Blockchain Applications in Supply Chain

Davor Dujak and Domagoj Sajter

Abstract Blockchain is a technological concept which evolves from the first cryptocurrency, Bitcoin, and disrupts constantly enlarging areas of economy. The concept of blockchain is developing, and while the future of Bitcoin remains unclear (as it is for the most elements of the economy) it is evident that the blockchain holds enormous potential for large-scale improvements. However, being a technology that could decrease significance many of today's large global corporations, institutions and power structures which have keen interest in preserving established hierarchies, its potential could well remain unexploited. This paper aims to introduce and present the concept of blockchain and its current applications in logistics and supply networks. Blockchain technology promises overpowering trust issues and allowing trustless, secure and authenticated system of logistics and supply chain information exchange in supply networks. The new implementations within supply chain are shifting from blockchain to a wider notion of distributed ledger technologies. Paper presents description and rationale behind current and possible future applications of blockchain in logistics and supply chain.

Keywords Blockchain · Cryptocurrency · Distributed ledger · Supply chain Logistics

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1 Introduction

The financial crisis of 2008. fuelled determination of a group of activists to develop a stable, decentralized, autonomous and sustainable financial system, one that would not be under the influence of individual "too big to fail" institutions—moreover—one that would not be under the influence of *any* institution whatsoever. The loss of trust in financial intermediaries which privatized profits but socialized losses motivated tech-savvy enthusiasts to employ internet as by now matured innovation, and significantly powerful (yet affordable) home computers in novel ways. Bitcoin as both payment system and fully digital currency was the first cryptocurrency launched in 2009. Two years later first alternative cryptocurrencies emerged, while at the beginning of 2018 there were more than 1300 of them, beside almost 500 tokens.[1]

One of the Bitcoin's main contributions is the technology of blockchain—its underlying architecture. The concept of blockchain is evolving, and while the future of Bitcoin remains unclear (as it is for the most elements of the economy) it is evident that the blockchain holds enormous potential for large-scale improvements of many different areas of economic system. However, being a strongly disruptive technology that could bring down many of today's large global corporations, institutions and power structures which have keen interest in preserving established hierarchies, its potential could well remain unexploited.

Blockchain has found its applications and is under development in logistics and supply chain activities as well. Radio-frequency identification (RFID), telematics, barcode and 2D codes, sensors-enabled technologies, Internet-of-things (IoT) and numerous other technologies are used for tracking products through supply chain. However, until recently their true potential was not fully exploited as the underlying data was available only within an institution—a company, or perhaps exchanged with limited group of trustworthy partners. Typically, there are numerous supply chain members each with their own information systems, but communication between these systems is limited at best. The main barrier was (and still is) the lack of trust in exchanging information. Blockchain technology promises overpowering trust issues and allowing trustless, secure and authenticated system of logistics and supply chain information exchange in supply networks. Based on these features and blockchain development in general, the pace of new implementations within supply chain is accelerating rapidly. Pilot projects are launched worldwide and supply chain industry is expecting changes.

For majority of companies blockchain is still a mystery when it comes to its practical use in logistic and supply chain activities. This paper aims to introduce and present the concept of blockchain and its current applications in supply chain management. By presenting its characteristics, current applications and future

[1]Data from https://coinmarketcap.com (accessed 5. 1. 2018). Tokens are digital assets such as vouchers, debt instruments (IOUs), or real-world objects. They are mostly based on the Ethereum blockchain.

trends, the goal is to provide basic material for academics and practitioners when considering its application in supply chain activities. We attempt to answer following research questions: what is blockchain and how does it function? What are the key features of blockchain applicable in the supply chain and in which supply chain areas are currently being applied? What are future possible development directions for blockchain applications in supply chain?

Paper is structured in four chapters. After the introduction, the second chapter presents the current state of the progress in supply networks. Third chapter analyses the features of blockchain as it came from the cryptocurrency universe, while the next one presents its current implementations and advantages in supply chain and logistics. The fifth chapter concludes.

2 Supply Networks

According to Waters [46, str. 7] supply chain "consists of the series of activities and organisations that materials move through on their journey from initial suppliers to final customers". When organisations "actively (and collaboratively) manage activities and relationships in supply chain to maximize customer value and achieve a sustainable competitive advantage", one can talk about supply chain management, which represents "a conscious effort by the supply chain firms to develop and run supply chains in the most effective & efficient ways possible" [24], str. 8; [7], str. 8; Supply Chain Resource Cooperative, North Carolina State University [41]. Most important supply chain activities are new product development, sourcing, production, logistics, demand management, coordination and integration. In that sense, logistics is part (although biggest) of supply chain management (Vitasek and CSCMP [45].

Although normative logistics and supply chain management delve into the term of "supply chain", positive economics exhibits that all economic structures which provide products and/or services from the origins to the final consumer are shaped as networks, with numerous participants (supply networks members) on each level and multiple links between them. Therefore, the term "supply networks" (sometimes "supply chain networks" or "distribution networks") is more appropriate since it describes more complex spatio-temporal structures which emphasize the number, position, the nature of relationships, activities, business objectives, capacity, information services and technology base of its participants [33]. Figure 1 represents supply network shown from the perspective of manufacturer.

Supply network of a certain supply chain member (in this case a manufacturer) consists of supply side of network (or supplier network) and of demand side of network (or distributive network). Supply side encompasses all entities of the

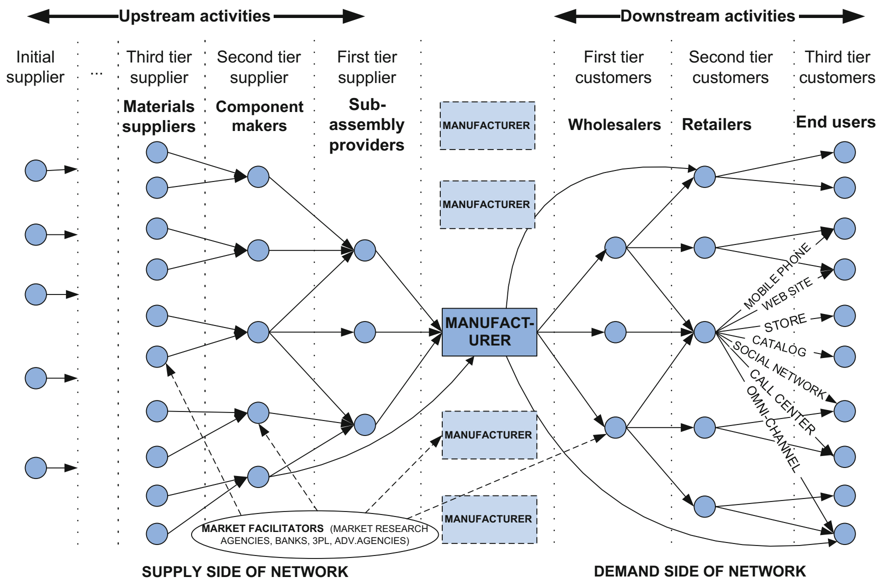

Fig. 1 Supply network around manufacturer. *Source* Revised according to Waters [46]

supply chain that provide inputs, either directly or indirectly to the focal[2] company. The demand side includes all supply chain members that the product passes through on its way to the end consumer [24].

