The Role of Blockchain in Developing Supply Chain Resilience against Disruptions

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1 Introduction and Background

The fragility and lack of resilience of global supply chains have attracted significant and ongoing attention following the outbreak of COVID-19. The persistent global supply chain crisis has been well covered by the media and by scholars. There have been significant delays in the delivery of goods, and rising costs have been the norm in the last year or two. The pandemic-induced global supply chain crisis has imposed a significant additional strain on customer products, manufacturers, carriers, and suppliers worldwide (Sherman 2020; Bailey 2020). This is not the first time that an unexpected disruption such as a disaster has revealed weaknesses in global supply chains. The 2008 global financial crisis (GFC) had significant impacts on global supply chains. The more recent 2011 tidal wave that affected Fukushima, Japan, caused the world's worst nuclear accident which disrupted the automotive industry because 60% of essential auto components were manufactured in the Fukushima area. The Icelandic volcano, Eyjafjallajökull, threw a thick ash cloud across Northern Europe and the European airspace had to be shut down, with airlines unable to fly and air freight disrupted (Langmann 2010). As a result, the manufacture and distribution of many components ceased, and Nissan and BMW quickly halted all production (Theguardian.com 2020). Similarly, the SARS epidemic, which emerged in 2003, affected sections of the electronics supply chain (David 2003). The COVID-19 pandemic has again exposed the risks inherent in global supply chains

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on a much larger scale. Companies worldwide rely on supplies coming from over 12,000 factories located in China, South Korea, and Southeast Asian areas significantly impacted by COVID-19 mitigation measures (Linton 2020).

COVID-19 and the attendant mitigation measures such as border closures and social distancing have resulted in staff shortages and capacity reductions in many industrial sectors, which has made it difficult for managers and industry leaders to react and respond quickly to supply chain disruptions (Butt 2021a, b; Meier and Pinto 2020). Moreover, transportation and logistics have been seriously impacted by such mitigation measures. For instance, the fear of COVID-19 contagion kept many drivers off the road, reducing a large portion of trucking capacity. Overall, COVID-19 has caused delays in deliveries, and entire supply chains have been adversely affected (Chen 2011). Before the COVID-19 pandemic, supply chains were excessively lean (Rivera 2007). They were often built to be low cost and based on Just-in-Time principles (Taylor 1999; Cox 2005). They were also fragmented, long, complex, and often opaque structures. When circumstances were good and stable, a lean supply chain benefited all stakeholders. However, even then, traceability, flexibility, and visibility were limited. However, when the pandemic broke out, underlying problems were exacerbated, and the cumulative consequences resulted in global chaos. Therefore, the pandemic has exposed inherent weaknesses in the design and operation of global supply chains while providing an opportunity to re-think strategic supply chain design to ensure less vulnerability, improved resilience and robustness, and a supply chain that is capable of providing better service to consumers (Boyes 2015).

1.1 Digitalization, Blockchain, and Supply Chain Resilience

The awareness and knowledge of supply chain vulnerability, supply chain resilience, and supply chain risk management (SCRM) have increased over the decade (Peck 2005, 2006; Glickman 2006; Christopher 2004; Pettit 2010), and many scholars have argued for, and advocated the value of, supply chain digitalization and industry 4.0 technologies as the means of mitigating supply chain risks and disruption (e.g., Ivanov 2021; Spieske 2021; Sawik 2022a, b). The authors take the view that, with the appearance of digitization and information analytics, organizations now have the technological tools to offer end-to-end risk management solutions to strengthen supply chain resilience. As some have argued, supply chain digitalization and Industry 4.0 can provide organizations with advanced record-keeping, connections, machines, and integration procedures, thereby improving the cooperation and reliability of members of the supply chain (Raab 2011).

Although these new technologies have a positive impact on productivity and work practices, they can also give rise to malicious electronic cyber-hack or ransomware operations that threaten supply chain security and product safety (Deloitte 2019). In order to resolve these issues, managers and scholars have undertaken initiatives using blockchain technology to secure data, and to ensure system integrity, transparency, security, and protection (Aceto 2019; Kshetri 2017).

Because its benefits need to be completely realized and demonstrated by numerous success stories, it will take some time for blockchain to be acknowledged as a practical tool that can improve security and reduce risk in the supply chain. Blockchain technology allows users to transfer their assets (including intangibles) without the risk of being hacked or the inconvenience of having to create a separate vault that limits the interactions between exchange partners. To expedite the application of blockchain technology, we need to know how blockchain works on a regular basis. Despite its potential benefits, blockchain technology can create a number of challenges when it comes to implementation, such as lack of organizational readiness or technical/infrastructure expertise, issues with scalability, and limited financial resources to invest in blockchain. Therefore, there is an urgent need to develop management strategies that can assist companies to overcome these challenges so that they can fully reap the benefits of blockchain technology. Unfortunately, many blockchain investigations concentrate on bitcoin frameworks, while others are anecdotal studies of potential blockchain applications such as counting smart contracts, financial services, circular economy, and authorizing with limited articles in supply chain management (Nandi 2021; Crosby 2016; Mainelli 2023; Raval 2016; Tapscott 2016; Underwood 2016; Yli-Huumo 2016). Given these gaps in blockchain research, in this chapter, we propose a blockchain architecture to overcome supply chain risks during the Covid-19 pandemic and during the subsequent recovery. Moreover, we suggest several ways by which managers can deploy blockchain to enhance supply chain resilience from a security perspective. We also identify and investigate relevant factors that may influence a company's decision to implement blockchain technology.

While some researchers have explored the application of blockchain in the supply chain, the contribution of this chapter goes beyond this by explaining how blockchain technologies can help manage and predict disruptions and bring greater resilience and balance to the supply chain (Swan 2015a; Ghadge 2019; Taylor 2019; Strozzi 2017).

The rest of this chapter is organized as follows. In Sect. 2, the basic definition and concept of blockchain technology and its general application is discussed. Section 3 explores the application of blockchain technology in non-supply chain management contexts. In Sect. 4, we discuss how blockchain technology can strengthen supply chain resilience. In Sect. 5, we examine the value and role of blockchain in mitigating disruptions and their destructive effects, with the aim of strengthening supply chain resilience. In Sect. 6, we discuss the potential of blockchain to mitigate supply chain disruptions resulting from the pandemic. Section 7 concludes the chapter with a summary and suggestions for further research.

