Blockchain Technology for Supply Chain Management

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Abstract Blockchain technology offers important opportunities for the supply chain management. This paper aims to overview the employment of blockchain technology in the field of the supply chain. Although the technology has been widely associated with cryptocurrencies, non-financial applications such as supply chain, power, and food industry are also promising. Blockchain can provide a permanent, shareable, auditable record of products through their supply chain, which improves product traceability, authenticity, and legality in a more cost-effective way. In this chapter, the potential improvement expectations via blockchain technology for the case of agribusiness were discussed. The proposed case for automotive manufacturing-micro factory with blockchain technology was also introduced.

Keywords Supply chain · Blockchain · Survey · Smart contract

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Introduction

The definition of a supply chain is given as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer" [1]. Products cross at least one border in global supply chains. The global supply chains are generally very large scale formations that may consist of complex patterns of production processes, transactions, and knowledge. World global merchandise exports totaled US$ 19.48 trillion in 2018 [2]. Based on World Bank data, more than $16 trillion in goods are shipped across international borders each year, and the yearly cost of global trade is estimated at $1.8 trillion annually (Maersk Strategy Group, May 2016). Global trade could increase by nearly 15%, boosting economies, and creating new job opportunities if barriers within the international supply chain are removed [3].

In a supply chain, ownership of products changes several times among participants until they are delivered to consumers. For low-added-value products such as agricultural commodities and certain types of mining commodities, supply chains function as an aggregation method by which goods are provided by many small-scale producers to larger-scale supply chain partners for further processing towards an end-product.

Existing supply chain models begin when two supply chain members, namely manufacturers and importers, send their products to the next stage of the supply chain. The next stage, also called the middle layer, includes the wholesaler, which processes the basic products received by the export, processor, and supply chain. In the last step, there is a retailer and foodservice that sells products. The main problem with this model is that the data is encapsulated in elements of the supply chain and shared less. For example, it is not possible for the consumer to verify the source of the food to be purchased [4].

Moreover, sustaining operations across a complex chain of resources, activities, and organizations can be hard for supply chain partners, especially when a large number of smallholders are involved. According to ISO standard 9000, the traceability concept is defined as "the ability to trace the history, application, use, and location of an item or its characteristics through recorded identification data". Lack of visibility and incentives may cause difficulties for sustainability.

Consumers cannot be sure about the reliability of data in current supply chain systems. The existing model becomes even more burdensome in the global supply chain. A reliable system is difficult, even impossible, on a global scale without building trust. With the advent of blockchain as a disruptive technology for most processes related to our daily lives, the transition to the use of blockchain technology [5] has begun to overcome all these challenges of supply chains. Participants and their roles in a typical blockchain integrated supply chain flow can be depicted as in Fig. 1. The tipping point for adoption is expected to be 10% of global gross domestic product (GDP) stored on blockchain ledgers by the expected date of 2027 [6].

