management -Tracking the flow of goods -Automation of transport process	(Rakic et. al., 2017)
14.	PeerLedger	-Tracking the flow of goods -Security of cargo -Trust management	https://peerledger.com/food-industry
15.	PharmaTrace	-Tracking the flow of goods -Trust management	https://www.pharmatrace.io/
16.	Provenance	- Tracking the flow of goods -Identification of counterfeit products -IoT support	https://www.provenance.org/case-studies
17.	Riddle&Code	-IoT support -Trust management	https://www.riddleandcode.com/product-1
18.	Skuchain	-Reduction of paperwork -Tracking the flow of goods -Trust management	http://www.skuchain.com/ec3/
19.	Skycell	-IoT support -Tracking the flow of goods	https://www.skycell.ch/software.html
20.	SmartLog	-Tracking the flow of goods -Automation of transport processes	https://smartlog.kinno._/articles/project-smartlog-blockchain-logistics
21.	Sweetbridge	-Trust management -Tracking the flow of goods -Reduction of paperwork	https://sweetbridge.com/

Cont. table 3.

22.	SyncFab	-Trust management -Tracking the flow of goods -Identification of counterfeit products	https://syncfab.com/SyncFab_MFG_WP.pdf
23.	TradeLens	-Trust management -Tracking the flow of goods -Identification of counterfeit products	https://www.tradelens.com/solution
24.	Vinchain	-Trust management -Reduction of paperwork	https://vinchain.io/
25.	Walmart, Hyperledger	-Tracking the flow of goods -IoT support -Security of cargo	https://www.hyperledger.org/wp-content/uploads/2019/02/Hyperledger_CaseStudy_Walmart_Printable_V4.pdf
26.	Waltonchain	-IoT support - Tracking the flow of goods	https://www.waltonchain.org/en/Uploads/2019-04-25/ 5cc171763aebb.pdf

Table 3 presents a subjective list of commercial uses of blockchain technology in relation to logistics and supply chain management. For the purposes of this article, Table 3 shows only the areas, to which individual solutions relate, while their broader characteristics can be found on the websites of individual applications (see "Source" column). As it is visible in Table 3, the presented solutions focus on a few key areas mentioned in previous parts of the article.

4. Conclusion

The blockchain technology based on the Distributed Ledger Technology, despite its common association with cryptocurrency markets, appears to be highly multidisciplinary. In today's market economy, numerous applications can be found in a wide spectrum of fields. One of them is undoubtedly the broadly understood logistics. This article emphasizes the fact that the described technology fits into the concept of Logistics 4.0, emphasizing the attributes of digitization of logistics systems. The author of the article also synthesized data from a number of reports of various types of institutions researching the implementation of blockchain technology in business, as well as the latest scientific publications, in order to prepare a non-exhaustive collection of areas of application of the blockchain technology in logistics and supply chain management. The future scientific task for the article author will be to focus on the problems and limitations of the implementation of the discussed technology in the logistics environment, and to conclude with a proprietary set of conditions that must be met by organizations interested in effective implementation of blockchain technology in its entirety or part of its business activity. These conditions will be the starting point for the preparation of a detailed set of recommendations and guidelines in the scope outlined by the set of conditions.

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