Convergence of Internet of Things and Blockchain Technology in Managing Supply Chain

Kamalendu Pal[a],*, Ansar-Ul-Haque Yasar[b]

[a]*Department of Computer Science, City, University of London, London, United Kingdom, EC1V 0HB*
[b]*Transportation Research Institute (IMOB), Hasselt University, Hasselt, Belgium, B-3590*

Abstract

Information and communication technologies (ICT) are ushering enormous evolution in recent decades, and many disruptive technologies, such as the Internet of Things (IoT), blockchain technology, big data, and service-oriented computing (SOC), have emerged. These technologies are guiding the supply chain management (SCM) community and enable the fusion of digital and physical world of many industries (e.g. automotive, retail, pharmaceutical, apparel). Modern supply chains have transformed into highly complex vale creating business networks and turned into an important source of competitive advantage. However, it has become increasingly challenging to cross-check the source of raw materials and maintain visibility of products and merchandise, while they are moving through the value chain network. The application of the IoT can help companies to observe, track, and monitor products, activities, and processes within their respective value chain networks. In combination with IoT, blockchain technology can enable a wider range of different application scenarios to improve value chain transparency and to increase the effectiveness of business transactions trust. In this way, business information system architecture plays an important role in storing, processing, and distributing data and information. This paper presents a blockchain-based architecture for the IoT applications, which brings distributed data processing capabilities using a SOC framework to support business services in the apparel manufacturing network.

Keywords: Apparel Manufacturing, Big Data, Blockchain Technology, Internet of Things, Service-Oriented Computing, Supply Chain Management

1. Introduction

Supply chains are an important part of every economy and every business [21]. The supply chain is tied to the complex processes of creation and distribution of goods and services. Depending on the product, the supply chain includes many phases, multiple geographical locations, several accounts and payment, several individuals, business partners, and means of transport.

In recent decades, global manufacturing businesses (e.g. apparel, automotive) are inclined to worldwide activities due to the economic advantage of the globalization of product design and development [24]. For example, in a typical apparel supply chain consists of the sequence of organizations – their facilities, functions, and activities – that involved in producing and developing a product or service. The sequence begins with raw materials purchase from selective suppliers and products are made at one or more manufacturing plants [22]. Then these products are moved to intermediate collection points (e.g., warehouse, distribution centers) to store temporarily to move to next stage of supply chain and ultimately deliver the products to intermediate-users or retailers or customers [22] [23]. The path from supplier to the customer can include several intermediaries – such as wholesalers, warehouse, and retailers, depending on the products and markets. Also, global apparel supply chains becoming increasingly complicated due to a growing need for inter-organizational and intra-organizational connectedness, which is enabled by advances in modern technologies and tightly coupled business processes. The information has been an important strategic asset in apparel business operational management. Also, apparel business networks are using information systems to monitor supply chain activities [22].

As a result, many textile and clothing businesses are investing in new ICT to harness smooth information sharing ability in supply chain operations. With recent progress in Radio Frequency Identification (RFID) technology, low-cost wireless sensor hardwires, and world wide web technologies, the Internet of Things (IoT) advance has attracted attention in connecting global apparel business activities and sharing operational business information more integrated way. These technologies promise to reshape the modus operandi of modern supply chains through enhanced data collection as well as information sharing and analysis between collaborating supply chain business partners. IoT technology supports the capability to connect and integrate both digital and physical business world. The process is quite simple: (i) collect data from real-world objects, (ii) communicate and aggregate those data into information, and (iii) present clear results to systems or users so that decisions can be made or object behaviour adapted.

Many academic and practitioner groups reviewed IoT technology adoption-related issues in SCM and logistics [2] [13]. In particular, a group of researchers analyzed the energy management in smart factories and concluded that IoT powered manufacturing can improve industrial supply chain competitiveness through more effective tracking of the flow of materials, leading to improvements in the effectiveness and efficiencies of important business processes [25]. The other important characteristics of IoT-based systems (e.g., sharing precise timely information related to production, quality assurance, distribution, and logistics) are also reported in the context of multi-party supply chains [4] [26]. It is also reported that the use of IoT-based application systems inside the production plant can improve the visibility of parts and processes, and by using IoT devices along the supply chain can help to improve productivity, reduce operational costs, and strengthen customer satisfaction [7].

Despite the huge applicability of IoT-based applications in supply chain management, there are many challenges for the deployment of this technology. As with any disruptive innovation, IoT technology presents many challenges to adopting it in supply chain operations. For example, due to the explosion of data generated by IoT-based system faces main challenges in data management, data mining, and security issues.