2 Blockchain Technology

Blockchain is a technology that consists of a distributed ledger that stores and exchanges transaction records or other data in a cryptographically secure, decentralized, and immutable format (Swan 2015b). In a blockchain, a 'block' is an information structure that contains a series of data records. Blockchain was created in 2008 by Satoshi Nakamoto, the creator of the Bitcoin whitepaper. Essentially, a sequence of data within a blockchain is an electronically distributed list of data stored by a client or participant on a computer network (Lu 2019). Moreover, blockchain deploys cryptography for transaction processes and verification on the ledger. An important benefit of this decentralized structure is that a business enterprise is not under the control of a single organization. Another benefit is that it can resolve issues of disclosure and accountability between people and institutions whose activities are not strongly regulated (Lu 2019). In blockchain, critical records can be updated securely and accurately in real time, thereby eliminating the need for technologies that are error-prone, which can compromise data confidentiality and security (Casey 2017). Blockchain gives greater transparency and a timely view of activity occurring within the network. Blockchain is attracting interest from supply chain management researchers due to its benefits such as its capability to securely store significant amounts of data, which offers great advantages to individual businesses and to supply chains in general (Kache and Seuring 2017). Also, blockchain enables the encryption and encoding of data, thereby greatly improving data exchange, transparency, performance, and reliability of a network (Misra 2018). The blockchain has four essential traits or attributes (Pattison 2017). First, it is designed to be distributed and it offers synchronization of structures. Hence, corporations can share data with trusted parties in inter-organizational commercial enterprise systems including supply chains and business consortia. Second, blockchain is made up of smart contracts. This is a pre-contract between contributors, and contracts are saved individually inside the blockchain. Smart contracts are computer protocols intended to digitally facilitate, validate, or establish negotiated terms and conditions. Smart contracts enable dependable transactions to occur without the need for third-party intermediaries since all transaction processes are undertaken automatically. Established protocols can help parties decide whether or not a specific transaction, including a particular fee, is authorized (Pilkington 2016). In addition, smart contracts can enable asset verification in a series of transactions involving non-monetary elements (Reyna 2018). This gives the various members of the supply chain network confidence that everyone is following the rules. Third, blockchains are built using Peer-to-Peer (P2P) networks and require all parties to agree to the validity of a transaction. This eliminates faulty or potentially risky transactions from the blockchain database. Fourth, the continuity of the date ensures that the agreed transaction is timely and remains unchanged. This continuity offers a record of the transactions and shows where the asset is located, when it is located, and what is happening to it. There are both public and private blockchains available. The main difference between them is membership, i.e., the users who can become part of the network. Public blockchains are entirely open. In other words, everyone can participate and become part of the network. Networks regularly have incentive mechanisms to encourage more individuals to take part. Bitcoin is one of the most extensive non-public blockchain networks ever created. One disadvantage of private blockchains is the large amount of computing power required to maintain a huge distributed ledger. To obtain consensus, all nodes within the network must be synchronized. This is done by solving a complicated, resource-intensive problem referred to as Proof-of-Work (POW) (Angrish 2018). Furthermore, blockchains require that potential participants be invited to join the network, and participants need to be confirmed. Firms and supply chains typically construct public networks instead of non-public open networks to ensure that access is exclusive. Current participants can determine future entries based totally on hard and fast policies established using the network initiator. Pilkington (2016) Regulators can provide licenses for participation. Alternatively, since the blockchain is decentralized, a consortium may want to decide whether an entity joins the community. Overall, although blockchain technology is relatively new, it has the potential to overcome or mitigate risks associated with the management of supply chains. “Blockchain is a new organizational paradigm for coming across, evaluating, and transferring any quantity (discrete units) of something of value and coordinating all human tasks on a far larger scale than ever before” (Swan 2015b).

3 Applications of Blockchain Technology in Non-SCM Contexts

The commerce and finance sectors are currently making the most use of blockchain technology. Blockchain was specifically designed for Bitcoin, a P2P decentralized virtual cryptocurrency network. Bitcoin has a multibillion dollar international market where buyers can shop anonymously without the control or intervention of authorities. Therefore, it is necessary to address the scope of regulatory problems related to governments and financial institutions in regard to trading with or without bank intervention. All transactions are dispatched to all nodes within the Bitcoin network, and recorded in the general public ledger (Crosby 2016). Blockchain structures are also being used to display monetary institution warranties, follow up monetary exchanges, and mitigate fraud. Using the activated smart contracts, there is network consensus that conditions have been met to allow for automatic payments (Guo 2016). To allow for automatic payments using activated smart contracts network consensus, conditions must be met. Blockchain technology also has the potential to be applied to areas other than coins and currencies, as distributed ledgers can be programmed to record anything of value. This includes birth and death certificates, marriage licenses, documents and deeds, financial reports, scientific procedures, and insurance claims, to name a few (Tapscott 2016). Blockchain applications have also been implemented in healthcare. For example, blockchain is used to track a patient’s condition after discharge, and blockchain electronic medical data can be controlled to improve the authentication, privacy, and sharing of records (Armstrong 2018; Marr 2018). In charitable organizations, blockchain has been used to increase the transparency of donations and show the link between donations and project results. In real estate, blockchain is being used to track complex regulatory processes that create value (Marr 2018). Retailers use blockchain to improve monitoring. Monitoring can be implemented in decentralized markets where items and services are traded without intervention (Chakrabarti and Chaudhuri 2017; Grewal 2021). The tourism sector uses blockchain technology to monitor and share information about motel accommodations, and to remove intermediaries for car-sharing and real-time travel (Rejeb 2019; Filimonau 2020). In the media and entertainment sectors, blockchain technologies track intellectual property rights and make payments to artists (Dutra A. 2018). In the public sector area, blockchain is deployed to establish voter identity and increase the credibility of vote counts (Osgood 2016). Overall, blockchain is already helping to improve transparency, transaction speed, and responsiveness. Blockchain is flexible, making it suitable for all trading as it facilitates settlement without dispute. Disputes are eliminated because all the global has a replica of the overall ledger and the invoice is generated automatically.