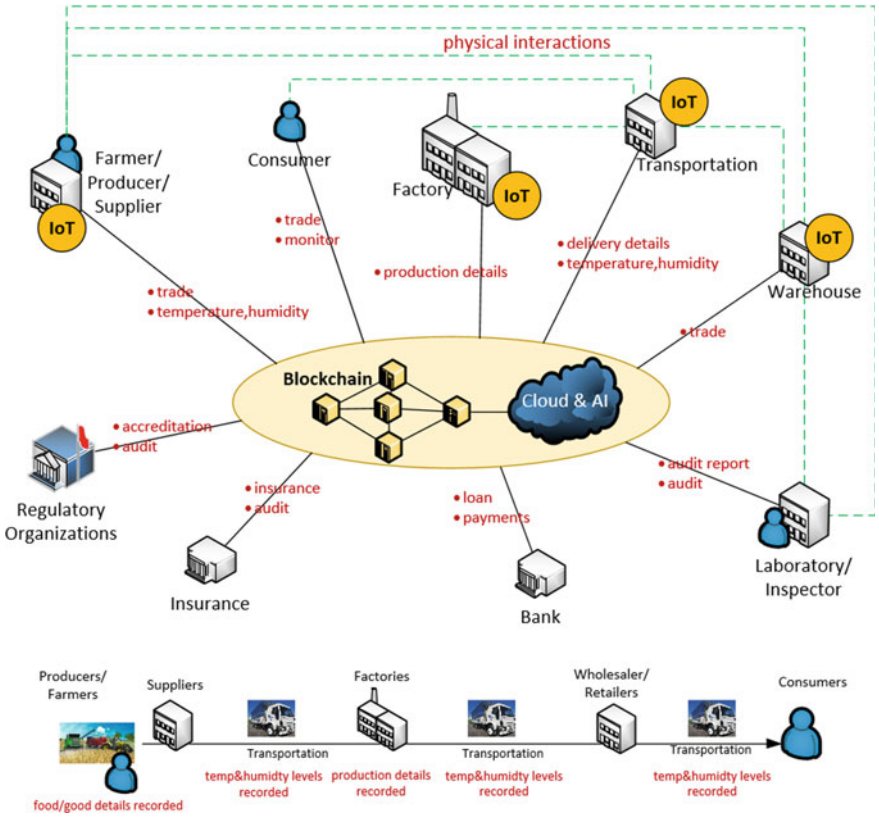

Fig. 1 Participants and their roles in a typical blockchain integrated supply chain flow

In this manuscript, opportunities, challenges, and possible research directions on blockchain-based supply chain solutions are surveyed. We believe this would be a starting point and guide for future studies.

Blockchain Background

The original idea and building blocks of blockchain technology are coming from crypto money and date back to the 1980s. Most recently, in 2008 December, the article by an author nicknamed Satoshi Nakamoto titled ''Bitcoin: A Peer-to-peer Electronic Cash System" popularized the blockchain technology. The blockchain concept consists of a combination of mathematics, cryptology, computer, and monetary science.

Blockchain technology, in fact, is a type of parallel and distributed computing architecture [5]. It allows us to eliminate central servers or trusted authorities in the

digital interactions of partners. Thus, it is classified as a disruptive technology that has the potential to transform most of the processes in our daily life radically. Simply, copies of the data, called ledger, are stored on thousands of computers working together, and all changes to the data are realized by consensus of partners. Every change made on data is recorded with a timestamp to ensure integrity and transparency. The stakeholders of the system do not have to trust each other. The factors that ensure the trust among them are that changes on the stored data can only be made according to the specified rules, these changes are kept in a ledger whose content is transparently open to audit, protected by cryptographic techniques, and a copy of this chain is available to all parties. It becomes possible for digital data to change ownership like assets in the physical world.

The main consensus protocols and mechanisms used to ensure the trust are Proof of Work (PoW), Byzantine Fault Tolerance (BFT), Proof of Stake (PoS), Proof of Authority (PoA) and Proof of Elapsed Time (PoET). The main purpose of the consensus mechanism is to ensure that proposed change requests are compatible with the existing status of data and defined rules. Blockchain computers, called nodes, perform these validations. Cryptography is mainly used to ensure the authenticity of change requests on data and the immutability of data in the ledger by organizing modification history as blocks that are cryptographically connected to each other. Privacy is another important issue in the blockchain. Thus, cryptography is also used to ensure the privacy of the participants. High availability of the ledger is provided by keeping the entire ledger at the nodes, not at a center. There are mainly two types of blockchain platforms namely, public and private according to the accesibility policy. In a public blockchain, anyone can send change requests to the network and can operate a node. In a private blockchain, also called permissioned blockchain, both sending requests to the network and having a node is restricted to a set of actors.

Problems of Supply Chain and Opportunities with Blockchain

The main objectives of the supply chain are listed as cost, quality, speed, dependability, risk reduction, sustainability, and flexibility [7]. Manufacturing has been globalized, leads well-defined supply chain management more crucial and valuable. In today's supply chain systems, it is difficult for customers to know exactly the value of a product due to a lack of transparency. In addition, investigating supply chains is mostly not feasible in case of suspicion of illegal or unethical activities. Heavy paperwork, process costs, and slow processes are other main challenges of the supply chain.

A literature survey on the research focuses on blockchain for the supply chain domain [2, 8–14] shows that the supply chain domain already benefits from blockchain technology because of its four main features (Fig. 2).