Data management challenges are associated with many technology-specific important issues. In apparel manufacturing business IoT sensors, machinery, and special-purpose devices generate a huge amount of data that need to be processed and stored. Business-specific data center architecture also plays a crucial role. Few apparel businesses would be able to invest in data storage sufficient to house all the IoT data collected from the networks. Consequently, they need prioritize data for operations or backup based on business-uses and value. Data centers are often distributed to improve processing efficiency and response time as IoT devices become more widely used for the global business operational facilities.

Data mining applications play important role in IoT-based infrastructure. As different types of data are available; and data consists not only traditional discrete data, but also of streaming data generated from digital sensors in apparel industrial plants equipment, automobiles, and shipping crates. These streaming data are about location, movement, vibration, temperature, humidity, and so on. Data mining tools can be used to invoke corrective processes to address immediate operational actions.

IoT-based supply chain information system's security is also a prominent challenge. As a growing number and variety of connected devices are introduced into IoT networks, the potential security threat escalates. Security challenges may be resolved by training developers to incorporate security solutions (e.g., intrusion prevention systems, firewalls) into products and operational services.

In this way, modern IoT-based infrastructure often regarded as the catalyst to improve supply chain information sharing ability. Information sharing across textile manufacturing networks is based on linking unique identifications of objects – tagged using RFID transponders – with records in supply chain database management systems. In this process, Electronic Product Code Information Services (EPCIS) is the most relevant industry standard. IoT technology is used heavily in apparel manufacturing business processes – e.g., inventory management, warehousing, and transportation of products, automatic object tracking and supply chain management. With access to precise information, apparel supply chain operational managers can perform their analysis on a nearly real-time basis and can take appropriate strategic decisions.

Despite contributing to the rapid development of IoT applications, the current IoT-centric architecture has led into a myriad of isolated data silos that hinders the full potential of holistic data-driven business applications with the IoT. Also, standalone IoT application systems face security and privacy-related problems. The blockchain technology has introduced an effective solution to the IoT based information systems security. A blockchain enhance IoT devices to send data for inclusion in a shared transaction repository with the tamper-resistant record and enables business partners to access and supply IoT data without the intervention of central control and management. This paper presents a blockchain-based design for the IoT applications that brings a secure distributed data management to support transactions services within a multi-party global apparel business network, as shown in Fig 1.
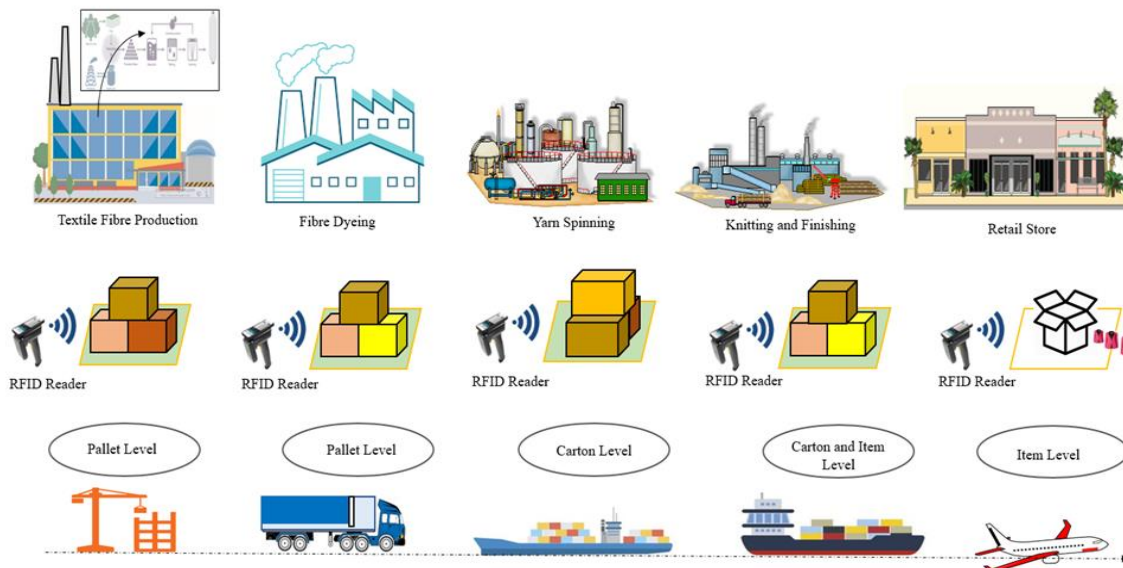
Fig. 1. RFID tagging level at different stages in the apparel manufacturing network