4 Blockchain Technology for Strengthening Supply Chain Resilience

4.1 Supply Chain Disruptions

Typically, supply chains move products and businesses forward through interactions among trade partners within a complex network. Supply chains are the mechanisms by which goods and services are delivered (Peck 2006). They are multi-level and complex, comprising flows of materials, goods, information, and money which pass within, and between, organizations linked by a range of tangible and intangible facilitators such as processes, relationships, activities, and information systems (Peck 2006). In practice, supply chains are also linked by physical transport, distribution networks, and communication infrastructures often across international borders (Christopher 2000; Peck 2005). However, some of these interactions can increase the vulnerabilities of supply chains which can result in disruptions. To mitigate these vulnerabilities, supply chain experts need to identify the weak links and evaluate the degree of risk posed to the entire supply chain network. Risk evaluations generally entail the following steps:

1. *Identifying the buying and selling partners in the supply chain*. These partners can shape points (or nodes) inside the supply chain network and show the parties who can produce supply chain agreements.
2. *Designing a supply chain or procedure scheme that shows the transaction and its data flow*. These flow depictions (shipment, container, capital, documents, etc.) can reveal potential bottlenecks (i.e., the weakest links) and the level of risk for instance in terms of cyberattacks. Figure 1 depicts the various potential sources of supply chain risk.
3. *Classifying and comparing vulnerabilities*. Risks can be categorized into distinctive classes according to the results of the risk evaluation (e.g., high, medium, low), and the calculated likelihood of the risk occurring. This risk evaluation can then be used to create an action or probability plan to mitigate the risk.

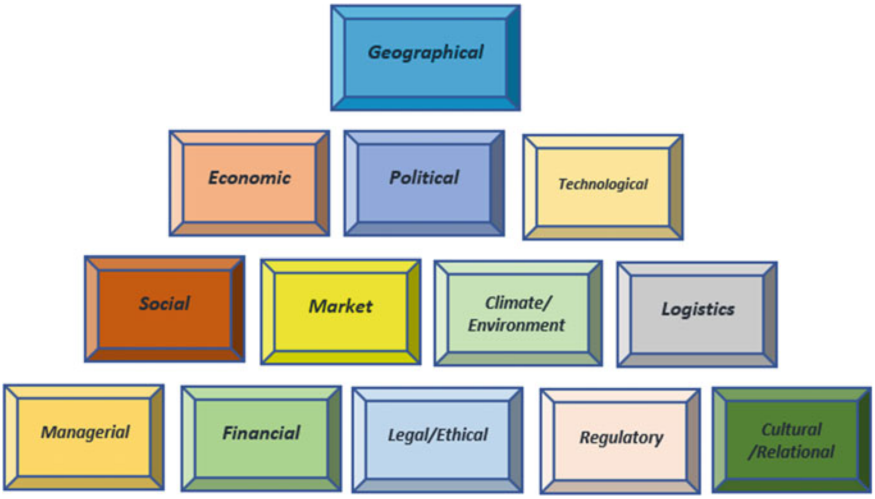

Fig. 1 Sources of risks related to supply chains (Seminar 2010)

Based on the extent of safety risks and vulnerabilities determined by the preceding steps, suitable mitigation measures are then developed and scheduled. In particular, a timetable ought to be established for the development of a plan of action with responsibilities for specific sub-plans assigned to individuals, and implementation procedures and expected outcomes documented. For instance, the use of a Radio Frequency Identification (RFID) system helps to detect potential security and safety breaches. This system can automatically collect information associated with product movement (e.g., expected time of arrival, port of entry/exit), and port authorities or cargo controllers can match received facts with pre-recorded/information documents (e.g., shipping documents, manifests). This enables them to identify suspicious trends (e.g., departures from high-risk nations), and red-flag incoming items (Min 2012). As a result, gateway security may be achieved through the early detection of anomalies that regularly result in safety or security failures.

4. *Setting up plans to govern and monitor risk reduction efforts* Each plan needs to be evaluated for its effectiveness and its impact on safety and security. In addition, it is essential to monitor the implementation of the plan and determine whether the scheduled milestones have been reached and whether progress is being made. This step is designed to improve the efficiency of security measures. By integrating blockchain technology with the mentioned steps, we can enhance security, strengthen connectivity, and ensure the safety of the supply chain. This powerful combination acts as a shield against security threats, providing an impregnable fortress to protect the integrity of the supply chain (Min 2019). Blockchain is hack-proof, tamper-proof, and irreversible because of its distributed ledger and network verification system (Karame 2018; Xu 2018).

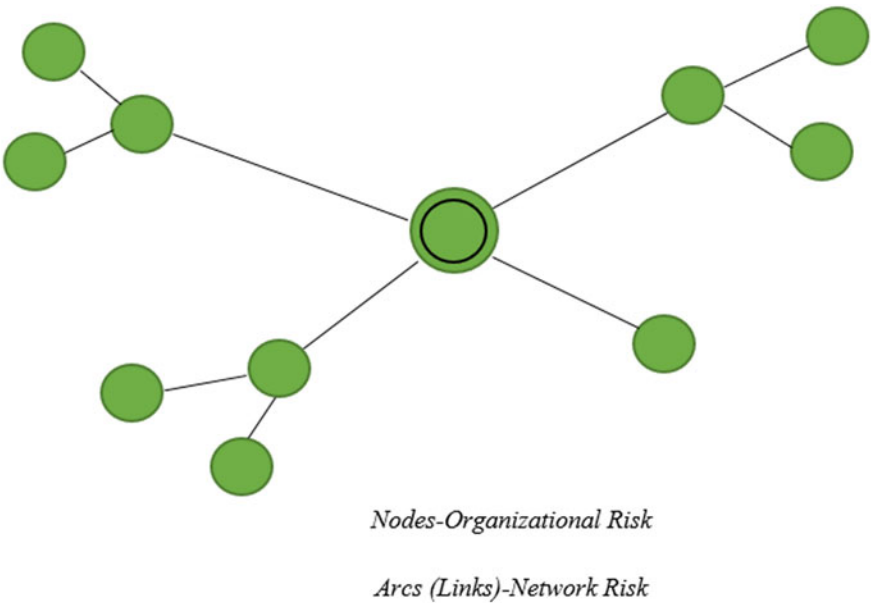

Fig. 2 The structure of supply chains with two kinds of potential risks (Grewal 2021)

Blockchain also provides automatic detectability, as an attach-only database of transaction data can be stored through a P2P network, and those historical facts will always remain by means of a fingerprint. In addition to this, a blockchain comprising nodes and arcs can be included within the ordinary supply chain structure (Fig. 2), and may be applied to capture each organizational and network risk related to the supply chain. A blockchain-based framework may be used to identify, analyze, and evaluate supply chain disruption elements and drivers based on empirical analysis of the four major disruption factor categories including (a) natural, (b) human-made, (c) system injuries, and (d) financials with drivers of disruption diagnosed and tested in a real-world industrial setting (Paul P. 2021) Significantly, a growing number of researchers and practitioners have placed supply chain resilience (SCRE) at the top of their agendas due to the increased susceptibility of global supply chains to disruptive events (Chowdhury 2017).