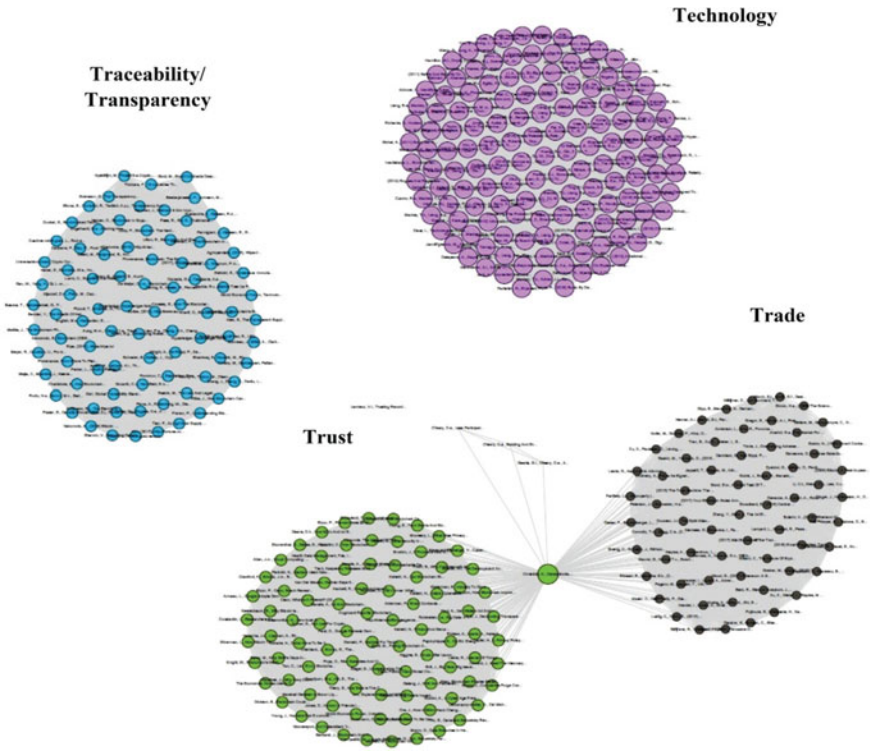

Fig. 2 Research focuses in literature for deployment of blockchain for supply chain [2]

In order to give an idea how blockchain might impact the needs of supply chain actors, we quoted Table 1 from literature. It presents Litke et al. [15] summary of how blockchain responds to the limitations that the actors of supply chains encounter today.

As a summary, Blockchain technology can benefit in many ways in the supply chain as it does in many other application areas. Employing blockchain in supply chain processes provides transparent, decentralized, secure, faster, and low-cost transactions. By eliminating unnecessary third parties and covering more daily life processes in digital systems minimizes paperwork. Blockchain establishes trust among trading partners. Making more detailed data available in blockchain improves supply chain monitoring ability and safety. This reduces insurance risks. Smart contracts and automated payments are game-changers. They add efficiency and remove bureaucracy, especially in insurance, and traceability. They also allow escrowed payment by keeping money until terms of the deal are met and agreed and then releasing automatically. Blockchain technology, in fact, provides missing infrastructure the cutting edge technologies need. Thus, increasing focus on providing integration and cooperation with technologies such as Artificial Intelligence, Big Data

Table 1 How blockchain can improve the existing limitations of supply chains [15]

Supply chain participants	Current limitations	Blockchain's impact
Producer	Lack of ability to prove the origin and quality metrics of products transparently	Benefits from increased trust of keep track of the production raw material and value chain from producer to consumer
Manufacturer	Limited ability to monitor the product to the final destination. Limited capabilities of checking quality measured from raw material	Added value from shared information system with raw material suppliers and distribution networks
Distributor	Custom tracking systems with poor collaboration capabilities. Limited certification ability and trust issues	Ability to have proof-of-location and conditions certifications registered in the ledger
Wholesaler	Lack of trust and certification of the products' path	Ability to check the origin of the goods and the transformation /transportation conditions
Retailer	Lack of trust and certification of the products' path, Tracking of products between consumers and wholesalers	Ability to handle effectively the return of malfunctioning products
Consumer	Lack of trust regarding the compliance of the product with respect to origin, quality and compliance of the product to the specified standards and origin	Full and transparent view on the product origin and its whole journey from raw material to final, purchased product

Analytics, Cloud Computing, and IoT will help to realize advanced supply chain systems.