The rest of this paper is organized as follows. Section 2 describes the background knowledge of key technologies for automation in the context of the global manufacturing industry. It also explains different paradigms of the ICT world, which are used for business processes automation purpose. Section 3 presents the proposed three-layer framework for an information system. Section 4 describes data storage and consolidation policy related issues. Section 5 explains the emerging issue in blockchain-based information system's deployment. Section 6 reviews related research works. Section 7 explains the future research direction. Finally, Section 8 concludes the paper by discussing relevant research issues.

2. Key Technologies for Automation

In recent decades, it has become a significant tendency for the apparel industry to adopt decentralization as a new manufacturing paradigm. At the same time, advantages in data analysis give more insights into apparel production lines, thus improving its overall productivity. This enables more efficient operations and facilities the shift from mass to customized production. This section presents a brief overview of important aspects of service-oriented computing, the IoT based information system, and provide an introduction on the blockchain technology.
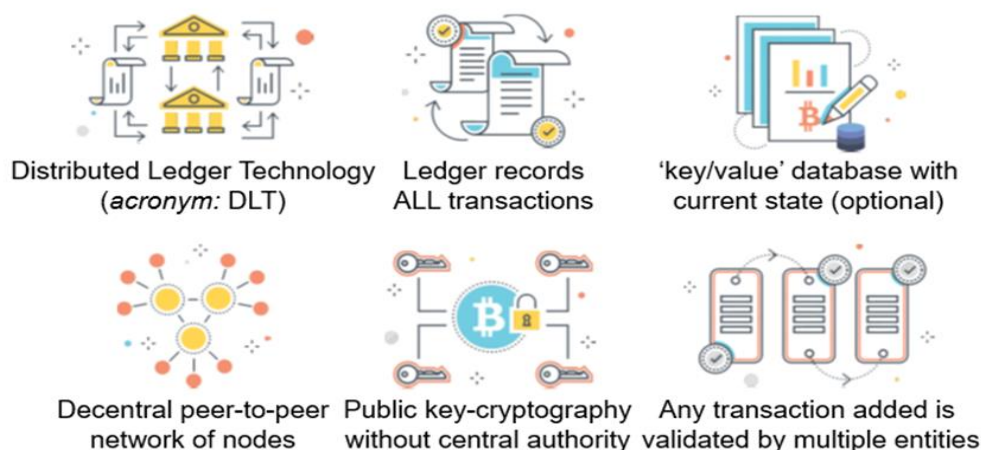

Fig. 2. Design steps of a decentralized blockchain application

* Corresponding author. Tel.: +442083907430
Fax: +000000000000; E-mail: k.pal@city.ac.uk

2.1. SERVICE-ORIENTED COMPUTING

Service-oriented computing (SOC) is an important computing paradigm that utilizes services as the constructs to support the development of distributed applications. Services are self-contained modules – deployed over standard middleware platforms, which can be described, published, located, orchestrated over computer networks. These platforms are mainly hosted in large-scale data center environment. The consolidation and centralization of data centers, however, yield an increased distance between clients and services. This arrangement creates different outcomes in high variability in latency and bandwidth. To address this issue, particularly with regards to resource-intensive and interactive applications, decentralized SOC architectures, namely cloudlets, have emerged. Cloudlets are small-scale data centers that are situated nearer to users and can mitigate low latency and high bandwidth guarantees. This research embraces this locality-aware data storage and processing trend and brings it to its full potential with decentralized access control layer which ensures ownership and security sharing of data.

2.2. IoT Based Information System

The IoT is a smart worldwide network of interconnected objects, which through unique address schemes can interact with each other and cooperate with their neighbor to reach common goals. The primary purpose of the IoT is to share information acquired by objects, which reflects the manufacturing business processes, transportation, consumption and other details of the textile and clothing industry detail. The gathered information can be used for corporate-specific applications.

The prompt and effective decision not only depend on reasoning techniques but also the quality and quantity of data. Every major apparel manufacturing paradigm has been supported by the advancement of Information Technology (IT) and its applications. For example, the wide adoption of enterprise resource planning (ERP) and industrial business processes automation made flexible apparel manufacturing systems feasible. It includes the technologies for computer-aided textile design, computer-aided garment development, and computer-aided process planning made computer integrated apparel manufacturing practice. In developing enterprise information systems (EISs), more and more enterprises rely on the professional providers of IT software service to replace or advance their conventional systems. Therefore, it makes sense to examine the change of the IT infrastructure and evaluate its impact on the evolution of apparel business process automation when a new IT solution (e.g. blockchain technology) becomes influential.

