Future Economics and Business Studies

E-ISSN: XXXX-XXXX

ARTICLE

Does Blockchain Matter in Industry 4.0? A Key Driver of Industry

Ali Imron [1], M. Elfan Kaukab [2*], Ali Akbar Anggara [3]

[1] Faculty of Creative Design and Digital Business, Institut Teknologi dan Sains Nahdlatul Ulama Pekalongan, Pekalongan, Indonesia; imron.alialta@gmail.com
[2] Faculty of Economics and Business, Universitas Sains Al-Qur'an, Wonosobo, Indonesia; elvankaukab@yahoo.com
[3] Faculty of Economics and Business, Universitas Muhammadiyah Purwokerto, Purwokerto, Indonesia; aliakbarang@ump.ac.id

*Correspondence Author: elvankaukab@yahoo.com

Abstract
The Internet of Things (IoT) has become a fundamental element of Industry 4.0 and is increasingly applied across multiple industrial domains. Nevertheless, reliance on cloud-based storage, computation, and communication introduces several drawbacks, including latency in data transfer, vulnerability to single points of failure, and risks of privacy breaches. In addition, centralized access control limits both the scalability and availability of IoT systems. Blockchain, as a decentralized, immutable, transparent, and tamper-resistant ledger, offers potential solutions to these challenges. The convergence of Blockchain with IoT has enabled the development of diverse distributed applications, ranging from smart healthcare, finance, and supply chains to smart cities, manufacturing, governance, agriculture, transportation, education, e-commerce, and energy grids. To fully address the demands of digital transformation within Industry 4.0, Blockchain integration with enabling technologies such as 5G and artificial intelligence is considered essential.

Keywords: industry 4.0, internet of things (iot), blockchain, 5g, artificial intellegence (ai)

Academic Editor: Gara Huang
Received: August 16, 2025 | Revised: August 25, 2025 | Accepted: August 30, 2025 | Published: September 01, 2025

Citation: Imron, A., Kaukab, M.E., & Anggara, A.A. (2025). *Does Blockchain Matter in Industry 4.0? A Key Driver of Industry*. *Future Economics and Business studies*, 1 (1), 1-20. https://doi.org/10.3390/xxxxx

1. Introduction

Blockchain technology originated with Bitcoin, the first and most successful cryptocurrency. Since the introduction of digital currency in 1983, the expansion of the Internet has created diverse opportunities for its use. At the core of digital currency lies the question of whether encryption should be applied to secure transactions and regulate currency issuance. Blockchain represents a decentralized, tamper-resistant ledger that operates as a distributed network rather than through centralized authority. It combines anonymity, cryptographic techniques, consensus protocols, smart contracts, and reputation mechanisms into a unified framework capable of providing accurate, secure, and traceable services at lower cost while minimizing reliance on intermediaries. With these attributes, blockchain offers businesses distinctive advantages, such as decentralization, stronger security, immutability, and support for strategic decision-making, making its practical application in information systems a crucial issue beyond mere theoretical discourse (Casino et al., 2019).

The accelerated advancement of blockchain has drawn significant attention from researchers. Academic studies increasingly examine its technical foundations, operating models, and potential challenges. However, research into blockchain's role within the field of information systems remains limited. Much of the existing literature has been descriptive in nature, emphasizing blockchain-enabled service provision and technology applications. This reflects a growing trend toward examining blockchain adoption, diffusion, and value creation. Current research spans not only finance and economics but also sociology, management, psychology, and related disciplines, demonstrating blockchain's expanding interdisciplinary relevance.

Industry 4.0, first conceptualized by the German government in 2011, represents a paradigm shift aimed at transforming the manufacturing sector (Javaid et al., 2021; Khan & Javaid, 2021; Li, 2018; Roblek et al., 2016; Vogel-Heuser & Hess, 2016; Xu et al., 2018b). The initiative is driven by technological advancements such as Cyber-Physical Systems (CPS), the Internet of Things (IoT), Internet of Services, Cloud Computing, Big Data, Machine Learning, Mobile Internet, Semantic Web, and virtualization (Li et al., 2015, 2018; Mabkhot et al., 2018; Wang et al., 2017; Whitmore et al., 2015; Xu et al., 2014). Its foundation rests on four essential dimensions: devices, connectivity, tailored services, and optimized data utilization (Aceto et al., 2020; Bellini et al., 2021; de la Peña et al., 2020; Harrison et al., 2016). By promoting decentralized production and integrating shared facilities within a global network, Industry 4.0 seeks to reconfigure value chains and digitalize traditional processes (Brettel et al., 2017; Haleem & Javaid, 2019; Lasi et al., 2014). This digital transformation connects the physical and virtual worlds, generating unprecedented opportunities for industrial growth and innovation (Viriyasitavat et al., 2019; Zhang et al., 2021b).

Viewed historically, Industry 4.0 follows three earlier industrial revolutions. The first was defined by steam and water power, enabling mechanical production and transportation. The second introduced electricity, which replaced steam and facilitated mass mechanization. The third brought about automation through electronics and information technology, significantly improving production efficiency and accuracy. Building upon these stages, Industry 4.0 leverages CPS as its central concept (Xu & Duan, 2019; Xu, 2020a, 2020b). CPS integrates data analytics, communication, and precise control, allowing it to analyze information, generate predictions, and dynamically link virtual and physical processes.

This unified system combines production, logistics, and services to enable real-time monitoring and management. CPS not only supplies relevant information instantly within value chains but also supports optimization of costs, resource allocation, and operational continuity. Through IoT and cloud computing, CPS establishes real-time interaction and cooperation between humans and machines, creating interconnected and adaptive smart factories. These factories are capable of monitoring physical processes, producing virtual counterparts, and making autonomous decisions to improve efficiency and flexibility. Industry 4.0 therefore enables dynamic, self-organizing networks that span organizations and enhance value creation.

The proliferation of connected IoT devices and the unprecedented data they produce present major challenges in terms of security and scalability for Industry 4.0 applications (Mohanta et al., 2020; Wu et al., 2020). Blockchain technology has been proposed as an effective approach to overcome these challenges by enabling tamper-resistant data sharing and secure communications across IoT systems (Alhejazi & Mohammad, 2021; Cagigas et al., 2021; Carvalho et al., 2021; Guo et al., 2021; He et al., 2020).

Blockchain, considered one of the foundational technologies of Industry 4.0, is characterized as a decentralized, transparent, immutable, and append-only ledger (Carvalho et al., 2021; Guo et al., 2021). It essentially acts as a distributed public record that stores transactions in sequential blocks, resistant to faults and malicious attacks (Chen et al., 2021b; Xu et al., 2021). Its design ensures properties such as transparency, fairness, anonymity, and traceability, making it applicable to financial transactions as well as broader value exchange scenarios (Jamil et al., 2021; Nanayakkara et al., 2021).

Different architectures of Blockchain exist, namely permissionless/public and permissioned/private, supported by diverse consensus algorithms like proof-of-work, proof-of-stake, and proof-of-authority (Gourisetti et al., 2019; Viriyasitavat et al., 2019a–2019d). Consensus protocols ensure that all participants maintain a consistent state of the ledger without depending on a central authority (Nerurkar et al., 2021). Encryption, digital signatures, and cryptographic hash functions safeguard integrity and authenticity, while each node keeps a complete copy of the ledger to validate new transactions autonomously (Cocîrlea et al., 2020; Zhang et al., 2021a).

By adopting a peer-to-peer network, Blockchain removes the reliance on intermediaries and enables decentralized governance. This facilitates trust, accountability, and transparency in multi-party systems, such as IoT networks (Alhejazi & Mohammad, 2021; Bouras et al., 2021). Features like smart contracts, tokenization, and distributed consensus add further layers of automation and efficiency, making Blockchain a suitable foundation for self-managing and autonomous IoT ecosystems (Upadhyay et al., 2021).

Moreover, Blockchain contributes significantly to improving privacy, scalability, and interoperability in digital infrastructures. It enables secure value transfer, ensures confidentiality in control systems, and supports cross-boundary trust between different agents and organizations (Song et al., 2021; Rathee et al., 2021). The convergence of Blockchain with edge computing and artificial intelligence further strengthens its potential by reducing latency, securing sensitive data exchanges, and supporting computation-intensive services in IoT and 5G environments (Gu et al., 2020; Haro-Olmo et al., 2021; Yang et al., 2020). Thus, Blockchain not only addresses the limitations of conventional IoT frameworks but also provides a secure, transparent, and decentralized infrastructure for building next-generation Industry 4.0 solutions.

2. Materials and Methods

In Industry 4.0, Blockchain acts as a catalyst for transformation by providing secure mechanisms for authentication, asset management, smart contract deployment, and data exchange (ElMamy et al., 2020). While its earliest applications were concentrated on cryptocurrency transactions, the introduction of Ethereum, which enabled smart contract creation and automated execution, opened the door to broader innovations outside the cryptocurrency sphere (Alwabel & Kwon, 2021; Lone & Naaz, 2021). Smart contracts function as coded agreements that self-execute on the Blockchain without relying on intermediaries, reducing both human error and the risk of fraudulent activity (Ante, 2020; Centobelli et al., 2021; Coblenz et al., 2020; Cocîrlea et al., 2020; Das et al., 2021; Marina & Taskov, 2020).