Both supply and demand side of network consist of a certain number of tiers that represent certain supply chain echelons or levels. Conditional on its position in supply network, a focal company can have various tiers on supply and on demand side. Activities carried out on the supply side of the network are referred to as *upstream* activities, while those on the demand side are *downstream* activities. They all focus on improving the flow (primarily material, but also flow of information, services, finance, knowledge, energy, etc.) within the supply network.

Figure 1 also shows the diversity of choices of distribution channels which a retailer (or other member) can use to reach the end user. Moreover, many contemporary retailers simultaneously use multi-channel approach, and some use *omni*-channel retailing approach. Omni-channel retailing is unified and integrated customer-centric experience that allows customers to shop through all possible distribution channels (tablets, smartphones, social networks, kiosks, stores, catalogues, call centres, etc.), at all times [29]. Today there is an increasing number of omni-customers—those that want to be able to buy anytime, any product, in all existing channels (that is, anywhere), through multiple channels at the same time or during the same purchase (e.g. examining the offer on a personal computer, trying

[2]Focal company (or company in focus) is supply network member from whose perspective is supply network (or supply chain) mapped.

out at a store, paying over a mobile device to avoid waiting in line at the cash desk, assessing the shopping experience through social networks after the goods were delivered home). In principle, the needs of omni-customers have not changed, but they are now met in new ways, mostly by using information and communication technology (ICT) that also causes changes across the entire supply network. The arrival of omni-customers coincides with the increased need for visibility and traceability in the supply network. Customers in general are constantly pushing new demands to the supply network members, and the customers' demand for feasible, simple insight into the origins of the product and its path through the supply chain has become increasingly common and companies cannot ignore it.

Successful performance in supply networks requires ensuring proper supply network design and continuous optimization of processes that occurs within. Design of the supply network is primarily a strategic, long-term concern. Therefore, when designing a supply network it is necessary to ensure that the supply chain configuration is effective in relation to the expected conditions, but also robust and flexible to adapt to unexpected changes in the surrounding conditions [21]. Design of the distribution or supply network is a form of strategic planning aiming to maximize the economic effects over a longer period of time and also present the consequences of strategic decisions on tactical activities such as the optimization of transport [8, 21]. Facilities in supply network (factories, warehouses, distribution centres, stores) constitute its structure and influence its performance and cost at the same time. While adding facilities enables better customer service (shorter lead time, increased product variety and availability, improved customer shopping experience, increased visibility of supply chain order and increased product return capability), it also means increases in inventory holding and facility costs, and decreases in transportation costs [11]. Therefore, the goal of optimizing the design of the supply or distribution network is to find a trade-off between minimizing the total cost of holding inventory, warehouse costs and transportation costs, while satisfying customer demand related primarily to delivery time. Simply put, network is optimized, "when a minimum of distribution facilities that will meet the customer's response time is reached" [19, str. 188].

There are different approaches to process optimization in supply networks and supply chain management, but this paper focuses on utilization of ICT as the enabler of optimization. Many classifications of ICT in supply chain management exist (see Segetlija et al. 2011). ICTs are often categorized on the basis of its main purpose:

- ICT for data collection and rough processing,
- ICT for data analysis with the aim of making managerial decisions and
- ICT for data integration and exchange.

A challenge of this classification is that new and emerging technologies used in supply chain are now fulfilling more than one purpose at once. In latest report, Gartner [36] gives an overview of emerging technologies in 2017 and most important strategic technology trends for 2018 where such integrative technologies are emphasized; blockchain is emphasized as one of most promising technologies when it comes to logistics and supply chain optimization.

3 Blockchain: Underlying Structure of Cryptocurrencies

The blockchain is a shared, distributed, decentralized, immutable and secure data structure [35]. It is also a protocol for establishing consensus on *valuable information* within a flat network without hierarchy. The "valuable information" can be a transaction with proper authorizations, which is the case for the Bitcoin network, but it can also be some other digital asset, such as property rights. Blockchain can be used as a database, but also as a platform which determines protocols for establishing consensus without a central hub or any intermediary institution.[3]

As a fully digital currency built on the internet for the internet, a Bitcoin is inseparable from its blockchain. They can be regarded as different expressions of the same reality; the blockchain is the consensual database of input/output transactions, and a unit of Bitcoin does not and cannot exist regardless of it. On the other hand, the clever design of the first blockchain is taken from Bitcoin, and its spin-offs are propagated into those areas of economy where there are needs for trust, consensus, security, transparency, storage of value, etc.; one of them being supply networks.

Blockchain relies on encryption. Cryptography can be used to prove knowledge of confidential information without revealing that information, and/or to prove the authenticity of that information. It originates in mathematics, and as such it is employed as a foundation for establishing mutual trust because the clarity, transparency and precision of algebra leave no space for tampering or any interventions. In the cryptocurrency system trustworthiness must no longer be extrapolated from reputational history, tradition, expertise, institutional position or similar sources, but from (complex) mathematics that encrypts information within a virtually impenetrable "shell" of a code. This code can then be easily sent over the internet without fear of anyone making even minuscule modification of the confidential and valuable information content.