In order for blockchain to handle potential threats to a supply chain and improve its resilience, it is vital to know the unique activities of the supply chain network. The resilience of a supply chain may be strengthened by taking the following measures:

1. Reducing or eliminating the potential risk by identifying its source. For example, routes that are prone to maritime thefts, and ports with a high rate of theft or strikes should be avoided.

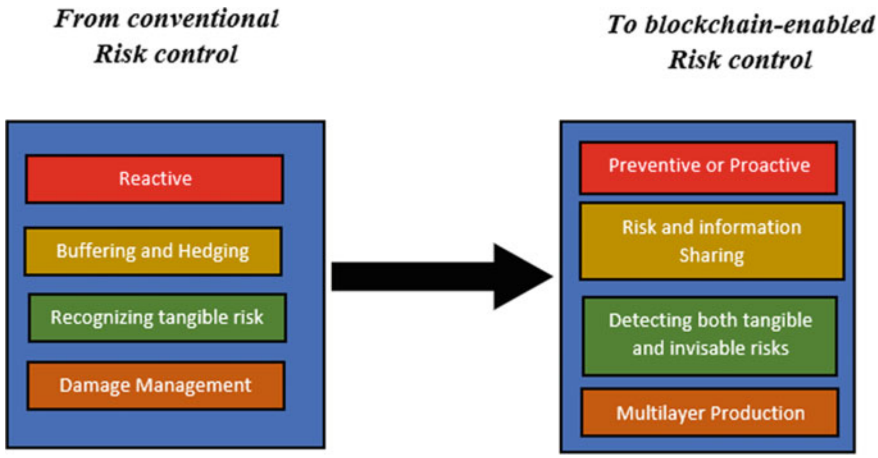

Fig. 3 Transition from conventional risk control to Blockchain-enabled risk control (Min 2012)

2. Reducing the effects of supply chain infractions by buffering with extra safety inventory, avoiding fuel fee rises for transport vehicles, and ensuring adequate insurance coverage.
3. Improving the resilience of supply chains to ensure quick recovery from infractions or unexpected crises or disasters. For instance, moving supply assets such as transportation vehicles closer to production factories.
4. Eliminating unacceptable behaviors resulting from the organization's mindset such as lax risk control practices and assumptions that predictions and forecasts are dependable, and accidents uncommon. Supply chain experts must remain open to new ideas like blockchain technology, as organizational resistance can stifle modern supply chain risk management.
5. Resilience is an essential enabler of Supply Chain Performance (SCP) because a resilient supply chain prevents disruptive impacts and assists in setting up and preserving appropriate levels of overall performance (Chowdhury 2019).

Many organizations that depend on traditional risk control methods are unaware of hidden risks such as cyberattacks, system hacking, forgery, credit failures, and contract fraud. Traditional forms of risk control have been applied to reduce obvious risks such as terrorism, theft, and natural disasters. However, these methods tend to be passive rather than proactive, and therefore, address risk management only after the event. By scrutinizing the P2P network, blockchain helps to identify and reduce risks that cannot be detected easily by supply chain members (e.g., sellers, buyers, financial institutions) during normal business transactions or supply chain activity. During various phases of a transaction, blockchain permits users to use multi-layered security scales. Figure 3 shows the traditional risk-control strategies and those enabled by blockchain.

4.2 Smart Contracts for Enhancing Supply Chain Resilience

In Sects. 4.2.1–4.2.4, we discuss how smart contracts based on blockchain technology may be applied to various sections of the supply chain to improve supply chain resilience.

4.2.1 Smart Contracts

The establishment of a transaction agreement is one of the first activities that occur in a supply chain, and contractual disputes can arise from fraudulent behavior and misunderstanding. Moreover, overall performance failures not only have the potential to ruin business partnerships, but they can also disrupt all activities within a supply chain if timely action is not taken to avoid far-reaching consequences. One of the most practical solutions to these supply chain issues is the smart contract. The smart contract is a computer-managed protocol intended to facilitate, confirm, or enforce contractual obligations by embedding contractual clauses (e.g., collateral, bonding, delineation of assets rights) within the system and then automatically executing the agreement (Szabo 1997). Hence, smart contracts not only establish the guidelines and conditions for a contractual agreement, but they also immediately establish the responsibilities of all parties involved. They are self-checking and self-running agreements that automate the settlement lifecycle to mitigate risk, and improve the effectiveness and efficiency of a company's transactional processes (Icertis 2017). Smart contracts can be converted to system codes that are saved and copied on the computer system and monitored with the aid of the blockchain that has been integrated into the system. Smart contracts can facilitate transparent transactions involving money, property, stocks, or any valuable item or product without the need for the services of intermediaries (Blockgeeks 2017). Hence, smart contracts are autonomous, thereby reducing transaction times and costs. Moreover, by integrating the Internet of Things (IoT) into the blockchain, contract fraud can be discovered easily, and/or avoided. Smart contracts make blockchain applications more operationally comfortable and economically attractive. Giovanni (2020) Additionally, as shown in Fig. 4, the integrity of asset transfers established by the agreement is improved because the decentralized network has many members and there is more robust security.