Because many Blockchain systems are inherently programmable, they enhance trust through stronger security, transparent traceability, and cost-effective operations. As a result, Blockchain has become increasingly recognized as a disruptive force that challenges centralized systems, serving as the underlying infrastructure for decentralized IoT-powered applications. These include solutions in areas such as smart healthcare, smart homes, urban management, energy distribution, transportation, manufacturing, logistics, banking, and insurance (Almagrabi et al., 2021; Lone & Naaz, 2021; Wang et al., 2021b; Yu et al., 2021).

2.1. Smart health care

The rapid progress in health monitoring technologies and the growing availability of remote diagnostic services have contributed to the widespread adoption of electronic health systems in recent years (Biswas et al., 2020; Xu, 2011). One of the key practices in this field is the use of electronic health records, which allow hospitals and medical organizations to document and classify patient information within their databases (Pournaghi et al., 2020; Santos et al., 2021). These systems gather continuous patient data through in-house monitoring devices and transmit it to nearby servers or connected devices for analysis (Aggarwal et al., 2021; Arul et al., 2021; Kumar & Tripathi, 2021a; Ray et al., 2020). However, such processes often lead to fragmented, redundant, and duplicated records across independent healthcare services. Ideally, patients should retain control over their medical data (Rajput et al., 2021), yet, at the same time, sharing these records with healthcare professionals is essential for improving service delivery and ensuring a holistic review of medical history (Charanya & Saravanaguru, 2020; Xiao et al., 2021).

Despite their benefits, electronic health systems face significant challenges, including issues of transparency, traceability, immutability, auditing, provenance, flexible access, trust, privacy, and security (Huang, Sun, et al., 2021; Huang, Zhang, et al., 2021). Currently, there is no unified, trusted platform for storing or exchanging medical information across the healthcare ecosystem (Cernian et al., 2020). Moreover, IoT-enabled devices connected to multiple entities expose vulnerabilities (Aujla & Jindal, 2020), while centralized storage models create risks of single points of failure and breaches of sensitive data (Arul et al., 2021; Biswas et al., 2020; Kumar & Tripathi, 2021b; Qin et al., 2021).

Blockchain technology, as a decentralized and tamper-resistant system, has the potential to transform healthcare data management (Yaqoob et al., 2021). With features such as transparency, distributed validation, and immutability, Blockchain can resolve many of the inefficiencies in managing patient records (Aggarwal et al., 2021; Cadoret et al., 2020; Hussien et al., 2021; Omar et al., 2020; Ray et al., 2020; Yuehong et al., 2016). It enables faster approval processes, seamless interaction among diverse stakeholders, and reduces misinformation and public anxiety during crises (Aggarwal et al., 2021; Omar et al., 2020; Ray et al., 2020). Beyond secure record management, Blockchain also supports interoperability among healthcare providers, facilitating precision medicine and individualized treatment approaches (Tan et al., 2020).

Furthermore, Blockchain-enhanced smart healthcare can go beyond data management by ensuring pharmaceutical product authenticity and preventing counterfeit drugs through supply chain traceability (Danese et al., 2021; Musamih et al., 2021). The incorporation of Blockchain in mobile health services, supported by service-oriented architectures, may also enable decentralized and patient-centered healthcare delivery (Santos et al., 2021).

2.2. Smart Finance

The conventional financial sector is constrained by several critical issues, notably inefficiency, elevated costs, and prolonged transaction durations (Hassani et al., 2018; Tian et al., 2020). As an emerging foundational technology, Blockchain provides a reliable infrastructure to enhance the security of financial operations while mitigating these weaknesses (Rajput et al., 2021; Viriyasitavat et al., 2019).

Its applications extend across numerous areas of finance, including cryptocurrency payments, banking operations, securities and derivatives trading, digital settlements, lending services, and financial auditing (Centobelli et al., 2021). Leveraging Blockchain, cryptocurrencies establish a decentralized certification process that upholds transparency and trust each time a transaction occurs online (Centobelli et al., 2021).

By combining Blockchain with cryptography, cryptocurrencies enable secure and pseudonymous exchanges (Tian et al., 2020). They function using consensus algorithms such as proof-of-work or proof-of-stake to validate transaction authenticity (Sapkota & Grobys, 2019). Well-known Blockchain-based digital currencies include Bitcoin, Ethereum, Litecoin, Ripple, and XRP (Kamidoi et al., 2021; Sapra & Dhaliwal, 2021; Zhao et al., 2021).

2.3. Smart Supply Chain

Industry 4.0 reshapes supply chains into intelligent systems characterized by sustainability, economic efficiency, and social value creation (Li, 2011, 2012; Sharma et al., 2021; Portna et al., 2021). IoT contributes significantly to this transformation, though its limited computing power and reliance on centralized cloud structures expose supply chains to vulnerabilities such as data manipulation and single point failures (Li et al., 2021; Sunny et al., 2020). Furthermore, traditional supply chains face challenges including information asymmetry, inadequate product quality, weak security, and lack of transparency (Lou et al., 2021; Zhang et al., 2021c). Blockchain technology addresses these weaknesses by enhancing supply chain visibility, trust, traceability, and operational efficiency (Centobelli et al., 2021; Khan et al., 2021). By reducing the bullwhip effect and ensuring immutable data management, Blockchain establishes trustworthy collaboration among stakeholders (Moosavi et al., 2021; Park & Li, 2021). It further minimizes reliance on intermediaries, ensures secure asset tracking, and streamlines logistics processes to reduce costs and delays (Kopyto et al., 2020; Maity et al., 2021; Saberi et al., 2019). Thus, Blockchain serves as a critical enabler for building agile, resilient, and smart supply chains (Chen et al., 2021a; Jabbar et al., 2020).

2.4. Smart Cities

Smart cities are designed as intelligent digital systems that leverage large-scale IoT networks to provide services based on real-time data collection and analysis (Bohloul, 2020; Cha et al., 2021; Ianuale et al., 2015). One common example is the smart home, which has improved daily convenience and reshaped modern lifestyles (Carter et al., 2020; Ren et al., 2021; Xu et al., 2018a). However, the rapid expansion of smart city applications also raises concerns regarding data security and privacy (Cha et al., 2021). For instance, crowdsourcing platforms often act as centralized trust hubs for requesters and workers, creating vulnerabilities since financial transactions depend on third-party institutions (Tan et al., 2021).

Blockchain technology is increasingly recognized as a key enabler of smart cities, helping them achieve sustainability in social, environmental, and economic dimensions (Wong et al., 2020). Its decentralized and encrypted structure ensures that information transmitted from edge computing devices remains accurate, secure, and tamper-proof (Ferreira et al., 2021). Moreover, the combination of Blockchain and artificial intelligence enhances the reliability and efficiency of urban infrastructure, public utilities, and citizen services (Alghamdi & Khan, 2021; Singh et al., 2020). Practical implementations include Blockchain-based smart contracts in real estate management to reduce costs and increase transparency (Jayabal & Sathia Bhama, 2021; Ullah & Al-Turjman, 2021), as well as Blockchain-supported waste management solutions. For example, Liu et al. (2021) propose a plastic credit system that tracks recyclability, while Chen and Ogunseitan (2021) introduce a Blockchain-based approach to e-waste repair, reuse, and remanufacturing.

2.5. Smart Manufacturing

Traditional manufacturing is typically organized around centralized control, a structure that results in high operational costs, lack of visibility into processes, delays, limited flexibility to manage unexpected events, and significant risks to security (Uysal & Mergen, 2021; Wang et al., 2020a; Wong et al., 2021; Zhang et al., 2020; Xu et al., 2013, 2012a; b). The integration of blockchain into manufacturing addresses these challenges by enabling decentralized, automated smart manufacturing systems that enhance productivity and efficiency (Ghobakhloo & Ching, 2019; Shahbazi & Byun, 2021a).

Smart manufacturing represents a holistic ecosystem, incorporating production units, resources, business processes, employees, suppliers, and customers. It merges cyber and physical technologies, leading to greater technical precision and complexity (Huo et al., 2020; Rossit et al., 2019). Operating as a multi-agent system, it is driven by intelligent, autonomous, and decentralized devices (Wang et al., 2016). Effective implementation requires both horizontal and vertical collaboration, as well as product lifecycle management and seamless information exchange. Through this, manufacturers are better positioned to deliver reliable, flexible, and adaptive production with reduced costs and improved responsiveness to customer needs (Rajput & Singh, 2020; Wang et al., 2016).

Industry 4.0, guided by smart technologies, reduces wasteful production, material handling inefficiencies, and energy consumption (Harikannan et al., 2020). Blockchain provides the foundation for intelligent automation by supporting decentralized control and connectivity, thus boosting sustainability and competitiveness (Villasante et al., 2020). With advancements in AI, IIoT, cloud platforms, and machine learning, the trajectory of manufacturing is moving toward smarter, data-driven decision-making and continuous improvement (Qu et al., 2020).

2.6. Smart Government

Smart government aims to enhance administrative efficiency, strengthen decision-making processes, and advance public service delivery (Shan et al., 2021). Blockchain serves as a secure and immutable data infrastructure that ensures the protection of sensitive governmental records, streamlines operational procedures, integrates hyper-connected services, and prevents corruption through tamper-proof mechanisms (Fallucchi et al., 2021; Hassija et al., 2020). A notable example is Mattereum, which enables the management of legal rights over assets, objects, and information by tokenizing property and introducing automated custodianship (Fallucchi et al., 2021). Similarly, Gao et al. (2021) propose a consortium Blockchain-based system for electronic certificate sharing, designed to overcome the complexities of cross-border governmental services.