IoT, for example, is already used in the supply chain domain to collect information about environmental conditions, to verify how long and under what conditions a cargo is loaded on a particular truck or port, and whether it is tampered with or affected by any incident that violates the shipping guidelines. IoT sensors also help companies to optimize and improve their supply chain systems. McKinsey Global Institutes research suggests that "Economic size of IoT applications globally will reach between 4 and 11 trillion by 2025.[1] However, using IoT and blockchain technology together will leverage systems thanks to the trust level achieved via blockchain technology. Matching data from the physical and digital world and validating their consistency will provide more trust between parties and prevent invoice disputes. Thanks to the robust digital infrastructure of IoT devices and sensors integrated with blockchain platforms, consumers can track the entire product life cycle throughout the supply chain.

[1] https://www.mckinsey.com/industries/semiconductors/our-insights/whats-new-with-the-internet-of-things.

As the recent situation by coronavirus pandemic showed the importance of supply chain infrastructures to communicate with multiple ecosystems. As the existing supply chain network has been highly affected by Covid-19, thus interoperability and compatibility seem to be crucial for the global supply chain after this pandemic. For the purpose, blockchain technology provides disconnected supply chain systems with low cost and maximum efficiency to interoperate securely [16].

Despite all its benefits, however, blockchain technology is not a "one size fits all" solution. New problems raise related to blockchain, and other assisting technologies should also be addressed to realize projects in the supply chain domain. Blockchain-based supply chain systems need various new legislative regulations. Current blockchain platforms cannot exactly fit the high level of transaction throughput requirements of supply chain systems. Supply chains combine diverse participants with varying interests. Thus, incentives need to be provided, such as efficiency gains, improved liquidity, and data security to motivate all participants. Security and privacy are other important issues. The data security concerns with IoT and lack of commonly accepted baseline protocol standards for IoT interaction. The current IoT ecosystem is built on a central model in which IoT devices are identified, connected, and validated. Thus, there is a need for transformation for blockchain adaptation.

Impact of Blockchain on the Logistics Industry

This subsection highlights the blockchain-based supply chain projects focused on rather Logistics subdomain.

Supply chain actors and startups focused on providing blockchain-based supply chain solutions to improve efficiencies and reduce operating costs. There has been a large number of ongoing projects. For example, Global Shipping Business Network (GSBN), created by nine ocean carriers and terminal operators, and global cross-border supply chains by IBM and Maersk collaboration, will be made available for the ocean shipping and logistics industry. United Parcel Service (UPS) employs blockchain to combine with the truckload pricing futures market, by enriching the real-time matching of loads and empty trucks with a data analytics and artificial intelligence. Similarly, Waltonchain is a blockchain/supply chain project to incorporate both digital and physical elements into one system. It employs IoT devices and RFID chips to ensure the security, traceability, and authenticity of the business.

For mining and jewelry industries, tracking assets from the mines to the consumers is important. Tracing an asset back to its provenance facilitates proving ownership in cases of thefts and attesting authenticity. Due to diamonds' high value, annually, $45 billion is lost to insurance fraud, and 65% of false claims pass undetected. EverLedger and De Beers, Jewelry Company, use blockchain to track assets throughout their lives with the aim of assuring the consumers for buying genuine articles. BHP Billiton, as the world's largest mining firm, plans to benefit from blockchain technology for better tracking and recording data throughout the mining process.

In addition to samples given, general-purpose, or logistic specific significant projects in the supply chain domain are summarized in Table 2.