4.2.2 Asset Tracking

Smart contracts can be used to track asset ownership. As soon as both tangible and intangible assets are recorded on the blockchain, ownership is permanent until the proprietor confirms otherwise. The paperless record created by the blockchain is immutable. In addition, blockchain works as a perfect and easily distinguishable record that completely tracks and saves all the supply chain-associated obligations

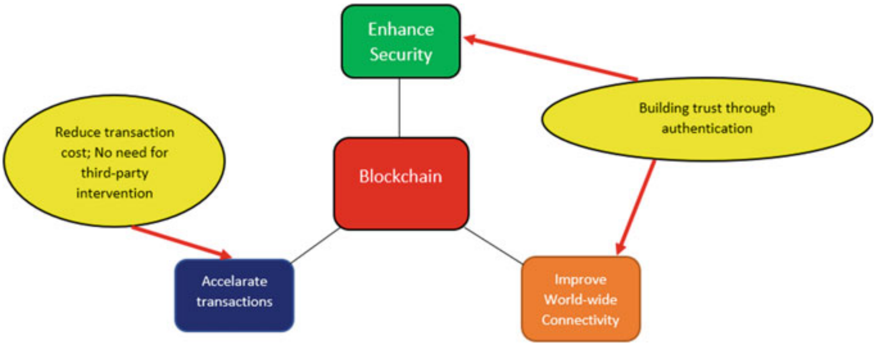

Fig. 4 Combination of blockchain and IoT (Giovanni 2020)

for a particular resource. Blockchain permits transparency all the way back to the origin of an asset. Therefore, blockchain prevents the exchange of false properties and makes it much easier to track objects as they are made and conveyed along the supply chain. In the U.S., the Treasury office follows and oversees the movement of physical resources in real time as they move from one party to another all along the supply chain, utilizing virtual information of exchanges of possessions recorded on blockchain (Higgins 2017). Furthermore, blockchain may be utilized to receive shipments in global logistics operations. For example, Maersk, the Danish integrated logistics company recently completed a 20-week blockchain proof-of-concept to track cargo movements. Blockchain technology's cryptographic signatures serve as a powerful safeguard, preventing unauthorized changes to shipping details like names and cargo identification. Furthermore, this integration minimizes the chances of lost shipments during transit, creating a streamlined and trustworthy supply chain environment that operates with greater efficiency (Min 2019; Green 2017; CBS 2015). Companies can also enforce a robust logistics system to control last-mile delivery and secure better overall performance through blockchain (Naclerio 2022).

4.2.3 Safe and Accurate Order Delivery

With easy access and no need for paper-based client information, blockchain will expedite order fulfillment through the supply chain by means of high-speed confirmation of a purchaser's credit history, stock repute, budget, and report on order/delivery popularity while delivering visibility during the order fulfillment process. As shown by the circles in Fig. 5, through the mechanization of the rotated order fulfillment stages, blockchain might reduce back-order fulfillment errors and increase the pace of the order fulfillment procedure. Moreover, because the blockchain ledgers are transparent and can be visited by any peer-to-peer network player (e.g., each customer and vendor), blockchain visibility will improve the transparency of the order fulfillment process and mitigate the risk of fulfillment errors.

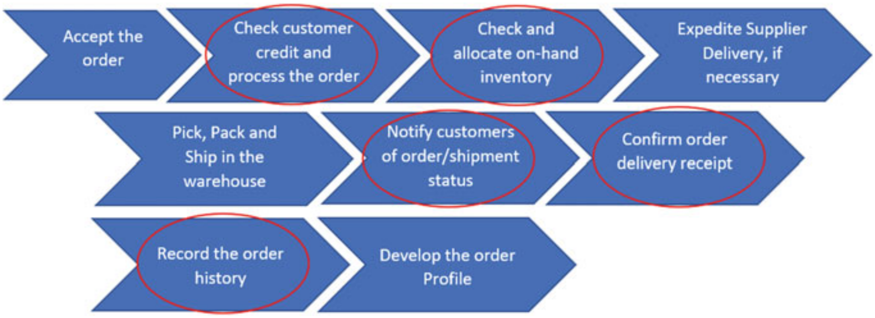

Fig. 5 Part of order fulfillment stages where blockchain technology can be applied (CBS 2015)

4.2.4 Cybersecurity

The last decade has seen a significant increase in cybercrime such as the hacking of the international meat processor JBS and the US oil distribution giant Colonial Pipeline (Naclerio 2022; Oloruntoba and Thompson 2021; Statista 2016). Cybercrime can cripple supply chain processes at any point in the supply chain network. However, despite cybersecurity measures such as antivirus, password security, and hazard cautions to address this issue, the risk of cybercrime has in no way lessened. Efforts at fighting cybercrime may utilize blockchain with its end-to-end encryption, immutability, and privacy, and could reduce the risk of system failure. The immutability of blockchain and the fact that each computer in a P2P network constantly checks data before storing it on the blockchain makes it a high-quality tool to reduce the risk of cybercrime and hacking. Thus, blockchain guarantees the integrity of the transaction record, and nobody, including the record proprietor, can alter the account as soon as the account is locked into the blockchain.

5 Blockchain Technology Applications for Resilience

Global supply chains require a technique that could help to organize facts reliably and provide tools for risk evaluation and disruption mitigation. Such risk management strategies can be constructed with the use of blockchain. Firstly, created to facilitate Bitcoin cryptocurrency exchanges, blockchain consists of a distributed ledger where transactions are patched to more than one computer rather than being stored in one central location. The transparency of transactions involving several parties provides straightforwardness and security. Once records are transferred to the blockchain, they cannot be altered, thereby ensuring permanence and trustworthiness. This becomes the keystone of a sound, computerized supply chain. When transactions are stored in blockchain, all relevant data are obvious to all supply chain entities. The permanence, traceability, and straightforwardness reveal the provenance of items along the entire supply chain.