2.3 Blockchain Technology

Blockchains have attracted wide attention as the basis of the cryptocurrencies, e.g., bitcoin [19]. Cryptocurrencies may or may not be the future of money, but blockchain-oriented technologies are very attractive for other types of business applications. In simple, blockchain is a distributed data structure comprising a chain of blocks. It acts as a distributed database or a global ledger that maintains records of all transactions on a blockchain network. The transactions are time-stamped and bundled into blocks where each block is identified by its cryptographic hash. The blocks form a linear sequence where each block references the hash of the previous block, forming a chain of blocks called the '*blockchain*'. A blockchain is maintained by a network of nodes and every node executes and records the same transactions.

Blockchain technology can be used for any data exchange, whether it is contracted, tracking of shipments and financial exchanges (payments). Each action is captured in the block and the data is distributed over many nodes (computer), making the system transparent. An important component of blockchain technology is 'leger' or 'register' and it is a process by which a record is kept for all the transactions of a business. A centralized ledger is governed by a single entity that is entrusted with proper maintenance of checks and balances. A distributed ledger technology (DLT) operates as a network in which users approve record of transactions. The data is replicated with multiple users and there is no one database.

Every user on the DLT network must make its determination and then the users '*vote*' on the correct version of the record of transactions. With an approved consensus, the ledger is updated with the transaction details. All the users or computers within the network maintain their copy of the ledger. There is no central owner or administrator of the distributed ledger. The data is stored and shared between everyone on the large network irrespective of their location or institution. Any change to the record is immediately registered in all copies of the distributed ledger. The security and accuracy of the distributed ledger are maintained through public-key cryptography (PKC) technique. PKC is an asymmetric encryption scheme that uses two sets of keys: a public that is widely disseminated and a private key that is only known to the owner. PKC can be used to create digital signatures and is used in a wide array of applications, such as '*HyperText Transmission Protocols*' (HTTPs) used in the Internet operation, for authentication in critical applications.

Transactions in a blockchain system are identical to their traditional database counterparts. These transactions are issued by the clients to the servers of the blockchain system. These transactions act on the data stored on all the participating servers. In its vanilla form, a blockchain transaction could be visualized as a set of reading/writing operations performed on each node of a replicated distributed database. To determine an ordering for all the incoming transactions, each blockchain application employs a consensus protocol, and some of the important steps in the blockchain operation are shown in Fig. 2.

In a blockchain-based infrastructure, once data is entered within the ledger system, then no one is capable to change this data in the future and this mechanism is known as '*tamperproof*''. However, a systematic effort is required for building a reliable blockchain-based information infrastructure. The main features of these systematic efforts are as follows: (i) Blockchain Protocols for Commitment: The protocol of commitment makes sure that valid transaction from apparel business processes are committed and stored in the blockchain information storage with appropriate *validation mechanism* and within a *stipulated time*; (ii) Consensus: Consensus consists of two functions: First, it allows blockchain to be updated while ensuring that every blockchain in the chain is valid as well as keeping participants incentivized and second, it prevents any single entity from controlling or crashing the whole blockchain system. The consensus aim is to create a distributed network

without central authorities with participants who do not necessarily need to trust each other.

The blockchain technology, at its core, features an immutable distributed ledger, a decentralized network that is cryptographically secured. The blockchain technology can reduce operational costs, create immutable transformation records, and enable transparent ledgers where updates are nearly instantaneous.

In this way, the rapid growth in usage of IoT devices has led to the emergence of various IoT-based applications in apparel supply chain business – such as utility monitoring, transportation, customer service, and so on. Some IoT applications also make use of blockchain-based techniques to incorporate user privacy and security in the development of applications. The next section of this paper is going to presents the proposed architecture based on IoT, blockchain, and SOC technologies.