Table 2 General-purpose or logistic specific significant projects in supply chain domain (extended version of Justin, 2019 [17])

Name/started in	Description	Partners
VeChain (VET) 2015	Smart contracts to track inventory. It tokenizes products and tracks each step through RFID labels as they navigate through the supply chain. The system allows us to view each historical detail of the product at any point in its lifecycle in the supply chain. Example of applications includes cold-chain logistics, automobiles, medical and healthcare, luxury and fashion	BMW, Haier, BIOS, BYD, DIG, DB Schenker
WaltonChain (WTC) 2016	It tracks objects via proprietary RFID technology. Detailed information is provided about locations a product passes, who handled it, and steps relating to the supply chain process	Fashionchain, MoneyNet, Huodull, Mitoq, Freyrchain
Ambrosus (AMB) 2017	Ethereum smart contract-based supply chain system, including proprietary IoT devices. It can be integrated easily into any industry or market that relies on supply chain or logistics. Ambrosus makes food and medicine safer by combining high-tech sensors and blockchain technology	BioFirm, Nestle, Cantone Group, Trek Therapeutics, Crypto Valley Association
OriginTrail (TRAC) 2013	A process sharing data throughout the supply chain. Businesses have an easy and effective way to exchange data, both in-house and across borders. A transparent way to increase accountability and efficiency	Ferdinand, Perutina, Natureta, Planika, H-Farm
Modum (MOD) 2016	A startup combining IoT devices and smart contracts to provide supply chain data to its clients as it becomes available in real-time. Modum users know if their product has been tampered with and whether or not they receive shipments on time	Swiss Commission for Technology, Institute for Supply Chain Management, and Communications Systems Group

(continued)

Table 2 (continued)

Name/started in	Description	Partners
Tael (WABI) 2017	A project which develops solutions for the authenticity of products. With the anti-counterfeit QR codes, a consumer can ensure that a product is valid and has not been tampered with prior to purchasing. It is popular in lower regulated countries like China	Blackmores, Nutrilon, Swisse, Nature's Fare
CargoCoin (CRGO) 2018	A project employing smart contracts to create a secure method of storage and transfer for tokenized goods in many different supply chain industries (shipping via land, sea, and air). It provides effective communication between cargo traders and transporters on a global scale. This allows providing a method for sending, receiving, rejecting, approving, or signing necessary documentation to all stakeholders of the supply chain process	Bancor, H&B, Bitrue, NoBar, CargoLine
Bext360 2016	Online platform to track goods on a public blockchain system throughout each step in the supply chain. This provides transparency. Assets are represented as tokens. and stored on Bext360 network to manage payments, smart contracts, and asset tracking throughout the entire lifecycle	Great Lakes Coffee, Coda Coffee, Moyee Coffee
ShipChain (SHIP) 2017	A project to provide end-to-end visibility for all products transported. The main goals are to lower costs, reduce theft and fraud, and reduce transaction times. Smart contracts are used to shorten the communication path between shippers and carriers. On an Ethereum blockchain, it only allows authorized parties to view details of the process	CaseStack, ScanLog, Sweetbridge, Direct Outbound

(continued)

Table 2 (continued)

Name/started in	Description	Partners
CargoX (CXO) 2015	A project using Ethereum blockchain technology to develop a cost-effective and smart bill of lading solutions that can process from anywhere in the world	TPG Logistics, MakerDAO, Europacific, Fracht AG, Mana, and DBA Group
ZetoChain 2018	It is the blockchain-enabled IoT solution to provide enhanced security, traceability, and scalability for food safety via IoT sensors	
Irene Energy 2018	Irene Energy operates a Stellar blockchain to create transparency in electrical supply chain management	
Devery 2018	Devery is a decentralized ecosystem providing developer tools to utilize Ethereum blockchain technology to secure supply chain & product verification	
EverLedger 2016	The platform enables buyers and sellers of high-value assets to trade with confidence. Its blockchain provides a secure record of an asset's origin and journey	Shairu & Atit Diamonds, Fred Meyer and Littman Jewelers

Impact of Blockchain on Agricultural and Food Industries

As summarized in Fig. 3, the Agriculture and Food Industries already take advantage of blockchain technology in order to get improvement in the various aspects of the supply chain such as traceability, insurance, finance, transaction, and optimization.

The projects and solutions employing blockchain are listed below as grouped by categories [18, 19, 13].

Agriculture trade and transactions.