5.1 Visibility

With the advent of the COVID-19 pandemic, the transparency of most global supply chains began to be questioned in 2020. During the pandemic, a company's sustainability depended on how well it knows and can see all aspects of its value chain. Supply chain structures can collapse under the significant stress of catastrophic global events. Many companies were unaware of the amount of upstream and downstream stock they had, which would enable them to modify demand in a timely fashion. If one company in the supply chain fails, this presents a risk to all other related companies. However, they did not understand enough about the network to realize that the new first-tier provider relies upon the identical old second-tier provider. Moreover, many of those corporations are located within the Chinese epicenter of the current pandemic. These "invisible" producers have had to quickly shut down, or have become understaffed because of quarantine regulations (Tom Linton 2020), which in turn greatly affects companies and supply chains across the world. A supply chain based on blockchain connects all parties within a network, unlocking complex worldwide structures and providing transparency at each step and in each link of the supply chain. Companies can view all tiers, locations, and production facilities of suppliers and subcontractors. Blockchain allows them to evaluate risk, simulate scenarios, perform what if evaluations, and take preventive actions. Additionally, businesses can respond rapidly to unexpectedly changing conditions. Real-time records on the precise location of a product offer businesses more flexibility and control. As an example, a Swiss company orders 100,000 devices, half of which have been made in Japan and half made in Wuhan, China. On the blockchain, the company notices a slowdown in manufacturing in Wuhan. This permits the organization to take the correct action to minimize any adverse impacts.

5.2 Digitization

The global shipment of goods decreased by an estimated 70% during the pandemic, and 40% of China's freight traffic was shut down because of quarantine regulations and fears of spreading infection. Countries have applied many precautions to contain the virus, including banning ships' crew members from disembarking (Ship-technology.com 2020). A few ports required ships to declare that all crew members were healthy and did not have the virus. If COVID-19 was suspected on board, the ships could not dock in port (portofantwerp.com 2020). Despite these precautions, port employees and truckers were still at great risk of infection due to their interactions with people from other regions or countries. A basic weakness of many global commercial enterprises is the lack of end-to-end digitization of various files and procedures within the supply chain, which makes it impossible to function without physical interaction. The level of human interplay in a supply chain creates the trust engendered by the use of specific documentation and/or techniques. Individuals, organizations, nations, and the supply chain need to improve the virtual and digital capabilities of their existing supply chains by establishing trustworthiness, which is not always a feature of business relationships as physical contacts and traditional methods go out of date. Trustworthiness ought to be system-specific. It needs to be scalable to support the supply chain in all circumstances. In this regard, blockchain technology can help enterprises to move toward a trusted virtual supply chain. The blockchain is a reliable virtual database that stores records of transactions between all entities. In this manner, the blockchain offers all participants a single source of information. The shipment of a single ocean container typically involves the participation of approximately 28 different parties, each having their own distinct data storage structures. Even before a ship arrives at the port, the government receives all information pertaining to the owner, shipment contents, team, and direction, all of which require a substantial amount of paperwork, which can be eliminated by using blockchain technology. Port authorities can then determine whether the delivery needs to be checked, quarantined, or cleared. This diminishes uncertainty and the need for human intervention. Blockchain has many advantages and has been implemented in many domains worldwide. Rotterdam, one of the busiest ports in Europe developed a blockchain-based solution for issues related to port logistics. The whole delivery process is document free (portofantwerp.com 2019). In the US, deliveries and orders are transparent to all parties in real time, and monetary transactions are concluded immediately, reducing danger and increasing reliability and interoperability using the US government blockchain in customs control. In the US, due to COVID-19, many logistics personnel have been working from home. This has been facilitated by blockchain which can handle transactions and data storage securely, so customs authorities are not physically present in ports (Gillis 2020). Smart contracts automate digital transactions and establish agreements and conditions. The reconciliation of cargo information can be a labor-intensive and time-consuming procedure, particularly in times of adversity. This places an economic burden on shipping businesses which are already prone to losing their business because of port and government regulations and occasional high volume of demand. Smart contracts may be beneficial in those situations. Through a smart contract, the bill of lading is digitally signed and established as soon as the truck transports the products to the warehouse, and payment is immediately transferred to the shipping company.

Transactions are immediately visible to all stakeholders such as banks, retailers, and shipping corporations. Hence, blockchain technology is of great value in this regard.

5.3 Provenance

Over the last decade, businesses have been pressured to provide dependable and visible supply chain processes, and never more so than during the COVID-19 pandemic. Clients worry that a product might have come from or passed through a place where the virus is rampant. Customers, practitioners, and governments now confirm the location of manufacturers and where they are within the supply chain, and whether or not goods might have been contaminated, spoiled or infected. As an example, consider meat being shipped in a refrigerated container. As soon as the meat arrives in the warehouse, the company takes numerous samples, and the quality is checked in a laboratory. Even though the products may be of high quality, the host organization might not be confident about the origin of the meat or the delivery process of the entire order. The only guarantee of the quality of the meat is the word of the logistics company that the refrigerated storage chain was as promised throughout the delivery process. These concerns can be addressed with the help of blockchain which gives transparency to the activities of various parties such as producers, shipping businesses, cargo transport companies, wholesalers, and retailers who are members of the same blockchain system. When counting the meat items or assessing their quality, the company stores this data and uploads it to the blockchain community. Next, the meat is packaged, transferred to refrigerated packing containers, and transported via sea to diverse areas. Upon arrival at the port, the meat products are transported by refrigerated vehicles to the wholesalers' warehouses from whence it is distributed to retailers. During the journey, tamper-resistant IoT devices within the storage holders and trucks can record temperatures and send readings to the blockchain on an hourly basis. Smart contracts may specify that when the temperature exceeds or falls below a certain level, an immediate notification is sent to relevant parties to warn them of these variations. Decisions can then be made about potentially discarding the product. When the product is bought, purchasers can track the entire product journey by simply scanning the QR code. Knowing the provenance of a product is particularly important in the case of food and other perishable products and food items in order to avoid poisoning. Products from affected areas can be quickly disposed of, and merchandise from secure regions can be shipped as usual. For example, in mid-March 2020, as the COVID-19 pandemic struck the USA with unintended effects and scale, hospitals struggled to ensure an adequate supply of crucial private protective equipment (PPE) that they needed on the front lines. So it is essential to study how corporations in the global food value chains managed their supply chain structures in reaction to the COVID-19, turning it more resilient and competitive in the present pandemic and in future disruptions (Ali 2022; Sanjoy and Moktadir 2021).

6 Role of Blockchain Technology in Mitigating Pandemic-Induced Supply Chain Disruptions

There are five main ways that blockchain helped to address supply chain disruption during the pandemic. These are discussed below.