2.7. Smart Agriculture

Food traceability plays a crucial role in both the agricultural industry and the shelf life of food products (Shahbazi & Byun, 2021b). However, traditional food supply chains often fall short of consumer expectations because of centralized control, lack of transparency, and unreliable traceability data (Chen et al., 2021c; Ren et al., 2021b; Yang et al., 2021). Blockchain offers solutions by enabling efficient sorting methods and facilitating agricultural data sharing, thus fostering autonomy and intelligence in precision farming. This integration enhances supply chain efficiency, ensures higher quality management, and improves food safety (Saurabh & Dey, 2021; Torky & Hassanein, 2020; Vivaldini, 2021; Xu et al., 2008).

2.8. Smart Transportation

Drones, or Unmanned Aerial Vehicles (UAVs), have become widely utilized in transportation systems for activities such as road surveillance, logistics delivery, and object tracking, all with limited human intervention (Bera et al., 2021; Jian et al., 2021). These tasks involve transferring vast amounts of data to remote servers for analysis, which necessitates high-performance computing resources, fast data transmission, and reliable networks (Chen et al., 2021a; Han et al., 2021). The rapid growth of UAV usage also brings risks, including security threats, crowded airspace, misuse, and accidental crashes (Singh & Venkatesan, 2021). To secure drone communication, privacy protection and authentication are critical (Xu et al., 2020). Yet, existing solutions struggle with transaction storage overhead, latency, bandwidth constraints, and inconsistent communication reliability (Gupta et al., 2021). Blockchain offers a promising approach by providing secure, reliable communication and safeguarding data integrity (Singh & Venkatesan, 2021). When combined with fog and cloud computing, Blockchain-equipped UAVs can deliver complex, authenticated services with high data availability (Chen et al., 2021a). In addition, Blockchain can enhance Vehicular Ad Hoc Networks (VANETs), which are crucial for real-time vehicle communication and road safety, by enabling secure, anonymous, and rapid vehicle authentication while ensuring transparent and decentralized data management (Maria et al., 2021; Kudva et al., 2021).

2.9. Smart Education

In higher education, current certification systems for academic achievements are often inefficient, costly, and prone to fraud (Capece et al., 2020; Castro & Au-Yong-Oliveira, 2021). Blockchain introduces the concept of *smart education* by enhancing the management of academic transcripts, credentials, student records, and digital libraries (Raimundo & Rosário, 2021). Through its immutable and verifiable nature, Blockchain ensures the authenticity of diplomas and certificates, enabling students to obtain secure, tamper-proof versions more efficiently (Capece et al., 2020). Furthermore, Blockchain promotes decentralization in online education and lifelong learning, granting learners greater autonomy over their educational data and progress (Mikroyannidis et al., 2020). It also strengthens privacy protection, facilitates data sharing, and enhances information traceability within e-Portfolios (Li, 2020; Zheng, 2021).

2.10. Smart e-Commerce

E-commerce has become one of the most dominant retail channels in recent years. Within this domain, Blockchain technology facilitates decentralized marketplaces by enabling secure, real-time transactions, minimizing fraudulent activities, and strengthening both traditional and digital commerce, as well as public and private transportation systems (Christidis & Devetsikiotis, 2016; Mohammed et al., 2021). For instance, Zhou et al. (2021b) developed a Blockchain-based decentralized reputation framework that records and manages the credibility of both buyers and sellers in e-commerce settings. Similarly, Li et al. (2020a) introduced a Blockchain-powered logistics finance execution platform, providing e-commerce retailers with improved efficiency in implementing logistics financing solutions.

2.11. Smart Grid

The global energy market is undergoing a transformation from centralized distribution toward peer-to-peer (P2P) energy exchange, fueled by the proliferation of microgrids that harness renewable resources (Hariharasudan et al., 2020). Households producing green energy can directly trade electricity with one another, creating new opportunities for economic benefit (Doan et al., 2021). To ensure efficiency in supply and demand, grid operators rely heavily on advanced data networks for monitoring, analysis, and system coordination (Khattak et al., 2020; Marín-López et al., 2020).

Blockchain serves as a critical enabler of this transition, as it allows secure integration of vast and growing interconnections in distributed grids. It supports the movement toward active distribution networks by safeguarding privacy and reliability in decentralized electricity transactions (Hariharasudan et al., 2020; Mollah et al., 2020; Guo et al., 2020).

Smart grids, designed with cloud and fog computing infrastructures, represent a new paradigm in power systems by incorporating renewable and green technologies (Khattak et al., 2020; Mollah et al., 2020). They enable two-way flows of both electricity and information across networks, allowing dynamic optimization of transmission based on real-time user needs and predictive scheduling (Kumar et al., 2020; Wang et al., 2020b; He et al., 2021). This innovation significantly reduces theft, losses, and operational expenses while improving customer interaction and comfort (Khattak et al., 2020). With self-healing mechanisms, smart grids empower consumers as active participants (Kumar et al., 2020). Blockchain further strengthens these capabilities by ensuring data integrity, preventing tampering, deletion, or unauthorized alterations of energy records (Khattak et al., 2020).

3. Result and Discussion

Blockchain technology offers significant potential for enhancing data sharing and trust computation, yet several obstacles remain unresolved. Key challenges include interoperability, survivability, and manageability (Hardjono et al., 2019). Current Blockchain systems also face major technical constraints such as excessive energy consumption, inefficiencies in consensus mechanisms, heavy computational overhead, and limited transaction throughput (Centobelli et al., 2021; Yang et al., 2020; Yun et al., 2020). High transaction latency further creates uncertainty among participants (Centobelli et al., 2021).

The operation of Blockchain requires massive computational resources, trusted authorities, extensive storage for ever-growing blockchains, and high CPU processing capabilities to execute consensus algorithms (Andola et al., 2020; Ekanayake & Halgamuge, 2021; Na & Park, 2021). Consequently, existing Blockchain solutions are not well-suited for IoT devices (Yun et al., 2020). Similarly, Blockchain mining and computation-intensive applications demand considerable processing and storage capacity, which limits its deployment in mobile environments (Nguyen et al., 2020). To ensure reliability, Blockchain systems must also achieve robust fault tolerance for maintaining safety and liveness in publicly accessible and verifiable ledgers (Nijsse & Litchfield, 2020). Despite its cryptographic foundations, Blockchain remains vulnerable to security breaches and privacy threats (Yu et al., 2021; Zamani et al., 2020; Zhou et al., 2021a). For instance, the structure of Blockchain makes the latest block particularly exposed to attacks, where malicious nodes may alter data, generate new blocks, and manipulate the chain (Alwabel & Kwon, 2021).

Beyond technical limitations, organizational and managerial barriers also hinder Blockchain adoption. These include misalignment with information system success models and task–technology fit (Alazab et al., 2021), low awareness and understanding among businesses (Mathivathanan et al., 2021), competitive and partner-related pressures (Kamble et al., 2021), inadequate top management support, insufficient competitive pressure, and lack of technical competence (Fernando et al., 2021). Regulatory uncertainty and the absence of clear legal frameworks further complicate adoption (Balasubramanian et al., 2021).

Nevertheless, Blockchain offers promising attributes such as decentralization, transparency, interoperability, immutability, traceability, and privacy protection, making it a viable enabler for Industry 4.0 applications (Zhang et al., 2020). Its integration with IoT significantly expands potential use cases (Centobelli et al., 2021), including smart healthcare, finance, supply chain, cities, manufacturing, government, agriculture, transportation, education, e-commerce, and energy systems.

Emerging technologies are reshaping the Blockchain landscape. The expansion of fifth-generation (5G) networks has accelerated data processing and transmission capabilities, while edge computing provides distributed computational power and reduces latency compared to traditional cloud computing (Shahbazi & Byun, 2021b; Sun et al., 2021; Wu et al., 2020). With the deployment of network slicing and mobile edge computing, 5G enhances network flexibility and responsiveness (Togou et al., 2020). The ubiquity of mobile devices further drives the development of Blockchain-enabled applications on mobile platforms (Kamble et al., 2021).

Artificial Intelligence (AI) also plays a crucial role in Industry 4.0, enabling capabilities such as self-optimization, self-awareness, and self-monitoring (Peres et al., 2020). By perceiving their environment, analyzing acquired data, and solving complex problems through learning, AI systems are transforming manufacturing processes and business models. The convergence of AI and Blockchain has the potential to establish secure, immutable, and decentralized infrastructures for managing the sensitive information generated and used by AI-driven systems (Centobelli et al., 2021). Organizations can benefit from this synergy to address the multifaceted challenges of digital transformation.

4. Conclusions

A comprehensive understanding of Blockchain adoption requires examining governance and risk management, technological features, potential benefits, and its integration with other emerging technologies such as IoT, cloud computing, and 6G. Such integration highlights that the relevant unit of analysis is not limited to individual firms but extends to networks and ecosystems shaped by Blockchain.

Blockchain stands as one of the most disruptive innovations in ICT, offering scalability, interoperability, and adaptability that provide fertile ground for further IS research. Future inquiries will likely address how organizations—both traditional and digital-native—can absorb and adapt Blockchain to create business value and sustain competitive advantage.

Acknowledgments: The authors would like to express their sincere gratitude to all individuals and institutions that provided administrative and technical support throughout this research. Special thanks are extended to Universitas Muhammadiyah Purwokerto for their valuable assistance and contributions.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manu- script; or in the decision to publish the results.