3. Proposed Enterprise Architecture

This section describes how SOC technology will improve efficiencies, providing new business opportunities, address regulatory requirements, and improve transparency and visibility of global apparel manufacturing activities. The IoT systems allow capturing real-time manufacturing business processes data from the plant-level operational environment. The enterprise architecture for distributed apparel manufacturing supply network used for current research is shown in Fig. 3. This architecture mainly consists of three layers: (i) IoT-based service, (ii) blockchain-based data controlling, and (iii) data storage and processing part.
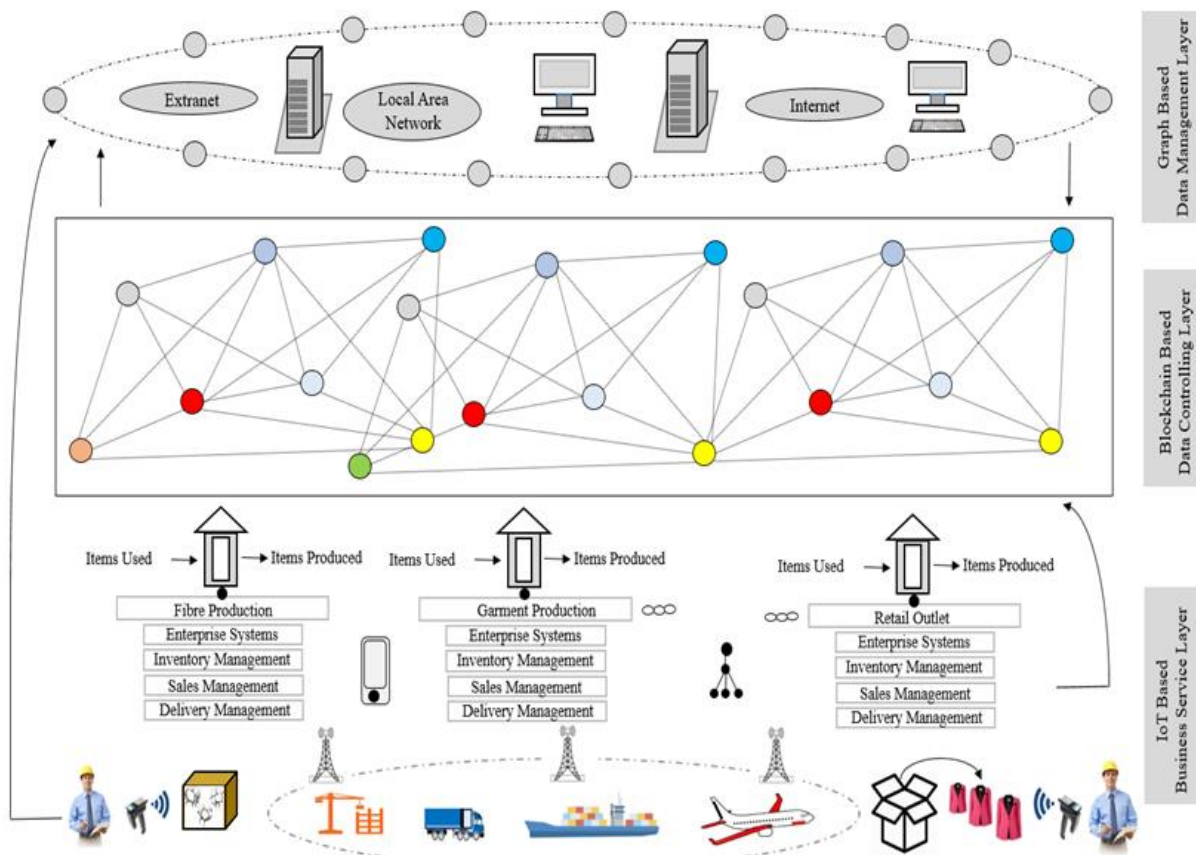

Fig. 3. Enterprise information system architecture for apparel business.

3.1 IoT-Based Service Layer

The development of the IoT has created many devices, such as sensors, interconnected and interoperable devices for data collection and exchange. The data obtained from the IoT can make apparel manufacturing more convenient through numerous types of decision-making at all its levels and areas of apparel business activities.

3.2 Blockchain-Based Data Controlling

The blockchain-based controlling part can potentially improve the IoT technology. IoT, one of the most promising ICT, has been ramping up recently. IoT is proposed to integrate the things (also named smart objects) into the Internet and provides users with various services. The typical applications of IoT include logistics management with RFID technology. The apparel industry is part of a complex and information-intensive supply chain comprising a set of organizations that are globally connected and distributed, including other critical infrastructures that support world trade, such as transport and

international border management.