1. Trust is fundamental because the pandemic hit the supply chain, inflicting shortages, rising costs, and great disruptions to factories, ports, suppliers, and purchasers, customers want a system they can trust. Blockchain is well-known for being a trustworthy system that can operate independently of a person or agency. The trustworthiness of blockchain lies in the fact that it creates an environment consisting of third-party validators, immutable data, unchangeable logic, and supplier information and traceability.
2. Blockchain establishes a foundation of trustworthiness; however, the natural environment brings it to life. Every blockchain establishes a new industry environment in which individuals collaborate and cooperate. But, when trustworthy industry partners participate as validators and solution providers within the industry sector, the advantages are numerous and give the industry additional vitality.
3. Inventory transparency ensures compliance with regulations and the timely transport and delivery of goods. During a pandemic, incorrect information about the most important items that should be delivered can result in severe losses, including loss of lives when there are shortages of essential items. Blockchain can offer real- time transparency of crucial supply chain processes such as procurement, production, transportation, and distribution.
4. The logistics and supply chain domain need a simple and quick solution to problems caused by disruptions such as the pandemic. Supply chain solutions may be very complicated, as massive consortia consisting of numerous members require a single source of trust. Solutions to supply chain problems cannot be created in a single day when an epidemic strikes. To address marketplace issues quickly, market-established and available solutions that have been applied for years are utilized. However, the extent of consolidation may be intimidating and can take a long time. Blockchain can simplify solutions and address supply chain issues quickly, or even prevent them.
5. Trusted digital identification bridges the trustworthiness gap between the digital world and the actual world. Blockchain-based digital identities play a critical role in building trust. Digital identification is defined as the connection between one's real identification and the digital world. A digital copy of any physical item (called a digital twin) is produced in a way that hampers or detects human attempts to change records. For digital business transactions within the supply chain, it is crucial to verify the authenticity of an identity and confirm the identity of one's transaction partner. During the pandemic, other functions of blockchain can help to strengthen supply chain resiliency. These features include ensuring the privacy of shared records, progressive industrial venture styles that bring partners together within the aggressive natural environment, and third-party

arrangement integrations that work on top of those ecosystems. With numerous supply chains now adopting blockchain, and interoperability being addressed effectively, society can become more resilient against the consequences of the current pandemic and future disruptions.

6.1 Discussion

The COVID-19 pandemic revealed the fragility of global supply chains. Companies need to thoroughly identify and assess problems throughout the recovery process and formulate strategies that will ensure the survival of their organizations and supply chains (Sanjoy 2021). Blockchain technology offers immutable record-keeping of all data (Adeodato 2020). Blockchain technology acts as a safeguard by archiving all shared data within a network, effectively preventing interruptions and data breaches commonly encountered through network attacks. Through decentralization, the risk of a single point of failure is dispersed, while the traceability feature of permanent record-keeping, supported by digital signature functions, eliminates the risk of insider attacks originating from individual vector (Bayramova 2021). This is because only authentic customers are permitted in the network. However, in spite of these capability benefits such as the strengthening of resilience against more than one disruption in the 'physical' and 'digital world', there are various challenges related to blockchain implementation for each vendor and each adopter. This requires developing guidelines (as a theoretical framework) that can be used by potential blockchain adopters and vendors. To avoid discrepancies between organizational needs and technological offerings, it is crucial for potential adopters of blockchain technology to clearly define their requirements. By doing so, they can effectively identify and choose appropriate blockchain applications and functionalities that align with their needs, as emphasized by Epiphaniou (2020). Furthermore, vendors are responsible for assessing the compatibility of companies' requirements with the available blockchain solutions, as highlighted by Kshetri (2019). In order to gauge the return on investment (ROI), it is essential to consider the potential value and costs associated with the latest technological solutions, as emphasized by (Lu 2017; Bayramova 2021). For example, adopting a traceability system is profitable for high-value goods (such as diamonds) as a means of preventing the counterfeiting of products (Kshetri 2019) or the selling of products that are perishable, such as medicines with use-by dates, or dairy and meat products that have been spoiled (Lu 2017). Hence, software program developers or vendors should verify the feasibility and degree of adaptability of the adopter's current system to ensure the successful integration of the proposed blockchain solution (Erol 2021). Ultimately, adopters must take into account the interoperability of their selected blockchain solution within supply chains, as the merits of this disruptive technology are leveraged through broad-based acceptance instead of being limited to only one supply chain enterprise (Sternberg n.d.). Furthermore, vendors must examine the degree of technological maturity of potential adopters in order for the blockchain technology to be successful (Erol 2021; Sternberg n.d.).

6.2 Managerial Benefits and Challenges of the Blockchain Technology

In addition to providing greater security as discussed in the previous sections, blockchain can offer a large number of managerial advantages to regular business practices (Techlab 2017; Takahashi 2017), which include: 1. Reduced transaction fees/time as a result of better-preserved blockchain structures that do not necessitate third-party involvement. 2. Improvement of visibility throughout the supply chain, resulting from the increased transparency of open ledgers accessible to all members. 3. The merging of digital and physical realms in the supply chain, as highlighted by Techlab (2017) and Takahashi (2017), leads to enhanced connectivity among trading partners. This integration enables the sharing of transactional information and data across the supply chain, promoting transparency. By utilizing advanced technologies like electronic data interchange (EDI), extensible markup language (XML), and application programming interface (API), blockchain paves the way for swift and traceable interactions, enabling the exchange of unchangeable records among supply chain collaborators, as emphasized by IBM (2017) and Min (2019).

Despite the many advantages of blockchain discussed in the previous section, it has some inadequacies and execution issues mainly due to its complexity, newness and revolutionary technology. A number of those issues are depicted in Fig. 6, the most pressing of which is associated with adaptability, interoperability, and administration.

Each node must process and verify each transaction in a blockchain, so blockchains inherently require massive computing strength and high-speed internet connections, which are not easy to construct even with state-of-the-art technology. If the blockchain centralizes the verification method, such an approach could defeat its unique purpose. In addition, the different platforms available for blockchain make it challenging to locate the optimal mixture of various structures and platforms that are interoperable. Because blockchain relies on a distributed ledger that could evade authorities' intervention, governments can put pressure on blockchain customers by imposing regulatory and criminal limitations. Therefore, this might impede blockchain's ability to guarantee the integrity and privacy of transactions and the movement of assets (De 2018). Unexpectedly, the delivered privacy, confidentiality, and security can make it extremely difficult for law enforcement authorities to choose who oversees digital wallets, making them more vulnerable to scammers looking to steal computerized monetary transactions recorded on the blockchain (Hackett 2017).