References

Abidi, M. H., Alkhalefah, H., Umer, U., & Mohammed, M. K. (2021). Blockchain-based secure information sharing for supply chain management: Optimization assisted data sanitization process. International Journal of Intelligent Systems, 36(1), 260–290.

Aceto, G., Persico, V., & Pescapé, A. (2020). Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0. Journal of Industrial Information Integration, 18, 100129.

Aggarwal, S., Kumar, N., Alhussein, M., & Muhammad, G. (2021). Blockchain-Based UAV Path Planning for Healthcare 4.0: Current Challenges and the Way Ahead. IEEE Network, 35(1), 20–29.

Alazab, M., Alhyari, S., Awajan, A., & Abdallah, A. B. (2021). Blockchain technology in supply chain management: An empirical study of the factors affecting user adoption/acceptance. Cluster Computing, 24(1), 83–101.

Alghamdi, N. S., & Khan, M. A. (2021). Energy-efficient and blockchain-enabled model for internet of things (iot) in smart cities. CMC-Computers Materials & Continua, 66(3), 2509–2524.

Alhejazi, M. M., & Mohammad, R. M. A. (2021). Enhancing the blockchain voting process in IoT using a novel blockchain Weighted Majority Consensus Algorithm (WMCA). Information Security Journal: A Global Perspective, 1–19. Almagrabi, A. O., Ali, R., Alghazzawi, D., AlBarakati, A., & Khurshaid, T. (2021). Blockchain-as-a-utility for next-generation healthcare internet of things. CMC-Computers Materials & Continua, 68(1), 359–376.

Al-Rakhami, M. S., & Al-Mashari, M. (2021). A blockchain-based trust model for the internet of things supply chain management. Sensors, 21(5), 1759.

Alsamhi, S. H., Lee, B., Guizani, M., Kumar, N., Qiao, Y., & Liu, X. (2021). Blockchain for decentralized multi-drone to combat COVID-19 and future pandemics: Framework and proposed solutions. Transactions on Emerging Telecommunications Technologies, e4255. Alwabel, M., & Kwon, Y. (2021). Blockchain consistency check protocol for improved reliability. Computer Systems Science and Engineering, 36(2), 281–292.

Andola, N., Venkatesan, S., & Verma, S. (2020). PoEWAL: A lightweight consensus mechanism for blockchain in IoT. Pervasive and Mobile Computing, 69, 101291.

Ante, L. (2020). Smart contracts on the blockchain–a bibliometric analysis and review. Telematics and Informatics, 101519.

Arul, R., Al-Otaibi, Y. D., Alnumay, W. S., Tariq, U., Shoaib, U., & Piran, M. J. (2021). Multi-modal secure healthcare data dissemination framework using blockchain in IoMT. Personal and Ubiquitous Computing, 1–13.

Aujla, G. S., & Jindal, A. (2020). A decoupled blockchain approach for edge-envisioned IoT-based healthcare monitoring. IEEE Journal on Selected Areas in Communications.

Bader, L., Pennekamp, J., Matzutt, R., Hedderich, D., Kowalski, M., Lücken, V., & Wehrle, K. (2021). Blockchain-based privacy preservation for supply chains supporting lightweight multihop information accountability. Information Processing & Management, 58(3), 102529.

Balasubramanian, S., Shukla, V., Sethi, J. S., Islam, N., & Saloum, R. (2021). A readiness assessment framework for Blockchain adoption: A healthcare case study. Technological Forecasting and Social Change, 165, 120536.

Bellini, P., Cenni, D., Mitolo, N., Nesi, P., Pantaleo, G., & Soderi, M. (2021). High Level Control of Chemical Plant by Industry 4.0 Solutions. Journal of Industrial Information Integration, 100276.

Bera, B., Das, A. K., & Sutrala, A. K. (2021). Private blockchain-based access control mechanism for unauthorized UAV detection and mitigation in Internet of Drones environment. Computer Communications, 166, 91–109.

Biswas, S., Sharif, K., Li, F., Latif, Z., Kanhere, S. S., & Mohanty, S. P. (2020). Interoperability and synchronization management of blockchain-based decentralized e-health systems. IEEE Transactions on Engineering Management, 67(4), 1363–1376.

Bohloul, S. M. (2020). Smart cities: A survey on new developments, trends, and opportunities. Journal of Industrial Integration and Management, 5(03), 311–326.

Bordel, B., Alcarria, R., & Robles, T. (2021). Denial of Chain: Evaluation and prediction of a novel cyberattack in Blockchainsupported systems. Future Generation Computer Systems, 116, 426–439.

Bouras, M. A., Lu, Q., Dhelim, S., & Ning, H. (2021). A Lightweight Blockchain-Based IoT Identity Management Approach. Future Internet, 13(2), 24.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2017). How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. FormaMente, 12.

Cadoret, D., Kailas, T., Velmovitsky, P., Morita, P., & Igboeli, O. (2020). Proposed implementation of Blockchain in British Columbia's Health care data management. Journal of Medical Internet Research, 22(10), e20897.

Cagigas, D., Clifton, J., Diaz-Fuentes, D., & Fernández-Gutiérrez, M. (2021). Blockchain for public services: A systematic literature review. IEEE Access, 9, 13904–13921.

Capece, G., Levialdi Ghiron, N., & Pasquale, F. (2020). Blockchain technology: Redefining trust for digital certificates. Sustainability, 12(21), 8952.

Carter, E., Adam, P., Tsakis, D., Shaw, S., Watson, R., & Ryan, P. (2020). Enhancing pedestrian mobility in smart cities using big data. Journal of Management Analytics, 7(2), 173–188.

Carvalho, A., Merhout, J. W., Kadiyala, Y., & Bentley II, J. (2021). When good blocks go bad: Managing unwanted blockchain data. International Journal of Information Management, 57, 102263.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. Telematics and Informatics, 36, 55–81.

Centobelli, P., Cerchione, R., Esposito, E., & Oropallo, E. (2021). Surfing blockchain wave, or drowning? Shaping the future of distributed ledgers and decentralized technologies. Technological Forecasting and Social Change, 165, 120463.

Cernian, A., Tiganoaia, B., Sacala, I., Pavel, A., & Iftemi, A. (2020). PatientDataChain: A Blockchain-Based approach to integrate personal health records. Sensors, 20(22), 6538.

Cha, J., Singh, S. K., Kim, T. W., & Park, J. H. (2021). Blockchainempowered cloud architecture based on secret sharing for smart city. Journal of Information Security and Applications, 57, 102686.

Charanya, R., & Saravanaguru, R. A. K. (2020). Integrity of e-health record ensured with context-based merkle tree through temporal shadow in Blockchain. International Journal of Information Technology and Web Engineering (IJITWE), 15(4), 72–87.

Chen, C. L., Chiang, M. L., Deng, Y. Y., Weng, W., Wang, K., & Liu, C. C. (2021a). A traceable firearm management system based on blockchain and IoT technology. Symmetry, 13(3), 439.

Chen, C. L., Deng, Y. Y., Weng, W., Zhou, M., & Sun, H. (2021b). A blockchain-based intelligent anti-switch package in tracing logistics system. The Journal of Supercomputing, 1–42. Chen, C. L., Lin, C. Y., Chiang, M. L., Deng, Y. Y., Chen, P., & Chiu, Y. J. (2021c). A traceable online will system based on blockchain and smart contract technology. Symmetry, 13(3), 466.

Chen, H., Chen, Z., Lin, F., & Zhuang, P. (2021d). Effective management for blockchain-based agri-food supply chains using deep reinforcement learning. IEEE Access, 9, 36008–36018.

Chen, M., & Ogunseitan, O. A. (2021). Zero E-waste: Regulatory impediments and blockchain imperatives. Frontiers of Environmental Science & Engineering, 15(6), 114.

Chen, J., Wang, W., Zhou, Y., Ahmed, S. H., & Wei, W. (2021e). Exploiting 5G and blockchain for medical applications of drones. IEEE Network, 35(1), 30–36.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. Ieee Access, 4, 2292–2303.

Coblenz, M., Oei, R., Etzel, T., Koronkevich, P., Baker, M., Bloem, Y., Myers, B. A., Sunshine, J., & Aldrich, J. (2020). Obsidian: Typestate and assets for safer blockchain programming. ACM Transactions on Programming Languages and Systems (TOPLAS), 42(3), 1–82.

Cocîrlea, D., Dobre, C., Hîrţan, L. A., & Purnichescu-Purtan, R. (2020). Blockchain in intelligent transportation systems. Electronics, 9(10), 1682.

de la Peña Zarzuelo, I., Soeane, M. J. F., & Bermúdez, B. L. (2020). Industry 4.0 in the port and maritime industry: A literature review. Journal of Industrial Information Integration, 100173.

Danese, P., Mocellin, R., & Romano, P. (2021). Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study. International Journal of Operations & Production Management. Das, D., Banerjee, S., Ghosh, U., Biswas, U., & Bashir, A. K. (2021). A decentralized vehicle anti-theft system using Blockchain and smart contracts. Peer-to-Peer Networking and Applications, 1–14. Demirkan, S., Demirkan, I., & McKee, A. (2020). Blockchain technology in the future of business cyber security and accounting. Journal of Management Analytics, 7(2), 189–208.