A Bitcoin can be defined as "a chain of digital signatures" [34, str. 2]. Within the first cryptocurrency network all communications are entirely transparent and non-encrypted; cryptography is used only for authorization purposes. Every single transaction input must be correctly authorized with a proper digital signature. In this manner a system is created where every communication (with the *money*—Bitcoins—being the substance of communication and sent via transactions) is visible to

[3]Intermediaries are not viewed "intruders" per se, but as entities which insert additional layers of costs into the price structure.

anyone, but only the owner of the private key[4] can unlock a transaction output (the address where at some prior point he received the communication—*money*) and use it subsequently as an input in a transaction, thereby redeeming (spending) it.

The crucial element of the arrangement is the algorithm of consensus. Reaching a consensus in a network where by definition a common starting ground is absolute absence of trust among participants, and where each partaker can be a malicious attacker using "insider" knowledge (with the open-source and transparent design), is achieved through controlled, gradual process governed by economic incentives, and through the design of the blocks [4].

The consensus about the rights to redeem information from the blockchain is established step-by-step, where in each step a block with pre-defined elements is constituted. A block contains[5]:

1. reference (pointer) to the previous block,
2. meta-data about the block content which contains the description about the internal structure of the data; a summary of all the transactions in the block[6],
3. the core subject—transaction data, and
4. a random number of specific length called *nonce*.

The four elements above produce together the fifth one: a partly-random value which will serve as a reference in the next block. The reference is partly-random because it is set up to be in a pre-determined interval, but within that interval it can take any value. That reference can be found only by trial and error: by searching through vast variety of nonces until the "winning" one appears. The "winner" produces the link of the current block which will be included into the next one, thereby making a chain.

Therefore, the work that needs to be done consists of:

- the verifications of transactions within a block (checking if the digital signatures are correct and if the user can rightfully redeem a previously received money), and
- finding a winning nonce.

The work is labelled *mining*, and the process is designed so that the miners need to bear hardware and electricity costs in order to be able to find a winning nonce. Their incentive is not grounded within their ideology, altruism, etc., but in new Bitcoins which are disbursed to the winner. Every time a block is found the miner gets rewarded with newly "minted" Bitcoins for finishing first, and the new race for the next block starts. Hence, the system is set up in a manner of a competitive

[4]Private keys are an unintelligible string of numbers and letters, thus not revealing the identity of the signatory to other parties in the network, which is another feature of the crypto-network.

[5]This is a simplification to an extent. The description of actual content of a bitcoin block can be found at [4].

[6]I.e. Merkle tree, a data structure used for efficiently summarizing and verifying the integrity of large sets of data [4].

market economy; the more a miner invests in his equipment and the energy that drives it, the more likely he is to find a nonce which proves that he actually did the work.[7]

To sum up (and simplify): mining is blockchain maintenance. It should be clear that a Bitcoin is just a piece of data in the blockchain which does not have any material backing, no underlying asset (not even hardware—memory chips, hard drives, processors—nothing) apart from the electricity spent to provide the proof-of-work. On the other hand, neither do fiat currencies possess real asset backing—they operate as currency because the governments declare them to be money using the historical heritage of paper money which was gradually established as valuable, but also through indolence of the society which accepts the paper as value without rigorous questioning. This provides that cryptocurrencies, albeit categorically virtual and non-palpable, in fact have *some* backing, and it could be argued that they have more backing than modern fiat currencies. In a digital world where electricity powers up all the computers and networks the most appropriate backing for a currency of the future is probably electricity.

Another attractive element of blockchain is its distribution. There is no single authoritative blockchain, no master-node (central server), and no one that controls rogue behaviour. The protocol—predetermined set of rules written in the program code—is the "custodian". Every node can have a complete transaction history[8] which it builds upon and shares among others. This dynamic of sharing the same vision, same protocols, same code and blockchain, but at the same time also competing for new currency through mining, is what gives Bitcoin its resiliency and antifragility.

Altogether, the aforementioned features characterize blockchain technology as a tool for building trust in a network where elements have no other means to establish it. Since the trust is at the core of all financial systems, building trust could be boiled down to building value; since value is money the circle is complete.

3.1 Evolution of Blockchain

The code of the first blockchain (Bitcoin) is open-source, meaning that it is free to use and anyone can see what is behind it and improve on it (given the knowledge and creativity). Anyone can use its architectural concepts and try something different with it, expand features, tinker with the specifications and launch a

[7]The question is: searching for a nonce is hard work and costly, but is it meaningful? Pushing the computer to the maximum speed to find an absolutely random number, of what use is that? The use is in providing an existential meaning to money in a digital world. Something cannot come from nothing; digital money cannot be borne out of thin air, from the cloud of zeros and ones. It is "minted" in a computational contest among the competitors which race to verify the contents of the blocks in the chain and to arrange the blocks in a meaningful manner.

[8]In bitcoin that is approx. 150 GB of data, in January 2018.

completely new currency, or fork the original and evolve. This, naturally, opened a vast new space of cryptocurrencies with ever expanding population of designs and users.

The first blockchain was designed to be a transaction protocol and a payment system, and as such its scripting language is intentionally limited: there are no loops or complex capabilities. Every instruction in the Bitcoin code (scripting language) is executed only once, linearly. This ensures that scripts have limited complexity and predictable execution times which is in computer science dubbed as non-Turing-complete[9] programming language. This also means that Bitcoin cannot execute powerful functions that could have infinite loops, which is a security feature intended to protect Bitcoin from malevolent or negligent participants who could otherwise block the network.

However, having an (fairly small and restricted) amount of free space within its data structure, Bitcoin programmers developed applications that could use this space. Although intentionally limited, Bitcoin protocol is not confined to naive input-output transactions; it can convey instructions regarding the transactions such as locking the cryptocurrency for a custom period, and/or requiring multiple signatures for authorization of spending an amount.

Building upon the ideas of first blockchain the developers of what could be called the next generation of blockchain introduced a network—Ethereum—with wider capacity of features. Ethereum's primary innovation was to expand Bitcoin's set of instructions into a fully-featured, Turing-complete programming language. Ethereum is built as a blockchain network which can run different kinds of decentralized applications ("ĐApps" or "dApps"). Even though a precursor Bitcoin could therefore be regarded as a special case of restricted blockchain application, specialized exclusively for transactions (a payment system). A "decentralized application" is sometimes used as a synonym and/or in parallel to "smart contracts". A decentralized application is a server-less peer-to-peer application which runs on a blockchain such as Ethereum, while a smart contract is an agreement written as an algorithm, directly into a code which can be invoked by a decentralized application.