Logistics and SCM are regarded as domains where blockchains are good fits for a series of reasons. During the lifecycle of the product, as it flows down the value chain (from production to consumption) the data generated in every step can be documented as a transaction, thus creating a permanent history of the product. Among things, blockchain technology can effectively contribute to (i) Recording every single asset (from product to containers) as it flows through the supply chain nodes, (ii) tracking orders, receipts, invoices, payments, and any other official document, and (iii) track digital assets (such as warranties, certifications, copyrights, licenses, serial numbers, bar codes) in a unified way and parallels with physical assets, and others. Moreover, the blockchain can contribute effectively, through its decentralized nature, to

sharing information about the production process, delivery, maintenance, and wear-off of products between suppliers and vendors, bringing the new opportunity of collaboration in complex assembly lines.

The challenges in logistics parameters, such as delays in delivery, loss of documentation, unknown source of products, errors, and so on, can be minimized and even avoided by blockchain implementation. Benefits of integrating the supply chain with blockchain are the follows increased sustainability, reduced errors, and delays, minimized transport costs, faster issue identification, increased trust (consumer and partner trust) and improved product transport and inventory management.

Blockchain technology enables complete supply chain visibility. Under full visibility, it is considered to show the movement of goods both spatially and temporally through various phases and processes of the supply chain, from the physical condition of the consignment at any given moment, through various variations of the goods (e.g. temperature deviations) and to support the decision making of logistics operators. This way of doing business or developing a business the process would fulfil the main task of logistics, which is to bring the goods to the right place, at the right time, and in the right amount. In the end, this provides enormous business value to its customers.

In this way, the collected data is often transmitted to unknown third parties without the awareness of users. For example, in apparel retail outlet some IoT customers may set their wearable devices in broadcast mode and when they are within discoverable range, any other smart object can access their data by sending unsafe requests. Academics and practitioners are expressing their concern about general data protection regulations (GDPR) related issues in supporting IoT-based applications [12] [20]. Also, data usage (including storage and analysis) can become important for sensitive data items, where personal data needs to have a great level of privacy and security.

4. Data Storage and Consolidation Policy

There are different blockchain platforms are used by industries and different data models are used on the platforms (e.g. Ethereum [9] adopt key-value data model, while a few of them like R3 Corda [6] use relational data model). This characteristic emphasises that any single blockchain platform not suitable for different types of data used in a wide range of apparel supply chain business applications. For example, geolocation data recorded from supply chain transport vehicles may not be

efficiently queried using a key-value store. Also, even though blockchain platforms such as Hyperledger Fabric [15] opt for pluggable storage model, service users have to decide at development time which storage to use (e.g. either LevelDB [17] (key-value store) or CouchDB [5] (document store). Thus, special techniques are required for supporting multiple types of data stores such as key-value, document, SQL, and spatial data stores simultaneously in the same blockchain system.

Unlike blockchains used in public cryptocurrency environments, a business blockchain network is not a single universal collaborative environment for every organization to join in this same network. Instead, each network usually includes a specific set of organizations sharing some common business interests, and more importantly, an organization may join several different blockchain networks due to the large scope of their business. It is likely that each network will have a different data schema and may record a different version of some common data referring to the same entity across the networks. Therefore, organizations need master data management rules, processes, and techniques to consolidate data across multiple blockchain networks that they participate in.

5. Issues of IoT-Based Blockchain Architecture

The acceptance of IoT-based technological solution, the use of Electronic Product Code (EPC) for individual products identification purpose, as well as of EPC global network for nearly real-time data gathering, object tracking and different types of business services providing a greatly improve accuracy for supply chain operation management [22].

Blockchain-based technologies allow for the decentralized aggregation of vast amounts of data generated from IoT devices and ensure that benefits are shared more equitably across supply chain exchange partners. Some of the research issues (e.g. scalability, security, and IoT data management) are highlighted in Table 1.

Blockchain facilitates machine-to-machine interaction where sensors and IoT devices attached to machinery will be synchronized, resulting in high flexibility and collaboration with exchange partners. The importance of this new capability lies in the secure communication, confidentiality, and integrity of the exchange transactions. Users can transact with the machine directly and engage in on-demand manufacturing services by sending transactions to a registered machine.

Blockchain-based distributed ledgers that harness smart contracts enable the embedding of business logic covering a wide range of purposes such as payment conditions, product acceptance, smart inventory replacement, predictive maintenance, and repairs.

By combining blockchain technology and IoT, business information exchange partners gain new and timely insights into their supply chain in real-time with more precise and reliable information about key processes, events, and product attributes – such as quality, performance, and availability. This fusion of IoT and blockchain technology can help to enhance end-to-end traceability and enable rapid recall capabilities of unsafe goods. As a result, exchange partners will be informed about the products, potential risks, and the preventative and corrective actions needed for sustaining enough flow of safe products to the final consumers.