- AgriChain—A blockchain company that focuses on end to end agricultural processing and reducing intermediaries.
- AgriDigital—A cloud, IoT, and blockchain-based commodity management solution for the global grains industry. It connects farmers, buyers, site operators, and financiers through a single platform. They are allowed to contract, deliver, and make payments securely and in real-time.
- AgriLedger—British social enterprise project that supports farmers' food origins, easier access to financing, and storage of transaction data.

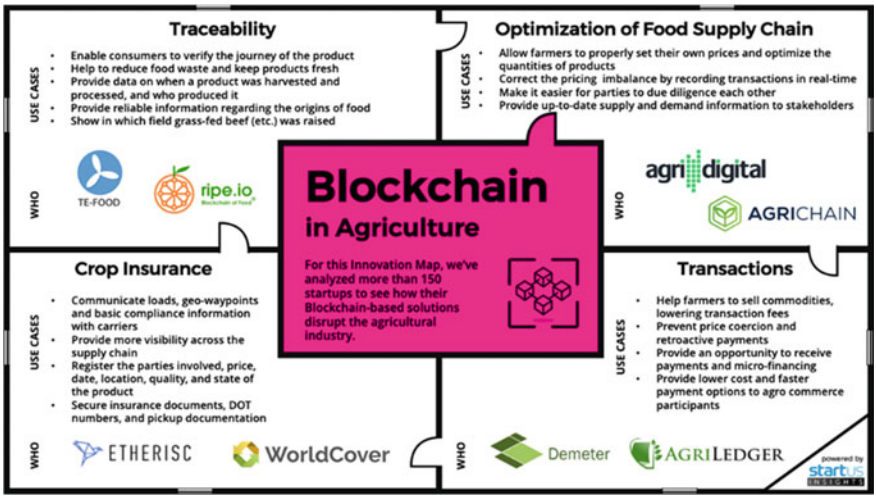

Fig. 3 The areas within the agricultural sector improved by blockchain (Startus Insights 2018 [13])

- AgUnity, FAO, Gates Foundation and International Finance Corporation (IFC) farming cooperatives run for and by local farmers. Collective bargaining, creating a network between farmers within which they can agree to share equipment and resources and helping farmers to select more profitable crops to plant.
- Agroxy- Ukrainian based agricultural product trading system.
- Demeter—A central hub for the leasing and cultivation of microdomains anywhere in the world without intermediaries, complexity, or the burden of a large organization.
  Agriculture finance and insurance.
- Worldcovr—Developing a product insurance system to protect against loss of yield by using satellites to monitor precipitation and trigger payments automatically.
- Trado—A consortium for innovative blockchain supply chain finance structure
- Etherisc—A blockchain company that offers farmers product insurance through decentralized insurance practices.
- FARMS, Financial and agricultural risk management platform integrated with satellite sensing for smallholders
  Food supply chains.
- One of the biggest retailers in the world, Walmart, is developing blockchain-based traceability for lettuce participation.
- Walmart is trying to keep track of fresh and leafy greens products back to the farm by using a blockchain platform developed by IBM. Walmart also uses blockchain technology to track its meat from China [20]. For this purpose, data such as cold chain processes and sales dates are stored in the blockchain.
- Global companies like Unilever, Nestle, and Dole also use blockchain for similar purposes.

- IBM Food Trust is a blockchain-based use case for cold chain logistics. Food Trust aims to create transparency and accountability in the food supply chain.
- TE-FOOD—With a Germany-based public permissioned blockchain platform (2016), customers can track their food all the way to their tables.
- Provenance is a UK startup (2018) to trace food. Consumers are able to get more information about where their products come from and if something is environmentally harmful or genuinely safe.
- Ripe, a startup aiming for a transparent digital food supply chain, uses quality food data to create the Food Blockchain that maps the food journey.

Impact of Blockchain on Automotive Industry and Micro Factory Concept

The automotive industry has long been considered the locomotive of the global supply chain. Blockchain-related supply chain use cases are also considerable for the automotive industry. Figure 4 summarizes the potential application areas for the automotive industry to use blockchain technology.

Since smart factories enable rapid retooling, small-scale manufacturing facilities may actually have a competitive advantage to produce customized products for specific local needs, at a local scale. Micro factory concept is a novel production facility to manufacture new generation electric vehicles.