Another innovation of Ethereum are its "sub-currencies". The cryptocurrency of Ethereum is named *ether*, but there are also dedicated *tokens*—sub-currencies (approx. 500 of them) which are used to power specific applications. ERC20 is the standard which defines the characteristics of all Ethereum tokens.

Interventions into the original design of the blockchain bring new features, but does not make newer blockchains necessarily superior [20]. By adding complexity to the protocol Ethereum presents a wider array of points where network-attackers can try to enter or extract data from the blockchain.

[9] A programming language is said to be Turing-complete if it can be used to simulate any Turing machine. Turing machine is able to answer any computable problem given enough time and space. The early computers were dissimilar machines because different machines were built for different programs. Mathematician Alan Turing created "Universal Turing Machine" that could take *any* program and run it. Our personal, home computers are universal machines, and they can be used for any program and solve every problem, given enough time and space (memory).

3.2 Types of Blockchain

From the original and still the largest blockchain the idea spun out into the economy encompassing many different designs. At the present point the concepts of blockchain could be categorized in three groups:

1. permissionless,
2. permissioned and
3. private blockchains [37].

Permissionless blockchains (such as Bitcoin, Ethereum, etc.) are decentralized, institutionless, fully public peer-to-peer networks where any member can join without needing a permission from other members.

Permissioned blockchain is similar to the notion of a federation, where a consortium of members permits entrance to new members only with the approval of the existing members. A node needs permission to become a part of the network, as there are barriers to entry in the exclusive club.

Private blockchain is the one where write and/or read permissions are kept centralized to one organization, and as such are disputed to be categorized as blockchains. Furthermore, if we define blockchain as a distributed, decentralized protocol-structure within a flat network without hierarchy, then even the federated, permissioned blockchains cannot be regarded as blockchains.[10] This explains the introduction of a wider concept—the term "distributed ledger technologies" (DLT) which encompasses broader variations of the original design.

Another element of discussion and disagreements is the possibility for the blockchain participants to conspire. One or more elements of the network can try to record false or counterfeit transactions in the new, upcoming block[11] and try to propagate it through the network, but they would need to have the majority of the network (51%) on their side for this attempt to be implanted in everyone's copy of the blockchain. In a permissioned blockchain with few participants it is relatively easy to form a cohort with 51% of votes. That means that the participants would need to trust each other in order not to associate in a >51% pool, but if they trust each other, then the question is do they need blockchain design in the first place. If the inner circle (within the permissioned blockchain) is built from members who trust each other this erases the blockchain's proposition as a trust building mechanism in a trustless network; when members within the network are confident in the behaviour of their peers (hence disallow outsiders to join) it is a question if they need a blockchain, or some version of "distributed ledger technology" would suffice. A permissioned blockchain could be reduced to simpler solutions such as a

[10] A case which affirms this position is the introduction of federated blockchain-based technology which replaces the previous clearing system on the Australian Stock Exchange, which is dubbed as "distributed ledger technology", but not as a *blockchain*.

[11] They cannot easily change previous blocks, especially those deeper in the chain; every intervention would be seen because all the subsequent blocks would not have a valid reference.

shared spreadsheet, saved online (in the cloud), with dedicated password for opening and for modification of the content, and with change log[12] [20].

There are numerous open roads with possibilities for further development of blockchain design, with new ones being unveiled regularly. Along with the blockchain the concepts of **side-chain** and **off-chain** emerged.

Sidechains are blockchains with different features from the original blockchain (main chain, usually Bitcoin), which—as the name suggests—are used side by side, in parallel with blockchain, thereby expanding functions and applications of the mainchain.[13] Sidechains are typically connected to the main chain via a two-way peg. A two-way peg is a method of "transferring" Bitcoins from the mainchain to a sidechain; an amount is first locked on an address on the main chain and then activated on the secondary chain. Sidechains are enabled by the more complex Bitcoin functions such as locking script (which "freezes" an amount for a pre-specified time, or until a condition is met) and multiple signatures script (which requires multiple signatures in order to spend an amount).

Off-chain designs broaden the uses of the blockchain by setting up networks which operate certain functions within the blockchain concept, but localizing certain operations away from the blockchain. The Lightning Network is a Bitcoin off-chain protocol where a collateral is made at the opening of the communication channel, and where mutual transactions are recorded locally (not on the blockchain). Only the final transactions, after settlement, are recorded on the blockchain. In a case of dispute a collateral can be taken to indemnify the damaged party. In this way subjects can theoretically have millions of Bitcoin transactions per second for longer periods, but only the final positions are "reported" on the blockchain.[14] The Raiden Network is Ethereum's version of Bitcoin's Lightning Network; an off-chain solution for performing ERC20-compliant token transfers on the Ethereum.

4 Blockchain in Supply Chain

Use of blockchain technology in supply chains and supply networks is fairly new in scientific considerations as first academic scientific papers with this topic appeared in Web of Science and Scopus databases in 2016 [42], and significant growth occurs during year 2017. Based on results of searches in three widely used scientific databases (Web of Science Core Collection, Scopus and EBSCOhost), as well as in the freely accessible Google Scholar it can be concluded that blockchain occupies

[12]Google Sheets and Microsoft Excel with Onedrive offer these for free.

[13]Rootstock is a platform for smart contracts in parallel blockchain with Bitcoin (a Bitcoin sidechain), and in this was an alternative to Ethereum.

[14]This could be used for arbitrage between exchanges which could stabilize the price of Bitcoin.

Table 1 Frequency of scientific papers and articles regarding Blockchain and supply chain

Searched term	Article repository			
	Academic databases			Google Scholar
	Web of science[a] (searched within: topic)	Scopus (searched within: article title, abstract, keywords)	EBSCOhost (searched within: title)[b]	
Blockchain	372	787	4.273	16.100
Blockchain and supply chain	**14**	**36**	**70**	**2.870**

Source Authors' search in Web of Science Core Collection, Scopus, EBSCOhost and Google Scholar databases, conducted on January 15th 2018

[a]includes databases of Web of Science Core Collection

[b]includes following databases: Academic Search Complete, Business Source Complete, Inspec, FSTA—Food Science and Technology Abstracts, SocINDEX with Full Text, CINAHL with Full Text, Regional Business News, MasterFILE Premier, Newspaper Source, Library, Information Science & Technology Abstracts, GreenFILE, GeoRef, GeoRef In Process, PsycINFO, PsycARTICLES, eBook Collection (EBSCOhost), CAB Abstracts, EconLit

considerable attention, while its use in conjunction with supply chain is significantly less investigated (Table 1).