7 Summary, Conclusions, and Future Research Directions

Discussions in this chapter suggest that blockchain technology is still in the embryonic stage, although it is likely to evolve to meet societal, economic, and political needs and applications. However, currently, blockchain technology has yet to be widely implemented in supply chains in real-world contexts. Most case examples

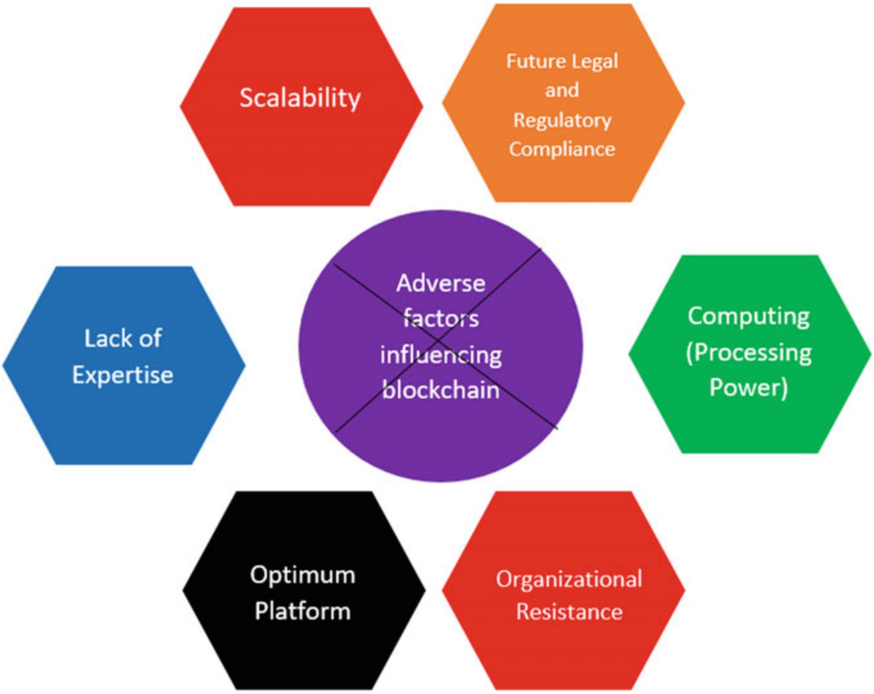

Fig. 6 Potential challenges of blockchain technology (De 2018)

lack standard strategies for designing and validating the blockchain solutions (Perboli 2018). As indicated by Deloitte Insights (2017), a mere 8% of blockchain projects have endured, leaving the majority as unsuccessful endeavors. This lack of success can potentially be attributed to individual users developing isolated blockchain applications, rather than focusing on creating foundational libraries that enable the development of multiple applications (Insights 2017). Furthermore, corporate-led projects tend to incur higher adoption costs compared to user-driven initiatives, as organizational blockchain projects are reportedly five times more likely to be replicated by competitors (Insights 2017; Bayramova 2021). The chapter has discussed the latest trends and filled gaps in the knowledge of blockchain technology. The chapter will enable both researchers and practitioners to better understand the blockchain technology landscape and trends. Further contributions of the chapter include highlighting the practical implications of blockchain for cyber risk management, and the need for guidelines that specify the necessities for blockchain software developers, vendors, and providers. The chapter also highlights the value of blockchain technology as a means of improving trust and time and cost- effectiveness within the supply chain, and strengthening the overall supply chain's resilience during disruptions, such as those caused by the COVID-19 pandemic. The chapter examined the role of smart contracts in enhancing supply chain resilience. It then examined the role of blockchain technology in the building blocks of resilience such as visibility, digitization, and provenance, and then examines the role of blockchain technology in mitigating pandemic-induced supply chain risks, and the benefits and managerial challenges of implementing blockchain technology.

Because blockchain is a relatively new development, there has been little research on it, and the concept is still unfamiliar to most people. Hence, the purpose of this chapter is to establish the conceptual framework for blockchain from a business perspective. The chapter discusses the increasing implementation of blockchain and identified the value of blockchain for supply chain management from a risk/security perspective using commonly accepted supply chain practices and processes. This chapter can be expanded to include and illustrate successful case studies of real-world blockchain programs while evaluating the effects of situational variables such as company size, functional department, budget sizes, and organizational readiness for blockchain adoption (Ashraf 2014; Cooper 1990; Davis 1989; Maruping 2017; Mathieson 1991; Oliveira 2011). Future studies may need to expand the scope of research to determine the causal relationships between these variables and the selection of the most appropriate blockchain solution, while taking into consideration cross-cultural and/or long-term factors. Also, future studies need to investigate the potential effects of different contextual variables along with industry traits, peer pressure, government intervention, and the degree of senior management support for blockchain adoption decisions. Other studies could compare the alignment of blockchain with supply chain resilience that incorporates business insights, cloud computing, robotics, and/or artificial intelligence (AI) (Min 2012). Technologically, blockchain can be an excellent solution to supply chain issues as it provides essential transparency, perceivability, tracking, and trust. In fact, it is emerging as a modern approach to building trust in trust-free surroundings while also providing assurance of availability and security in data management. Dwivedi (2022) It is simple to integrate blockchain with existing enterprise asset-planning systems and supply chain structures. Blockchain levels the playing field by creating an open market and taking control from people who in the past have taken advantage of the weaknesses of current systems. However, on the downside, the implementation of blockchain can cause major disruption to current processes and it could meet with resistance from some supply chain actors.

Some may resent transparency, fearing that blockchain could reveal their network's vulnerabilities and risk factors to their clients. Also, acceptance of, and adaptation to, change can be difficult. However, if supply chain stakeholders or their representatives utilize this opportunity to develop more effective systems, the global supply network can become more robust and much better suited to the volatile requirements of our modern-day world. Customers can be the driving force of this change. Implementation can be facilitated by establishing a consortium of stakeholders in the supply chain network for the purpose of discussing the benefits and demerits of implementing blockchain in global networks. This is because it is likely that there will be other unexpected and unavoidable disruptions, making it essential to take ambitious steps now to design and implement an ultra-resilient supply chain model for the future.

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