Doan, H. T., Cho, J., & Kim, D. (2021). Peer-to-Peer Energy Trading in Smart Grid Through Blockchain: A Double Auction-Based Game Theoretic Approach. IEEE Access, 9, 49206–49218.

Du, Y., Wang, Z., & Leung, V. (2021). Blockchain-Enabled Edge Intelligence for IoT: Background, Emerging Trends and Open Issues. Future Internet, 13(2), 48. ElMamy, S. B., Mrabet, H., Gharbi, H., Jemai, A., & Trentesaux, D. (2020).

A survey on the usage of blockchain technology for cyber-threats in the context of industry 4.0. Sustainability, 12(21), 9179.

Ekanayake, O. A., & Halgamuge, M. N. (2021). Lightweight Blockchain Framework using Enhanced Master-Slave Blockchain Paradigm: Fair Rewarding Mechanism using Reward Accuracy Model. Information Processing & Management, 58(3), 102523.

Falcone, E. C., Steelman, Z. R., & Aloysius, J. A. (2021). Understanding Managers' Reactions to Blockchain Technologies in the Supply Chain: The Reliable and Unbiased Software Agent. Journal of Business Logistics, 42(1), 25–45.

Fallucchi, F., Gerardi, M., Petito, M., & De Luca, E. W. (2021, January). Blockchain framework in digital government for the certification of authenticity, timestamping and data property. In Proceedings of the 54th Hawaii International Conference on System Sciences (p. 2307). Fernando, Y., Rozuar, N. H. M., & Mergeresa, F. (2021). The blockchain-enabled technology and carbon performance: Insights from early adopters. Technology in Society, 64, 101507.

Ferreira, C. M. S., Garrocho, C. T. B., Oliveira, R. A. R., Silva, J. S., & Cavalcanti, C. F. M. D. C. (2021). IoT registration and authentication in smart city applications with Blockchain. Sensors, 21(4), 1323. Gao, Y., Pan, Q., Liu, Y., Lin, H., Chen, Y., & Wen, Q. (2021). The notarial office in e-government: A Blockchain-based solution. IEEE Access, 9, 44411–44425.

Ghobakhloo, M., & Ching, N. T. (2019). Adoption of digital technologies of smart manufacturing in SMEs. Journal of Industrial Information Integration, 16, 100107.

Gopalakrishnan, P. K., Hall, J., & Behdad, S. (2021). Cost analysis and optimization of Blockchain-based solid waste management traceability system. Waste Management, 120, 594–607.

Gorkhali, A., Li, L., & Shrestha, A. (2020). Blockchain: A literature review. Journal of Management Analytics, 7(3), 321–343. Gourisetti, S. N. G., Mylrea, M., & Patangia, H. (2019). Evaluation and demonstration of blockchain applicability framework. IEEE Transactions on Engineering Management, 67(4), 1142–1156.

Gu, S., Luo, X., Guo, D., Ren, B., Tang, G., Xie, J., & Sun, Y. (2020). Joint Chain-Based Service Provisioning and Request Scheduling for Blockchain-Powered Edge Computing. IEEE Internet of Things Journal. Guo, J., Ding, X., & Wu, W. (2020). A blockchain-enabled ecosystem for distributed electricity trading in smart city. IEEE Internet of Things Journal. Guo, Y. M., Huang, Z. L., Guo, J., Guo, X. R., Li, H., Liu, M. Y., Ezzeddine, S., & Nkeli, M. J. (2021). A bibliometric analysis and visualization of blockchain. Future Generation Computer Systems, 116, 316–332.

Gupta, R., Kumari, A., & Tanwar, S. (2021). Fusion of blockchain and artificial intelligence for secure drone networking underlying 5G communications. Transactions on Emerging Telecommunications Technologies, 32(1), e4176.

Haleem, A., & Javaid, M. (2019). Additive manufacturing applications in industry 4.0: a review. Journal of Industrial Integration and Management, 4(04), 1930001.

Han, T., Ribeiro, I. D. L., Magaia, N., Preto, J., Segundo, A. H. F. N., de Macêdo, A. R. L., Muhammad, K., & de Albuquerque, V. H. C. (2021). Emerging drone trends for Blockchain-based 5g networks: Open issues and future perspectives. IEEE Network, 35(1), 38–43.

Hardjono, T., Lipton, A., & Pentland, A. (2019). Toward an interoperability architecture for blockchain autonomous systems. IEEE Transactions on Engineering Management, 67(4), 1298–1309.

Hariharasudan, A., Otola, I., & Bilan, Y. (2020). Reactive power optimization and price management in microgrid enabled with blockchain. Energies, 13(23), 6179.

Harikannan, N., Vinodh, S., & Gurumurthy, A. (2020). Sustainable industry 4.0–an exploratory study for uncovering the drivers for integration. Journal of Modelling in Management. Haro-Olmo, F. J., Alvarez-Bermejo, J. A., Varela-Vaca, A. J., & LópezRamos, J. A. (2021). Blockchain-based federation of wireless sensor nodes. The Journal of Supercomputing, 1–13. Harrison, R., Vera, D., & Ahmad, B. (2016). Engineering methods and tools for cyber–physical automation systems. Proceedings of the IEEE, 104(5), 973–985.

Hassan, M. U., Rehmani, M. H., & Chen, J. (2020). Differential privacy in blockchain technology: A futuristic approach. Journal of Parallel and Distributed Computing, 145, 50–74.

Hassani, H., Huang, X., & Silva, E. (2018). Banking with blockchained big data. Journal of Management Analytics, 5(4), 256–275.

Hassija, V., Chamola, V., Krishna, D. N. G., Kumar, N., & Guizani, M. (2020). A Blockchain and Edge Computing-based Secure Framework for Government Tender Allocation. IEEE Internet of Things Journal.

He, Y., Wang, Y., Qiu, C., Lin, Q., Li, J., & Ming, Z. (2020). Blockchain-based edge computing resource allocation in IoT: A deep reinforcement learning approach. IEEE Internet of Things Journal.

He, Y., Xiong, W., Yang, B. Y., Zhang, R., Cui, M. L., Feng, T. T., & Sun, Y. E. (2021). Distributed energy transaction model based on the alliance Blockchain in case of China. Journal of Web Engineering, 359–386.

Huang, H., Sun, X., Xiao, F., Zhu, P., & Wang, W. (2021a). Blockchain-based eHealth system for auditable EHRs manipulation in cloud environments. Journal of Parallel and Distributed Computing, 148, 46–57.

Huang, K., Zhang, X., Mu, Y., Rezaeibagha, F., & Du, X. (2021b). Scalable and redactable blockchain with update and anonymity. Information Sciences, 546, 25–41.

Huo, J., Zhang, J., & Chan, F. T. (2020). A fuzzy control system for assembly line balancing with a three-state degradation process in the era of Industry 4.0. International Journal of Production Research, 58(23), 7112–7129.

Hussien, H. M., Yasin, S. M., Udzir, N. I., Ninggal, M. I. H., & Salman, S. (2021). Blockchain technology in the healthcare industry: Trends and opportunities. Journal of Industrial Information Integration, 22, 100217.

Ianuale, N., Schiavon, D., & Capobianco, E. (2015). Smart cities and urban networks: Are smart networks what we need? Journal of Management Analytics, 2(4), 285–294.

Iyer, K. V., & Kumar, V. R. (2021). Using blockchain technology in credit rating industry to promote an innovative bond-pays model. International Journal of Innovation Science. Jabbar, S., Lloyd, H., Hammoudeh, M., Adebisi, B., & Raza, U. (2020). Blockchain-enabled supply chain: analysis, challenges, and future directions. Multimedia Systems, 1–20. Jamil, F., Kahng, H. K., Kim, S., & Kim, D. H. (2021). Towards Secure Fitness Framework Based on IoT-Enabled Blockchain Network Integrated with Machine Learning Algorithms. Sensors, 21(5), 1640.

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2021). Significant applications of big data in Industry 4.0. Journal of Industrial Integration and Management, 1–19. Jayabal, C. P., & Sathia Bhama, P. R. (2021). Performance analysis on diversity mining-based proof of work in bifolded consortium blockchain for Internet of Things consensus. Concurrency and Computation: Practice and Experience, e6285. Jian, X., Leng, P., Wang, Y., Alrashoud, M., & Hossain, M. S. (2021). Blockchain-Empowered Trusted Networking for Unmanned Aerial Vehicles in the B5G Era. IEEE Network, 35(1), 72–77.

Kakarlapudi, P. V., & Mahmoud, Q. H. (2021, February). A Systematic Review of Blockchain for Consent Management. In Healthcare (Vol. 9, No. 2, p. 137). Multidisciplinary Digital Publishing Institute. Kamble, S. S., Gunasekaran, A., Kumar, V., Belhadi, A., & Foropon, C. (2021). A machine learning based approach for predicting blockchain adoption in supply Chain. Technological Forecasting and Social Change, 163, 120465.

Kamidoi, Y., Yamauchi, R., & Wakabayashi, S. I. (2021). A protocol for preventing transaction commitment without recipient's authorization on Blockchain and it's implementation. IEEE Access, 9, 24390–24405.

Karamchandani, A., Srivastava, S. K., Kumar, S., & Srivastava, A. (2021). Analysing perceived role of blockchain technology in SCM context for the manufacturing industry. International Journal of Production Research, 1–32. Khan, I. H., & Javaid, M. (2021). Role of Internet of Things (IoT) in adoption of Industry 4.0. Journal of Industrial Integration and Management, 2150006.