Blockchain as a technology in logistics and supply chain is in its developing phase. Even now, it is mostly in the form of tests and pilot projects in many private and public companies, industrial associations (e.g. The Blockchain in Trucking Alliance), followed by or in collaboration with blockchain labs at almost all prestigious universities in the world (e.g. MIT, Columbia, Duke, Berkeley, Cambridge, Cornell, etc.). On a macro level distributed ledger technologies and their uses in supply chain gained considerable attention. Government of the USA recently established an open-source tool for developing and testing blockchain technology services for government, and for public purposes as well [43]. The China Federation of Logistics and Purchasing, the leading logistics association in China, established its own Blockchain Application Subcommittee with main goal of developing standards for blockchain technology [9]. Similar organization are operating in Russia (Russia Blockchain Consortium), Netherland (Dutch National Blockchain Coalition) and many other developed countries.

There are two main characteristics of blockchain technology that are important for its implementation and meaningful use in logistics and supply chains/supply networks (Fig. 2):

- secure, verified, trustable exchange of information through blockchain in real time that makes them accessible to all members of supply network or to anyone else (depending on the type of blockchain),
- possibility of automatic verification and execution of agreed transactions when certain requirements are met through smart-contracts—applications that are living on blockchain [12].

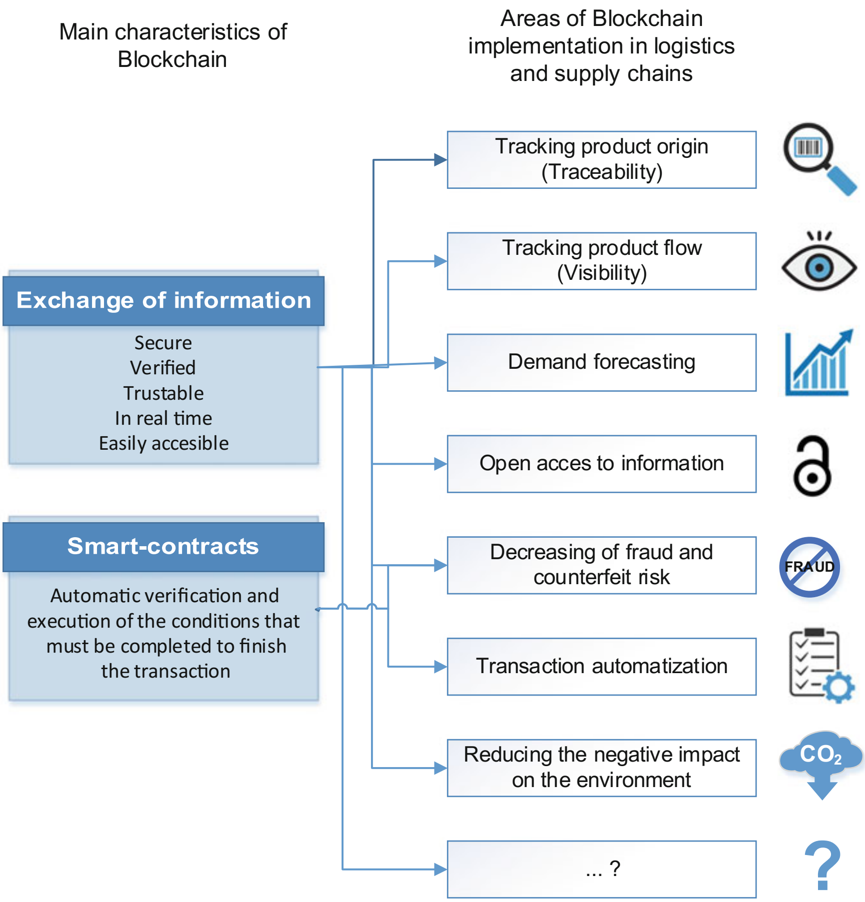

Fig. 2 Characteristics and implementation areas of blockchain in logistics and supply chain. *Source* Authors

Based on these main features of blockchain, implementation areas for its use in logistics and supply chain are being developing in various directions. Some of the most important current implementation areas of blockchain in logistics and supply chain are (Fig. 2) tracking product origin as well as tracking product flow through supply network, demand forecasting, decreasing of counterfeit and fraud risk, open access to information in supply chain, reducing the negative impact on the environment and transaction automatization through smart contracts. In many cases, implementation areas of blockchain are combined in supply chain management, and blockchain is simultaneously used for example for tracking product origin and flow, but also for decreasing fraud risk and more accurate demand forecasting.

A recent study by Hackius and Petersen [23] examined blockchain use in logistics and supply chain management industry on a sample of 152 logistics experts (from consulting, logistics services and sciences; from Germany, United States, Switzerland and France). The results show that companies are still hesitant to dedicate resources for possible blockchain applications. For research purposes blockchain use in supply chain was divided in four areas (use cases): easing paperwork processing, identification of counterfeits and products, facilitation of origin tracking and operationalization the Internet of Things. While in all areas blockchain is evaluated to offer considerable benefits, probability of adoption receives lower ratings than the benefits. Highest benefits are expected from easing paperwork processing. Another focused survey [14] on 42 supply chain management professionals found low level of blockchain awareness between them (this with low level of understanding is also main barrier for implementation), and tracking product moving through supply chain as most likely use for 80% of them. As a main advantage of blockchain improved supply chain visibility and transparency was recognized.

The following paragraphs describe prominent implementations of the blockchain in logistics and supply chain, as well as noticeable examples of practices around the world.

4.1 Traceability and Visibility Enhancements

So far, the most widespread implementation of blockchain for supply chain purposes is in process of verifying origin of product (mostly place, time and who made it) and information about path that products passes from its place of origin all to the way to final consumer (or just from any supplier to any consumer). Questions of traceability and visibility have always been key issues in providing high logistical service to customers. Possibility of providing information where the product is really coming from, who made it, where it was transported, by who and how, or just simply where it is now, is of high value for all customers and true competitive advantage for a company which provide it. On one hand, these information allow better planning and synchronization of customer's processes, leading to further optimizations in operational way. On the other hand, most companies or individuals acting as customers don't really know what is actually happening with products upstream in supply chain, and because of lack of transparency they are actually making less accurate assessment of product's value and are raising questions like: Are these apples really organic? Is this product manufactured truly without children labour? What are true number behind this car's pollution characteristics? Blockchain has ability to provide reliable information to customers concerning product origins and freight route for improved product evaluation before making a decision.