Whenever goods and related documentation (e.g., bills of landing or ship notifications) pass from one actor in the supply chain to another, items are subject to counterfeiting or theft. To protect from this, blockchain technology involves the creation of a digital "*token*", which is associated with physical items when they are created. The final recipient of the item can then authenticate the token, which can follow the history of the item to its point of origin. End users have more confidence in the information they receive since no one entity or group of entities can arbitrarily change the information contained within the blockchain. Due to most goods' linear flow from material origin to the final consumer, blockchain is a suitable technology to enable supply chain traceability. Since goods and their associated "tokens" usually are not traded between competitors within a given blockchain, this operational facet helps maintain anonymity. As such, participant confidentiality may be maintained.

Logistics and supply chains processes can be significantly improved by introducing the blockchain technology. Even the simplest application of the blockchain technology could bring the supply chain great benefits. Registering the transfer of products on the digital ledger as transactions makes it possible to identify the main data relevant for the SCM.

As blockchain is considered to be a solution for connecting and managing IoT devices reliably, logistics might be one of the most promising fields of application, given a large amount of possible IoT objects in a logistics environment (such as vehicles, shipments, etc.). For example, Walmart aims at improving last-mile deliveries through coordinating delivery drones using the blockchain. Moreover, IoT devices connected to the blockchain could also make use of cryptocurrencies, enabling them to interact autonomously with other parties through smart contracts to pay fees and duties by themselves, e.g., for priority access to restricted air corridors [6].

6. Related Research

Academics and practitioners identified industrial business processes, particularly supply chain and logistics management, are important areas for deploying IoT based information system applications [13]. IoT based industrial information systems can enhance the competitiveness of enterprise through more effective tracking of the flow of raw materials, leading to improve the effectiveness and efficiencies of business processes [25]. In the context of globalized business practice, with multiple collaborating-partners based supply chains, IoT-based applications enhance to facilitate the sharing of more precise and timely information relevant to production, quality control, distribution, and logistics [4]. However, researchers expressed their concern regarding standalone IoT-based applications along with global supply chain management [21]. The main concerns were raised on the issues of standalone IoT systems security and privacy.

Different hybrid information system architectures (e.g. IoT with blockchain, cloud based IoT and blockchain technology) have been proposed by the research community. A blockchain enhances IoT-based applications tamper-resistant characteristics. In recent years, different blockchain-based information management systems have been reported by researchers. For example, IBM has developed a new

blockchain-based service that is designed to track high-value items through complex supply chains in a secure cloud-based application system [17]. Another exemplary industrial application is a fine-wine Provence-tracking service, known as the Chai Wine vault, developed by London-based Company

Table 1. The research issues of combing IoT with blockchain technology

Internet of Things (IoT)	Blockchain Technology
Scalability	• There continues to be the quest for scalable transaction throughput in the blockchain. Some of the blockchain-based information systems implementations use a computationally expensive consensus method (by design) for requiring solving a cryptographic puzzle in the process. Instead, the permissioned blockchains where participants have identified use consensus methods based on a variant of Byzantine fault-tolerant state machines, which have been chosen to provide higher transaction throughput and lower consensus latency. • To assess the effectiveness and scalability of IoT-based blockchain technology, early implementation and performance evaluation are important research challenge.
Security	• With the proliferation of global apparel business exchange partner relationships, textile and clothing industries are driven to protect their data and information as well as the integrity of their physical objects to protect against theft and different types of illicit trade including diversion and counterfeiting. Also, blockchain-based information systems can transform the potential advantages of IoT and bridging the difference of device-data interoperability while keeping security and privacy intact.
IoT data management	• There are research issues regarding design decisions of IoT data streams, storage, and processing applications. Hence, one important problem is interpreting the data concerning reference data and business glossary. Technical problems include identification of reference data entities, automatic interpretation, and managing the reference data as they are provided by external sources.

Ever ledger [11] in business-partnership with fine-wine expert Maureen Downey. Blockchain-based digital identification tools for physical property and packaging have been reported to enhance high-value parts for supply chain management [16]. An innovative anti-counterfeit application, called Block Verify, is designed, and deployed for tracking anti-counterfeit products [14] to create a sustainable business world. A start-up company from Finland (i.e. Kouvola) in partnership with IBM, developed a smart tendering application for the supply chain management. The reported application is built on an automatic blockchain-based smart contract [3]. Another blockchain-based smart contract, called SmartLog, the application was launched by Kouvola in recent years [1].