Khan, S., Singh, R., & Kirti. (2021). Critical Factors for Blockchain Technology Implementation: A Supply Chain Perspective. Journal of Industrial Integration and Management, 2150011. Khattak, H. A., Tehreem, K., Almogren, A., Ameer, Z., Din, I. U., & Adnan, M. (2020). Dynamic pricing in industrial internet of things: Blockchain application for energy management in smart cities. Journal of Information Security and Applications, 55, 102615.

Kopyto, M., Lechler, S., Heiko, A., & Hartmann, E. (2020). Potentials of blockchain technology in supply chain management: Long-term judgments of an international expert panel. Technological Forecasting and Social Change, 161, 120330.

Kudva, S., Badsha, S., Sengupta, S., Khalil, I., & Zomaya, A. (2021). Towards secure and practical consensus for blockchain based VANET. Information Sciences, 545, 170–187.

Kumar, N. M., Chand, A. A., Malvoni, M., Prasad, K. A., Mamun, K. A., Islam, F. R., & Chopra, S. S. (2020). Distributed energy resources and the application of AI, IoT, and blockchain in smart grids. Energies, 13(21), 5739.

Kumar, R., & Tripathi, R. (2021a). Towards design and implementation of security and privacy framework for internet of medical things (iomt) by leveraging blockchain and ipfs technology. The Journal of Supercomputing, 1–40. Kumar, R., & Tripathi, R. (2021b). DBTP2SF: A deep blockchain- based trustworthy privacy-preserving secured framework in industrial internet of things systems. Transactions on Emerging Telecommunications Technologies, 32(4), e4222.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industrie 4.0. Wirtschaftsinformatik, 56(4), 261–264.

Latif, S., Idrees, Z., Ahmad, J., Zheng, L., & Zou, Z. (2021). A blockchain-based architecture for secure and trustworthy operations in the industrial Internet of Things. Journal of Industrial Information Integration, 21, 100190.

Lazrag, H., Chehri, A., Saadane, R., & Rahmani, M. D. (2020). Efficient and secure routing protocol based on Blockchain approach for wireless sensor networks. Concurrency and Computation: Practice and Experience, e6144. Li, H., Han, D., & Tang, M. (2021a). Logisticschain: A Blockchainbased secure storage scheme for logistics data. Mobile Information Systems, 2021. Li, L. (2012). Effects of enterprise technology on supply chain collaboration: Analysis of China-linked supply chain. Enterprise Information Systems, 6(1), 55–77.

Li, L. (2018). China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0." Technological Forecasting and Social Change, 135, 66–74.

Li, L. (2020). Education supply chain in the era of Industry 4.0. Systems Research and Behavioral Science, 37(4), 579–592.

Li, M., Shao, S., Ye, Q., Xu, G., & Huang, G. Q. (2020a). Blockchainenabled logistics finance execution platform for capital-constrained E-commerce retail. Robotics and Computer-Integrated Manufacturing, 65, 101962.

Li, S., Xu, L., & Zhao, S. (2015). The internet of things: A survey. Information Systems Frontiers, 17(2), 243–259.

Li, S., Xu, L., & Zhao, S. (2018). 5G Internet of Things: A survey. Journal of Industrial Information Integration, 10, 1–9.

Li, X., Zheng, Z., & Dai, H. N. (2021b). When services computing meets blockchain: Challenges and opportunities. Journal of Parallel and Distributed Computing, 150, 1–14.

Li, Z., Xu, M., Nie, J., Kang, J., Chen, W., & Xie, S. (2020b). NOMAEnabled Cooperative Computation Offloading for BlockchainEmpowered Internet of Things: A Learning Approach. IEEE Internet of Things Journal. Liu, C., Zhang, X., & Medda, F. (2021). Plastic credit: A consortium blockchain-based plastic recyclability system. Waste Management, 121, 42–51.

Liu, X. (2021). Towards Blockchain-Based Resource Allocation Models for Cloud-Edge Computing in IoT Applications. Wireless Personal Communications, 1–19. Lone, A. H., & Naaz, R. (2021). Applicability of Blockchain smart contracts in securing Internet and IoT: a systematic literature review. Computer Science Review, 39, 100360.

Lou, M., Dong, X., Cao, Z., & Shen, J. (2021). SESCF: a secure and efficient supply chain framework via blockchain-based smart contracts. Security and Communication Networks, 2021. Ma, Z. F., Meng, J. L., Wang, J. H., & Shan, Z. G. (2020). Blockchainbased Decentralized Authentication Modeling Scheme in Edge and IoT Environment. IEEE Internet of Things Journal.

Mabkhot, M. M., Al-Ahmari, A. M., Salah, B., & Alkhalefah, H. (2018). Requirements of the smart factory system: A survey and perspective. Machines, 6(2), 23.

Maity, M., Tolooie, A., Sinha, A. K., & Tiwari, M. K. (2021). Stochastic batch dispersion model to optimize traceability and enhance transparency using Blockchain. Computers & Industrial Engineering, 154, 107134. Maria, A., Pandi, V., Lazarus, J. D., Karuppiah, M., & Christo, M. S. (2021). BBAAS: Blockchain-Based Anonymous Authentication Scheme for Providing Secure Communication in VANETs. Security and Communication Networks, 2021. Marina, N., & Taskov, P. (2020). Blockchain-Based Application for Certification Management. Tehnički Glasnik, 14(4), 488–492.

Marín-López, A., Chica-Manjarrez, S., Arroyo, D., Almenares-Mendoza, F., & Díaz-Sánchez, D. (2020). Security Information Sharing in Smart Grids: Persisting Security Audits to the Blockchain. Electronics, 9(11), 1865.

Mathivathanan, D., Mathiyazhagan, K., Rana, N. P., Khorana, S., & Dwivedi, Y. K. (2021). Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modelling (TISM) approach. International Journal of Production Research, 1–22. Meng, W., Li, W., & Zhou, J. (2021). Enhancing the security of blockchain-based software defined networking through trust-based traffic fusion and filtration. Information Fusion, 70, 60–71.

Mikroyannidis, A., Third, A., & Domingue, J. (2020). A case study on the decentralisation of lifelong learning using blockchain technology. Journal of Interactive Media in Education, 2020(1).

Mohammed, S., Fiaidhi, J., Ramos, C., Kim, T. H., Fang, W. C., & Abdelzaher, T. (2021). Blockchain in eCommerce: A special issue of the ACM transactions on internet of thingsBlockchain in eCommerce: A special issue of the ACM transactions on internet of things. ACM Transactions on Internet Technology (TOIT), 21(1), 11–55.

Mohanta, B. K., Jena, D., Ramasubbareddy, S., Daneshmand, M., & Gandomi, A. H. (2020). Addressing security and privacy issues of IoT using blockchain technology. IEEE Internet of Things Journal, 8(2), 881–888.

Mollah, M. B., Zhao, J., Niyato, D., Lam, K. Y., Zhang, X., Ghias, A. M., Koh, L. H., & Yang, L. (2020). Blockchain for future smart grid: A comprehensive survey. IEEE Internet of Things Journal, 8(1), 18–43.

Moosavi, J., Naeni, L. M., Fathollahi-Fard, A. M., & Fiore, U. (2021). Blockchain in supply chain management: a review, bibliometric, and network analysis. Environmental Science and Pollution Research, 1–15. Mukherjee, A. A., Singh, R. K., Mishra, R., & Bag, S. (2021). Application of blockchain technology for sustainability development in agricultural supply chain: justification framework. Operations Management Research, 1–16. Musamih, A., Salah, K., Jayaraman, R., Arshad, J., Debe, M., Al-Hammadi, Y., & Ellahham, S. (2021). A Blockchain-based approach for drug traceability in healthcare supply chain. IEEE Access, 9, 9728–9743.

Na, D., & Park, S. (2021). Fusion chain: A decentralized lightweight blockchain for IoT security and privacy. Electronics, 10(4), 391. Nanayakkara, S., Rodrigo, M. N. N., Perera, S., Weerasuriya, G. T., & Hijazi, A. A. (2021). A methodology for selection of a Blockchain platform to develop an enterprise system. Journal of Industrial Information Integration, 23, 100215.

Nerurkar, P., Patel, D., Busnel, Y., Ludinard, R., Kumari, S., & Khan, M. K. (2021). Dissecting bitcoin blockchain: Empirical analysis of bitcoin network (2009–2020).

Journal of Network and Computer Applications, 177, 102940. Nguyen, D. C., Pathirana, P. N., Ding, M., & Seneviratne, A. (2020). Privacy-preserved task offloading in mobile blockchain with deep reinforcement learning. IEEE Transactions on Network and Service Management, 17(4), 2536–2549.

Nijsse, J., & Litchfield, A. (2020). A Taxonomy of Blockchain Consensus Methods. Cryptography, 4(4), 32. Omar, I. A., Jayaraman, R., Salah, K., Yaqoob, I., & Ellahham, S. (2020). Applications of blockchain technology in clinical trials: Review and open challenges. Arabian Journal for Science and Engineering, 1–15. Park, A., & Li, H. (2021). The effect of Blockchain technology on supply chain sustainability performances. Sustainability, 13(4), 1726.

Peres, R. S., Jia, X., Lee, J., Sun, K., Colombo, A. W., & Barata, J. (2020). Industrial artificial intelligence in industry 4.0-systematic review, challenges and outlook. IEEE Access, 8, 220121–220139.