To increase tracking of product origin and way through supply network, blockchain technology is commonly used in pairs with radio frequency identification technology (RFID)—transponders (or tags) on products that carry different product information and are read (or written on) in contactless way through radio waves imitating by different “scanners”. The need for use of RFID with blockchain technology (especially in manufacturing supply chain) is highlighted by Abeyratne ands Monfared [1]. RFID system provides the fastest form of non-contact transfer of product information into a digital format—from a product to a computer, or from a computer to a product. It allows you to read information from a large number of products simultaneously, and can record new information on them. The capacity of the information to be written to (depending on the size of the memory chip in the product tag) can be significantly higher than in currently most widely-used product labelling approach—barcode technology. It can include information on origin, place of origin, time stamps, who was responsible for certain activities at generation and distribution, mode of production, places, route and modalities of transportations, temperature of transportation, time constraints of each activity, etc. When RFID started to be used in connection with different sensors on products (e.g. for moisture, movement, temperature, sound, vibration, force, magnetic, acceleration, optical, chemical/gas) and collected information were exchanged through Internet, Internet of Things (IoT) was developed. However, the question of authenticity, verification and security of collected and exchanged information remains insufficiently resolved and regulated. And there comes the blockchain. When the information are collected and transferred to a digital format, blockchain technology enables the verification of this information and entering into a shared distributed ledger, which is complemented and verified in real time. Blockchain provides a form for supply chain mapping [17] and a secure information exchange platform. Data types that are entered in blockchain may be similar to those that are collected by RFID technology, as well as additional data such as environmental impact data, additional processing data or analysis through which the product has passed. The advantage achieved by writing and exchanging with blockchain technology stems from equal visibility of activity and product location information for all members of the supply network and the fact that this information is reliable, secure, authentic and verified only by the members from the supply grid that are authorized to provide them, and no one else can subsequently change it. Other option is to use permissionless blockchain in which case this information become available to any interested party.

Secure product origin tracking complemented by blockchain technology has find its implementation possibilities in many industry, and mostly in food supply chains. Food product and ingredients tracking has special importance when food poisoning, diseases or other forms of contaminations occurs. Blockchain enables much faster and accurate identification of point of origin of problem, followed by recalls and other measures. It is special challenge for food and fast moving consumer good (FMCG) retailers who has to provide all traceability connected information for their customers but almost never have full view of what is happening in upstream part of supply chain. Companies like Walmart, IBM and its partners work on developing standards and solutions for greater safety of food in whole food supply chain by testing tracking and tracing food like pork or mangoes from China to United States. According to Walmart, blockchain supply chain tracking of mango reduced the time it took to trace a package of mangoes from the farm to the store from days or weeks to two seconds [27]. But even if everything functions well, information about food journey can help supply chain members to better prepare for shipment delivery resulting in faster operations and shorter lead time to consumers. Further, consumers have more time to enjoy in product consumption and feel more confident in product that they are eating. Tian [42] has developed an agri-food supply chain traceability system, based on RFID & blockchain technology where RFID serves for implementing data acquisition, circulation and sharing while blockchain technology is used for guaranteeing that shared and published information is reliable and authentic.

Companies from automotive industry (Toyota, Volkswagen, General Motors) are also considering a blockchain technology in different supply chain areas from additive manufacturing to tracking auto parts from the point of manufacturing to assembly plants, but also in self-driving cars sector.

Use of blockchain is not limited just to large companies and their collaboration with ICT giants like IBM. American agricultural conglomerate Cargill is testing blockchain technology to provide to consumers ability to trace the origin of their Thanksgiving turkey back to the farm [40]. Companies like Provenance specializes in developing software solutions powered by blockchain for product traceability and visibility. Provenance solutions enables every physical product to come with a digital 'passport' that proves authenticity and origin [26] *and* that can be tracked through blockchain. Such applications enable to all verified supply chain members to upload and or read information on blockchain as well as final consumers to easily read all this information about product online, in-store or on-pack. Through use of this kind of application, supply chain members insure competitiveness of their products among customers, but also better control of their whole supply chain. Just a simple QR code or RFID tag (on primary packaging of a product) readable by simple app on smartphone can provide access for consumers to all truly relevant data about product origin, processing, transportation, temperature, safety or quality that are inerasably recorded on blockchain. This way consumers have confident in what they're buying and can make true assessment of products quality and value, which ultimately contributes to the growth of loyalty to the brand and the company.

4.2 Improved Demand Forecasting

Demand management is crucial element of supply chain management based on its coordination and integration capabilities. Demand management is not only collaborative approach to planning demand in supply chain, but also includes tools for influencing the demand and supply, by which the demand and supply in the supply chain are adjusted to maximize the profits of the entire supply chain. Demand management in the context of supply chain management can be defined as the preparation of supply chain members for future events in the supply chain through coordinated efforts to forecast expected future demand, jointly influencing demand

and accordingly creating their supply [16]. Most authors agree that demand management consists of following elements:

- demand forecasting and planning,
- supply planning in accordance with demand, and
- collaborative influencing on demand and supply.

Transparency and simultaneously complete security (provided by blockchain) is the basis for successful and long-term information exchange necessary for demand management in the supply network. In a not collaborative managed supply chains there is the risk of losing information in the supply chain—whether they will be provided to competitors or information content will be changed? Therefore each member of supply chain derives their own demand forecast based on available orders from the previous member downstream in supply chain (his buyer) and these demands are called derived demands. This results in a large amount of safety inventory (increasingly rising upstream in the supply chain) which actually are added to the already secured safety inventories on earlier supply chain level. This creates an unnecessarily large amount of inventories in supply chain that financially burdens the chain, slows the material flow and requires unfavourable ways to deal with these excess inventories. This phenomena is called Bullwhip effect and was more popularized by Lee et al. [31].