Local Motors established automobile-building micro-factories across Phoenix, Las Vegas, and Knoxville and host an open library of vehicle designs to include and empower communities of global designers, engineers, manufacturers, and automotive

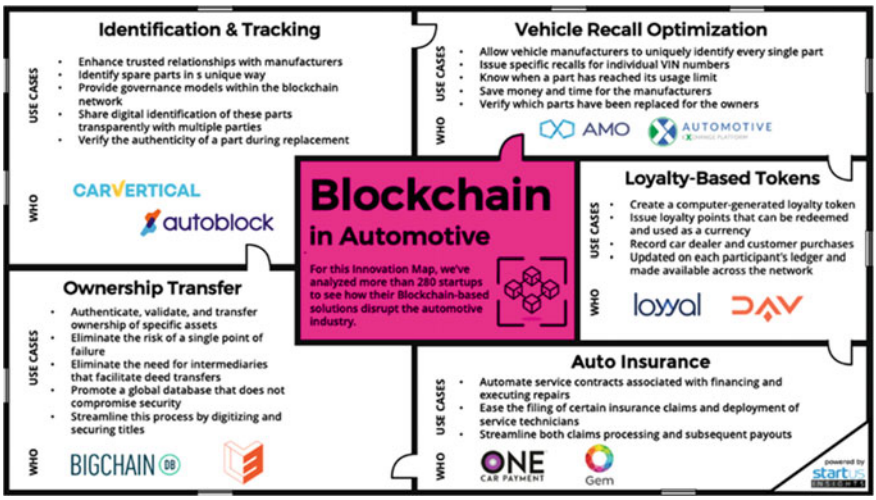

Fig. 4 The areas within the automotive sector improved by blockchain (Startus Insights 2019 [12])

enthusiasts. It can be claimed that, with the advanced technology, there is a potential for a decentralized production to democratize the manufacturing function, as the Internet makes the information accessible for everyone, designing and manufacturing would be more accessible to everybody within distributed manufacturing. However, weak supply chain infrastructure can lead to high distribution costs.

For this reason, supply chain security is critical for micro factory networks. The well-defined supply chain for components such as the motor/inverter, tubular SHSS, electronic board, lights, seats, battery cells, etc. is required. It can be improved by integrating blockchain technology into the supply chain for future studies.

Each micro factory/country has the capability to create its own brand with customization according to the demand of its local market. The proposed network model for micro-factories is the collaboration to make their local brand stronger and compatible in the already captured automotive industry. Therefore, a globally distributed network will be established with the replication of micro factories. To succeed in this highly distributed network, central authority is required. However, it is not defined in sharing economy concepts developed for micro factories. The distribution of data into the network securely without intermediaries is a challenge of this model. However, this can be overcome by implementing blockchain technology, which allows transacting peer-to-peer and trusts each other by using collaboration and cryptography without a third party [21]. It means all transactions will perform between related micro factories and engaged suppliers, a central authority to control and manage the system is not needed. The data of all micro factories distributed across a global ledger, using the highest level of cryptography. To hack a blockchain network, someone needs to reach all computers in that network, which is almost impossible. Thus, blockchain offers a more secure model, which can be adaptable to the micro factory network. Consequently, this micro factory network consists of a smart contract between parties that allow them programmatically to define the rules and steps that should be performed any time and a certain type of event is recorded in the blockchain.

Blockchain is a simple way of passing information in a fully automated and safe way without the need for third parties since ‘central authority’ does not exist. Besides, it provides transparency, speed, accessibility, and coherence so that the blockchain logic fits the business model of micro factory networks.

Discussion and Conclusion

This study suggests that blockchain technology has certainly an important role in enhancing and fundamentally transforming supply chains in many industries. It will be expected to create more sustainable solutions for supply chain bottlenecks experienced today in many industries such as logistics, agriculture, and automotive. By removing the intermediaries with blockchain-based transformations, the transactions will become faster and secure thanks to cryptography. Therefore, the infrastructures are evolving along with regulatory changes, technological advancements, new

financial mechanisms that will facilitate blockchain-based supply-chain management systems.

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