Portna, O. V., Iershova, N., Tereshchenko, D. A., & Kryvitska, O. R. (2021). Economic business partnerships within Industry 4.0: new technologies in management.

Pournaghi, S. M., Bayat, M., & Farjami, Y. (2020). MedSBA: a novel and secure scheme to share medical data based on blockchain technology and attribute-based encryption. Journal of Ambient Intelligence and Humanized Computing, 1–29.

Preikschat, K., Böhmecke-Schwafert, M., Buchwald, J. P., & Stickel, C. (2020). Trusted systems of records based on Blockchain technology-a prototype for mileage storing in the automotive industry. Concurrency and Computation: Practice and Experience, e5630.

Qin, Q., Jin, B., & Liu, Y. (2021). A secure storage and sharing scheme of stroke electronic medical records based on consortium Blockchain. BioMed Research International, 2021. Qu, J. (2021). Blockchain in medical informatics. Journal of Industrial Information Integration, 100258.

Qu, Y., Pokhrel, S. R., Garg, S., Gao, L., & Xiang, Y. (2020). A blockchained federated learning framework for cognitive computing in industry 4.0 networks. IEEE Transactions on Industrial Informatics, 17(4), 2964–2973.

Raimundo, R., & Rosário, A. (2021). Blockchain System in the Higher Education. European Journal of Investigation in Health, Psychology and Education, 11(1), 276–293.

Rajput, A. R., Li, Q., & Ahvanooey, M. T. (2021, February). A Blockchain-based secret-data sharing framework for personal health records in emergency condition. In Healthcare (Vol. 9, No. 2, p. 206). Multidisciplinary Digital Publishing Institute. Rajput, S., & Singh, S. P. (2020). Industry 4.0 model for circular economy and cleaner production. Journal of Cleaner Production, 277, 123853.

Rathee, G., Ahmad, F., Sandhu, R., Kerrache, C. A., & Azad, M. A. (2021). On the design and implementation of a secure blockchain-based hybrid framework for Industrial Internet-of-Things. Information Processing & Management, 58(3), 102526.

Ray, P. P., Dash, D., Salah, K., & Kumar, N. (2020). Blockchain for IoT-based healthcare: background, consensus, platforms, and use cases. IEEE Systems Journal.

Ren, Y., Leng, Y., Qi, J., Sharma, P. K., Wang, J., Almakhadmeh, Z., & Tolba, A. (2021a). Multiple cloud storage mechanism based on blockchain in smart homes. Future Generation Computer Systems, 115, 304–313.

Ren, W., Wan, X., & Gan, P. (2021b). A double-blockchain solution for agricultural sampled data security in Internet of Things network. Future Generation Computer Systems, 117, 453–461.

Roblek, V., Meško, M., & Krapež, A. (2016). A complex view of industry 4.0. Sage Open, 6(2), 2158244016653987.

Rossit, D. A., Tohmé, F., & Frutos, M. (2019). A data-driven scheduling approach to smart manufacturing. Journal of Industrial Information Integration, 15, 69–79.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), 2117–2135.

Santos, J. A., Inácio, P. R., & Silva, B. M. (2021). Towards the Use of Blockchain in Mobile Health Services and Applications. Journal of Medical Systems, 45(2), 1–10. Sapkota, N., & Grobys, K. (2019). Blockchain consensus protocols, energy consumption and cryptocurrency prices. Energy Consumption and Cryptocurrency Prices (June 13, 2019).

Sapra, R., & Dhaliwal, P. (2021). Blockchain: The Perspective Future of Technology. International Journal of Healthcare Information Systems and Informatics (IJHISI), 16(2), 1–20.

Saurabh, S., & Dey, K. (2021). Blockchain technology adoption, architecture, and sustainable agri-food supply chains. Journal of Cleaner Production, 284, 124731.

Schinckus, C. (2020). The good, the bad and the ugly: An overview of the sustainability of blockchain technology. Energy Research & Social Science, 69, 101614.

Schletz, M., Cardoso, A., Prata Dias, G., & Salomo, S. (2020). How can Blockchain technology accelerate energy efficiency interventions? A Use Case Comparison. Energies, 13(22), 5869.

Shahbazi, Z., & Byun, Y. C. (2021a). Improving transactional data system based on an edge computing–blockchain–machine learning integrated framework. Processes, 9(1), 92. Shahbazi, Z., & Byun, Y. C. (2021b). A Procedure for Tracing Supply Chains for Perishable Food Based on Blockchain. Machine Learning and Fuzzy Logic. Electronics, 10(1), 41. Shan, S., Duan, X., Zhang, Y., Zhang, T. T., & Li, H. (2021). Research on collaborative governance of smart government based on blockchain technology: An evolutionary approach. Discrete Dynamics in Nature and Society, 2021. Sharma, M., Kamble, S., Mani, V., Sehrawat, R., Belhadi, A., & Sharma, V. (2021). Industry 4.0 adoption for sustainability in multi-tier manufacturing supply chain in emerging economies. Journal of cleaner production, 281, 125013.

Singh, J., & Venkatesan, S. (2021). Blockchain mechanism with Byzantine fault tolerance consensus for Internet of Drones services. Transactions on Emerging Telecommunications Technologies, 32(4), e4235.

Singh, S., Sharma, P. K., Yoon, B., Shojafar, M., Cho, G. H., & Ra, I. H. (2020). Convergence of blockchain and artificial intelligence in IoT network for the sustainable smart city. Sustainable Cities and Society, 63, 102364.

Song, L., Wang, X., Wei, P., Lu, Z., Wang, X., & Merveille, N. (2021). Blockchain-Based Flexible Double-Chain Architecture and Performance Optimization for Better Sustainability in Agriculture. CMC-Computers Materials & Continua, 68(1), 1429–1446.

Sridevi, S., & Karpagam, G. R. (2021). Investigation on Blockchain Technology for Web Service Composition: A Case Study. International Journal of Web Services Research (IJWSR), 18(1), 1–23.

Sun, Y., Xue, R., Zhang, R., Su, Q., & Gao, S. (2020). RTChain: A Reputation System with Transaction and Consensus Incentives for E-commerce Blockchain. ACM Transactions on Internet Technology (TOIT), 21(1), 1–24.

Sun, Z., Wang, Y., Cai, Z., Liu, T., Tong, X., & Jiang, N. (2021). A two-stage privacy protection mechanism based on blockchain in mobile crowdsourcing. International Journal of Intelligent Systems, 36(5), 2058–2080.

Sunny, J., Undralla, N., & Pillai, V. M. (2020). Supply chain transparency through blockchain-based traceability: An overview with demonstration. Computers & Industrial Engineering, 106895.

Tan, L., Tivey, D., Kopunic, H., Babidge, W., Langley, S., & Maddern, G. (2020). Part 2: Blockchain technology in health care. ANZ Journal of Surgery, 90(12), 2415–2419.

Tan, L., Xiao, H., Yu, K., Aloqaily, M., & Jararweh, Y. (2021). A Blockchain-empowered crowdsourcing system for 5G-enabled smart cities. Computer Standards & Interfaces, 76, 103517.

Tian, Y., Lu, Z., Adriaens, P., Minchin, R. E., Caithness, A., & Woo, J. (2020). Finance infrastructure through blockchain-based tokenization. Frontiers of Engineering Management, 7(4), 485–499.

Togou, M. A., Bi, T., Dev, K., McDonnell, K., Milenovic, A., Tewari, H., & Muntean, G. M. (2020). DBNS: A distributed blockchainenabled network slicing framework for 5G networks. IEEE Communications Magazine, 58(11), 90–96.

Torky, M., & Hassanein, A. E. (2020). Integrating blockchain and the internet of things in precision agriculture: Analysis, opportunities, and challenges. Computers and Electronics in Agriculture, 105476.

Udokwu, C., & Norta, A. (2021). Deriving and formalizing requirements of decentralized applications for inter-organizational collaborations on Blockchain. Arabian Journal for Science and Engineering, 1–18. Ullah, F., & Al-Turjman, F. (2021). A conceptual framework for blockchain smart contract adoption to manage real estate deals in smart cities. Neural Computing and Applications, 1–22. Upadhyay, A., Mukhuty, S., Kumar, V., & Kazancoglu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. Journal of Cleaner Production, 126130.

Uysal, M. P., & Mergen, A. E. (2021). Smart manufacturing in intelligent digital mesh: Integration of enterprise architecture and software product line engineering. Journal of Industrial Information Integration, 22, 100202.

Veeramakali, T., Siva, R., Sivakumar, B., Mahesh, P. S., & Krishnaraj, N. (2021). An intelligent internet of things-based secure healthcare framework using blockchain technology with an optimal deep learning model. The Journal of Supercomputing, 1–21. Villasante, C., Mabe, J., Les-Aguerrea, I., Peña, A., Sánchez, M., & López, S. (2020). SMARTCSP: enfoque Industria 4.0 para una reducción efectiva de costos de las plantas termoeléctricas (CSP). DYNA-Ingeniería e Industria, 95(6).

Viriyasitavat, W., Anuphaptrirong, T., & Hoonsopon, D. (2019a). When blockchain meets Internet of Things: Characteristics, challenges, and business opportunities. Journal of Industrial Information Integration, 15, 21–28.

Viriyasitavat, W., Xu, L., & Bi, Z. (2020). Specification Patterns of Service-Based Applications Using Blockchain Technology. IEEE Transactions on Computational Social Systems, 7(4), 886–896.