Supply chain management theory and practice are based on collaborative demand management for avoiding bullwhip effects and optimizing inventory levels through supply chain. In theory all supply chain members (in practice more likely 2 or 3 connected members on different supply chain echelons or levels) produce one common demand forecast based on the data of the independent demand. In supply chains there is only one point of so called independent demand—*the amount of product demanded (by time and location) by the end-use customer of the supply chain* [32]. Either this end-use customer is B2B buyer or final consumer who buys from retailer, he is only one who creates true independent demand for certain products. All other upstream members of supply chain should create their own demand based on this independent demand and that will allow avoiding of multiple additional safety stocks on each new upstream supply chain echelon. Main prerequisite for this common (collaborative) forecast of demand is exchange of data about independent demand between all members of supply chain and main barrier and *crucial problem of contemporary supply networks is lack of trust* for exchanging information between supply chain members. Due to its highest level of system security (from its launch in 2008, Bitcoin's blockchain never "crashed", was never "frozen", nor it was ever hacked) blockchain directly enables solution to fundamental problems for suboptimal achieving of supply network coordination and integration. Savings are possible and can be realized solely on the basis of the belief that the information on original/independent demand is true, available in real time and will not be changed or delivered to competition. Depending on type of blockchain, certain information about independent demand will be accessible only to supply chain members with permission or to any supply chain member (and no one else can delete or change records without other's permission). This way blockchain is becoming *a global system for mediating trust and selective transparency* [10]. Use of blockchain changes a nature of trust. In this trustless network, trust is not connected to a person or a company, but *the burden of trust is within the system ... trust is built in blockchain* [13]. It comes to using the same database without the need for personal confidence—because everyone has the ability to monitor and check the chain for themselves. Buy leaving a problem of trust a side, there is open road for increasing information exchange and trade itself in supply networks. At the same time, even this new trust concept is not taken for granted and therefore trust evaluation models to evaluate enterprises' joint credibility and association credibility under blockchain environment are developing [47].

Additionally, final customer (and/or consumer) could connect to an blockchain-based application, and thus become a "true" member of supply chain with rights and possibilities (finally) to directly express his opinions and needs. Feedbacks from customers could be coming in real time, enabling more accurate forecasting, and radically changing production and retail landscape.

4.3 Open Access

Depending on type of blockchain information/records on blockchain could be available to everyone or just to limited number of participants on distributed ledger. This open access to information in supply chain can provide benefits like ease of paperwork processing, reducing the number of needed direct communications and providing more information to final customer and/or consumer.

When it comes to logistics and supply chain, open access benefits are most recognized in areas of transportation. Maersk and IBM have been developing for some time cargo tracking applications (primarily for containers), as well as application for digitalization of the entire international trade. They started open broad cooperation (with other participants like Microsoft, DuPont, Dow Chemical, Tetra Pak, Port Houston, Rotterdam Port Community System Portbase) from June 2016 enabling container shipping and connected data on blockchain to interested party [28], primarily to insurance companies and banks but as well to all supply chain members, through whole time of goods traveling and by that reducing costs of insurance. At the beginning of January 2018 they announced intention for establishing of global trade digitization platform [44], with tamperproof repository and secure transactions built on open standards of blockchain and designed for use by the entire global shipping ecosystem. Maersk states example when they tested shipping of container of flowers from Kenya to port of Rotterdam requiring around 200 communications between connected organizations during which many waste, spoilage and defects is happening. They also tests international shipments of mandarin oranges from California and pineapples from Columbia. It is estimated that processing of documents and information for container shipments can cost as much as the physical transport itself [44]. By involving all participants of information and material flow into blockchain application and by creating digitized document workflow they managed to ensure all documents and activities in supply chain to be available and visible to every partner, supported with information about who, where and when issued them or move the goods. This decreases the need for domestic and international direct communication, avoids mistakes, waiting, and other forms of waste, and ensure significantly faster information transactions and indirectly faster material flows in supply chain. All information becomes decentralized available reducing delays and various forms of fraud. Main benefit would be accurate and real-time information about the disposition of shipments for ports, terminals, ocean carriers and intermodal transporters allowing them more efficient preparation and planning for their own activities and end-to-end visibility in supply chain activities. According to Marine Transport International estimation blockchain could save $300 per only one container in terms of labour and documents processing [22]. As around 70 million containers are shipped in world every year [3], savings could be considerable. IBM’s and Maersk’s goal was to start capturing data from 10 million containers by the end of 2017. Additionally, blockchain could help in better optimization of empty containers use through wider access of its availability at nearby ships or ports [15]. Two biggest European port (Rotterdam and Antwerp) have also recognized potentials of blockchain [18]. In future, blockchain will probably extend significantly to other transport modes as well, where it can be paired with some type of existing telematics technology for more secure and transparent exchange of information regarding fleet management.

The use of BC technology in the supply chain can contribute to the more environmentally friendly behavior of both companies and consumers. Most obvious advantage is decreasing of need for paper form documentation enabled through open access and decreased number of online communications and transactions. Additionally, after the lifetime of the product, trustless information about its production and use stages (lifecycle records) can enable more efficient recycling, (re)manufacturing and leasing of existing products [26]. Finally, by tracing carbon footprint of a product using blockchain it is possible to give appreciation to ecologically successful companies and their products, or to penalize the opposite ones. This could be done through charging higher carbon tax or just giving reliable information that will allow consumers to choose not to buy products with higher carbon footprint. Open access to data about products can also significantly increase consumer’s trust in it and, as earlier mentioned, can be combined with traceability features of blockchain.

4.4 Fraud Prevention

Verification of authenticity and origin, as well as open access to these data can be strong weapon in combat against fraud and counterfeit products. These blockchain features are especially used in pharmaceutical and luxury jewellery industry.

In pharmaceutical supply chain there are many instances through which medications pass (raw materials suppliers, medical institutions, manufacturers, repackagers, wholesalers, logistics companies, retailers, and patients) and blockchain could help managing such complex supply chain by ensuring medicines visibility and proper reaction in case of need for recalling medicines if problem arises. But still the biggest issue are counterfeit medicines—pharmaceutical market is world's largest fraud market with sales of counterfeit medicines ranging from US $ 163 billion to $217 billion per year according to *PricewaterhouseCoopers (PwC)*—this is especially connected with online purchase of drugs for which the World Health Organization estimates that 50% of the drugs on the Internet are fake [6]. Therefore, pharmaceutical serialisation (prescription drug labelling system for authentication through supply chain from manufacturer to consumer) is practice that becomes mandatory in almost all developed countries—from 2019 will be mandatory in European Union as well (Commission delegated regulation EU 2016/161). Using blockchain as distributed ledger with records on medicines and its origin simplifies serialization and has a potential to significantly decrease this fraud. Consumers could be enabled to choose medicines based on true and verified information from blockchain and to avoid unaware risk for their health arising from use of fake medicines.