Viriyasitavat, W., Xu, L., Bi, Z., Hoonsopon, D., & Charoenruk, N. (2019b). Managing qos of internet-of-things services using blockchain. IEEE Transactions on Computational Social Systems, 6(6), 1357–1368.

Viriyasitavat, W., Xu, L., Bi, Z., & Pungpapong, V. (2019c). Blockchain and internet of things for modern business process in digital economy—the state of the art. IEEE Transactions on Computational Social Systems, 6(6), 1420–1432.

Viriyasitavat, W., Xu, L., Bi, Z., & Sapsomboon, A. (2019d). New blockchain-based architecture for service interoperations in internet of things. IEEE Transactions on Computational Social Systems, 6(4), 739–748.

Vivaldini, M. (2021). Blockchain in operations for food service distribution: Steps before implementation. The International Journal of Logistics Management, 32(3), 995–1029.

Vogel-Heuser, B., & Hess, D. (2016). Guest editorial Industry 4.0–prerequisites and visions. IEEE Transactions on Automation Science and Engineering, 13(2), 411–413.

Wang, H., Zhang, M., Ying, H., & Zhao, X. (2021a). The impact of blockchain technology on consumer behavior: A multimethod study. Journal of Management Analytics, 8(3), 371–390.

Wang, M., Xu, C., Chen, X., Zhong, L., Wu, Z., & Wu, D. O. (2020a). BC-mobile device cloud: A Blockchain-based decentralized truthful framework for mobile device cloud. IEEE Transactions on Industrial Informatics, 17(2), 1208–1219.

Wang, Q., Li, R., & Zhan, L. (2021b). Blockchain technology in the energy sector: From basic research to real world applications. Computer Science Review, 39, 100362.

Wang, S., Ouyang, J., Li, D., & Liu, C. (2017). An integrated industrial ethernet solution for the implementation of smart factory. IEEE Access, 5, 25455–25462.

Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. Computer Networks, 101, 158–168.

Wang, W., Huang, H., Zhang, L., & Su, C. (2020b). Secure and efficient mutual authentication protocol for smart grid under blockchain. Peer-to-Peer Networking and Applications, 1–13. Wang, Z., Zheng, Z., Jiang, W., & Tang, S. (2021c) Blockchain-Enabled Data Sharing in Supply Chains: Model, Operationalization and Tutorial. Production and Operations Management. Whitmore, A., Agarwal, A., et al. (2015). The Internet of Things— A survey of topics and trends. Information Systems Frontiers, 17(2), 261–274.

Wong, P. F., Chia, F. C., San Kiu, M., & Lou, E. C. (2020). Potential integration of blockchain technology into smart sustainable city (SSC) developments: a systematic review. Smart and Sustainable Built Environment. Wong, P. M., RK Sinha, S., & Chui, C. K. (2021). Blockchain in manufacturing quality control: A computer simulation study. Plos one, 16(3), e0247925.

Wu, Y., Dai, H. N., & Wang, H. (2020). Convergence of blockchain and edge computing for secure and scalable IIoT critical infrastructures in Industry 4.0. IEEE Internet of Things Journal. Xiao, Y., Xu, B., Jiang, W., & Wu, Y. (2021). The HealthChain Blockchain for Electronic Health Records: Development Study. Journal of Medical Internet Research, 23(1), e13556.

Xu, B., Li, L., Hu, D., Wu, B., Ye, C., & Cai, H. (2018a). Healthcare data analysis system for regional medical union in smart city. Journal of Management Analytics, 5(4), 334–349.

Xu, L. (2011). Enterprise systems: State-of-the-art and future trends. IEEE Transactions on Industrial Informatics, 7(4), 630–640.

Xu, L. D. (2020a). The contribution of systems science to Industry 4.0. Systems Research and Behavioral Science, 37(4), 618–631.

Xu, L. D. (2020b). Industry 4.0—Frontiers of fourth industrial revolution. Systems Research and Behavioral Science, 37(4), 531–534.

Xu, L. D., & Duan, L. (2019). Big data for cyber physical systems in industry 4.0: a survey. Enterprise Information Systems, 13(2), 148–169.

Xu, L., He, W., & Li, S. (2014). Internet of things in industries: A survey. IEEE Transactions on Industrial Informatics, 10(4), 2233–2243.

Xu, L., Liang, N., & Gao, Q. (2008). An integrated approach for agricultural ecosystem management. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 38(4), 590–599.

Xu, L., Lu, Y., & Li, L. (2021). Embedding blockchain technology into IoT for security: A survey. IEEE Internet of Things Journal, 8(13), 10452–10473.

Xu, L., Viriyasitavat, W., Ruchikachorn, P., & Martin, A. (2012a). Using propositional logic for requirements verification of service workflow. IEEE Transactions on Industrial Informatics, 8(3), 639–646.

Xu, L., & Viriyasitavat, W. (2014). A novel architecture for requirement-oriented participation decision in service workflows. IEEE Transactions on Industrial Informatics, 10(2), 1478–1485.

Xu, L., & Viriyasitavat, W. (2019). Application of blockchain in collaborative Internet-of-Things services. IEEE Transactions on Computational Social Systems, 6(6), 1295–1305.

Xu, L., Wang, C., Bi, Z., & Yu, J. (2012b). AutoAssem: An automated assembly planning system for complex products. IEEE Transactions on Industrial Informatics, 8(3), 669–678.

Xu, L., Wang, C., Bi, Z., & Yu, J. (2013). Object-oriented templates for automated assembly planning of complex products. IEEE Transactions on Automation Science and Engineering, 11(2), 492–503.

Xu, L. D., Xu, E. L., & Li, L. (2018b). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941–2962.

Xu, X., Zhao, H., Yao, H., & Wang, S. (2020). A Blockchain-enabled Energy Efficient Data Collection System for UAV-assisted IoT. IEEE Internet of Things Journal. Yan, Z., Peng, L., Feng, W., & Yang, L. T. (2021). Social-Chain: Decentralized Trust Evaluation Based on Blockchain in Pervasive Social Networking. ACM Transactions on Internet Technology (TOIT), 21(1), 1–28.

Yang, L., Li, M., Si, P., Yang, R., Sun, E., & Zhang, Y. (2020). EnergyEfficient Resource Allocation for Blockchain-Enabled Industrial Internet of Things with Deep Reinforcement Learning. IEEE Internet of Things Journal. Yang, X., Li, M., Yu, H., Wang, M., Xu, D., & Sun, C. (2021). A Trusted Blockchain-Based Traceability System for Fruit and Vegetable Agricultural Products. IEEE Access, 9, 36282–36293.

Yaqoob, I., Salah, K., Jayaraman, R., & Al-Hammadi, Y. (2021). Blockchain for healthcare data management: Opportunities, challenges, and future recommendations. Neural Computing and Applications, 1–16. Yu, Z., Song, L., Jiang, L., & Sharafi, O. K. (2021). Systematic literature review on the security challenges of blockchain in IoT-based smart cities. Kybernetes. Yuehong, Y. I. N., Zeng, Y., Chen, X., & Fan, Y. (2016). The internet of things in healthcare: An overview. Journal of Industrial Information Integration, 1, 3–13.

Yun, G., Zhygulin, V., & Zheng, Q. P. (2021). Residential energy trading with blockchain technology. Energy Systems, 1–18. Yun, J., Goh, Y., & Chung, J. M. (2020). DQN based optimization framework for secure sharded blockchain systems. IEEE Internet of Things Journal. Zamani, E., He, Y., & Phillips, M. (2020). On the security risks of the blockchain. Journal of Computer Information Systems, 60(6), 495–506.

Zhang, J., Tan, R., Su, C., & Si, W. (2020). Design and application of a personal credit information sharing platform based on consortium blockchain. Journal of Information Security and Applications, 55, 102659.

Zhang, J., Zhong, S., Wang, J., Yu, X., & Alfarraj, O. (2021a). A Storage Optimization Scheme for Blockchain Transaction Databases. Computer Systems Science and Engineering, 36(3), 521–535.

Zhang, C., & Chen, Y. (2020). A review of research relevant to the emerging industry trends: Industry 4.0, IoT, blockchain, and business analytics. Journal of Industrial Integration and Management, 5(01), 165–180.

Zhang, C., Chen, Y., Chen, H., & Chong, D. (2021b). Industry 4.0 and its Implementation: a Review. Information Systems Frontiers, 1–11. Zhang, Y., Liu, Y., Jiong, Z., Zhang, X., Li, B., & Chen, E. (2021c). Development and assessment of blockchain-IoT-based traceability system for frozen aquatic product. Journal of Food Process Engineering, 44(5), e13669.

Zhao, W., Jin, S., & Yue, W. (2021). A stochastic model and social optimization of a blockchain system based on a general limited batch service queue. Journal of Industrial & Management Optimization, 17(4), 1845.

Zheng, Y. (2021). Design of a Blockchain-Based e-Portfolio Evaluation System to Assess the Education and Teaching Process. International Journal of Emerging Technologies in Learning, 15(5).

Zhou, J., Feng, Y., Wang, Z., & Guo, D. (2021a). Using Secure MultiParty Computation to Protect Privacy on a Permissioned Blockchain. Sensors, 21(4), 1540.

Zhou, Z., Wang, M., Yang, C. N., Fu, Z., Xin, S., & Wu, Q. J. (2021b). Blockchain-based decentralized reputation system in E-commerce environment. Future Generation Computer System.