Similar combination of blockchain use for traceability and fraud avoiding can be noticed in luxury jewellery industry. Company named Everledger has recognized this need and intents to make the diamond supply chain more transparent, and consequently to reduce fraud, black markets and trafficking. They take 40 metadata points that describe a diamond (e.g. serial number, colour, carats, the cut, the clarity, angles) and they digitally secure records about them on blockchain with linkages to the laser inscription on the girdle of the stone. So far they uploaded 1.6 million diamonds on blockchain platform [39]. Their services are mostly used by insurance companies, banks and open market places in transaction authentication process, and they started to expand their business concept to other luxury goods such as precious wines and artworks.

Increased availability of new technologies usually increases possibility of frauds as well. This is also case with different types of additive manufacturing technologies that allows almost anyone to manufacture individual parts of questionable quality. Kennedy et al. [30] proposed an anti-counterfeiting method coupling lanthanide nanomaterial chemical signatures with blockchain technology for producers and end users to verify authenticity and quality.

4.5 Transaction Automatization

Smart contracts are actually already incorporated in all previously mentioned areas of blockchain use in supply networks and logistics. The main advantages of self-executing transactions on blockchain (smart contracts) are that there are no need for third party (e.g. bank, lawyer or broker) to act as intermediary, and therefore the transaction itself is much faster (especially important for supply chain and logistics) and cheaper, with less possibilities for errors and disruption in execution. Contract in a shape of rules that must be met are embedded in digital code, stored and secured. To create such kind of smart contract, participants in blockchain has to agree about rules as they could be later changed only based on new agreement of them all. Although still mostly in testing phase, in logistics and supply chain management is expected that smart contracts on permissioned blockchain will find its long term place in near future. Bellow will be explained few more complex smart contract applications in logistics and supply chain that are mostly in experimental phase.

In Finland, organization Kouvala Innovation works on experimental approach to connect pallets with shipping tasks, and willing carriers. Pallets are equipped with RFID tags and they communicate their need to be transported to potential carriers on blockchain platform. When best carrier's offer for asked transportation (through mining application) is aligned with requested conditions (price and service), contracts are automatically concluded and executed on blockchain. Carrier is coming for pallets with load and their each move is also recorded [5]. This an example of smart contract on blockchain that carries tasks of smart tendering and smart sourcing.

Delloite [38] argues Blockchains can make supply chain and trade finance documentation more efficient. By providing indisputable level of security for existing digital documents and quick access to all supply chain members, blockchain has a potential to persuade them to leave execution of transactions to smart contracts created on the basis of commonly agreed rules.

Watson IoT Center, Capgemini and IBM work on prototype called Smart Container Management—system that includes containers equipped with sensors sending information on blockchain that are available to all supply chain participants. Different smart contract terms can be activated—e.g. if regulated temperature during transportation decreases below a given threshold, a shipment of replacement products can be triggered in real-time, as well as an insurance proposal, a contractual penalty for the forwarder and a reorder at the supplier [25].

Blockchain in Trucking Alliance association is considering smart contract blockchain application between truckers and brokers that could "automatically provide fuel reimbursements when truckers fill up their tanks, or pay drivers as soon as they deliver their freight" [2], or enable only authenticated drivers to pick up goods (as a way to avoid fake drivers fraud attempt that became frequent in United States).

Table 2 SWOT analysis of blockchain application in supply chain

Strengths	*Opportunities*
–Decentralization –Transparency –Security –Stability –Automated trust-building system –Automatization of transactions	–Expanding features –New cryptographic functions –New trust-building protocols (proof-of-stake, etc.) –Integration within Internet-of-things
Weaknesses	*Threats*
–Often not user-friendly –Complex to understand –Many features still in development phase –Achieving consensus regarding system-wide changes within permissionless blockchains –Energy consumption	–Currently mostly unregulated –Lobbying for extensive regulation from intermediary corporations which are being threatened by DLT –Opposition from centuries-old institutions that could be wiped out by DLT

Source Authors

5 Conclusion

Although it is not clear (at this time) if the blockchain is an overemphasized solution[15] looking for the problems it could solve—just another technological innovation which gets people excited but in the end under-delivers—or an actual disruptive force which will sweep across the economy, its potential is certainly unlimited.

The gentle shift in terminology from "blockchain" to "distributed ledger technologies" indicates also distancing and separation from the ideology of the original blockchain designers, notwithstanding that it is the particular worldview that brought the blockchain to mainstream attention. Controlling and taming it could also filter out its main proposition—decentralization.

Blockchain as a technology is not going to replace existing supply chain technologies, but its characteristics of a secure information storage and exchange, as well as automatization of transaction, could assure its place as an important support and upgrade in supply networks (SWOT analysis in Table 2). Regardless of its weaknesses and threats, Blockchain significantly changes information and financial flows that are support to material flows, and thus enables optimization of material flows itself (through cost decreasing and customer satisfaction increasing) as well as raise of exchange based on improved trust in supply chain.

Improving existing and developing new consensus algorithms is at heart of the blockchain future. Cryptography could lay foundation for building trust, as it can

[15]Industry is stacked with buzzwords which do have both meaning and purpose, but often get over-used and abused to the point where they become hollow phrases. Examples are *artificial intelligence, big data, cloud-based, disruptive, Internet 3.0* (or higher), *machine learning, internet-of-things, open-source,* etc. Blockchain, unfortunately, seems to be on the same path.

substantially enhance communication between elements in the supply network. Zero-knowledge protocols (a variant of which is a *zero-knowledge succinct non-interactive argument of knowledge—zkSNARK*—already used in some cryptocurrencies) can provide proofs of knowledge of confidential information within certain network elements without revealing this information to the other network participants. Moreover, these protocols can be used to guarantee that communicated data is true and legitimate even though information about the sender, the recipient and other transaction details remain confidential and concealed. Meaningful embedding of these protocols within supply networks could propel them to a substantially higher level.

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