A research group [27] described how virtual resources and blockchain technology can be used for configuration management in an IoT based system. In recent research, Rahim Rahman and his colleague introduced permission-based blockchain protocols to handle the provisioning of the virtual network [28].

Due to globalization manufacturing supply chain networks are going through an evolutionary change through continued digitization of its business practices. These global manufacturing chains are evolving into value-creating networks where the value chain itself turns into an important source of competitive advantage. At the same time, developments are in progress to integrate blockchain technology with other innovative technological solutions (e.g. IoT-based applications, cloud-based solutions, and fog computing-based automation), leading to novel structures of modern apparel manufacturing supply chains, new types partnerships, holistic mechanisms of collaboration and value-enhancing applications for the global apparel business. The reported research in this paper is one of these values creating applications, which explains the adoption of IoT-based item description and use in blockchain infrastructure, to reap the combined advantages for future-generation apparel business supply chain management.

7. Future Research Directions

With current use of IoT technologies, and blockchain-based applications adoption in the manufacturing industry, data privacy issues remain a crucial preoccupation of regulatory bodies. The European General Data Protection Regulation (GDPR) permits users to control their data and information about any devices involved in collecting and processing this data. The overall goal is to permit individual entities to have full rights and control over their data assets and to be able to transfer their data without any unmitigated risk. Blockchains gives the advantages of a distributed ledger that can securely manage digital transactions – where the centralization of data is not needed. In future this research will take an initiative that how blockchain technology can be used to develop an audit trail of data generated in IoT devices, providing GDPR rules to be verified on such a trail. This mechanism will help to translate a set of such rules into smart contracts to protect personal data transparently and automatically.

8. Conclusion

Today's supply chain businesses face significant volatility, uncertainty and complexity imposed by a dynamic operating environment. Changes in consumer buying pattern – the demand for a lower price, better service levels, mobile commerce and so on – necessitate customer intelligence and varying fulfilment models. These have introduced significant stress on retail supply chain networks, compelling high street businesses to revisit their supply chain design strategies. It includes the deployment of appropriate information systems that improve supply chain execution. In such scenarios, enterprise information systems architecture plays a very important role.

Companies in the logistics and manufacturing industries can implement decentralized concepts for goods and transport containers tracking. Driven by the demand for greater transparency in the supply chain, which allows traceability from start to finish, comprehensive technical solutions are required. This is often a challenge for information technology (IT) solutions that focus on centralized solutions with complex access rights. Blockchain or derived concepts can provide a remedy because they have already provided industrial solutions, which addressed these issues.

This paper presents a hybrid enterprise information systems architecture, which consists of IoT applications and a blockchain-based distributed ledger to support transaction services within-in a multi-party global apparel business network. The IoT is a smart global network of interconnected objects, which through unique address schemes can interact with each other and cooperate with their business partners to achieve common objectives. The data obtained from the IoT applications along apparel business processes can make operational decision-making much easier. However, standalone IoT application systems face *security* and *privacy*-related problems.

Security and business organizational issues tend to enhance the need to build a manufacturing supply chain management system leveraging blockchain ledger technology. Regardless of the particularities of the specific textile manufacturing supply chain-related application, blockchain can offer a wide range of advantages. By registering and documenting a product's (for example - cotton, fibre, textile cloths) lifecycle across the manufacturing supply chain nodes increases the transparency and the trust of the participating business partners. Finally, the paper presents a research proposal outlining how blockchain technology can impact important aspects of the IoT system, the GDPR related issues, and thus provide the foundation for future research challenges.

9. References

[1]   AhIman, R., Finish city partners with IBM to validate blockchain application in logistics, 2016, (online – https://cointelegraph.com/news/finish-city-partners-with-ibm-to-validate-blockchai-application-in-logistic).

[2]   Atzori, L., Iera, A., Morabito, G. The Internet of Things: A survey, Computer Network, 2018, 54, 2787-2805. https://doi.org/10.1016/j.comnet.2010.05.010

[3]   Banker, S. Will blockchain technology revolutionize supply chain applications? 2016, (online – https://logisticsviewpoints.com/2016/20/will-blockchain-techology-revolutionize-supply-chain-applications/).

[4] Chen, I., Guo, J., Bao, F. Trust management for service composition in SOA-based IoT systems, In Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC), 2014, Istanbul, Turkey, 6-9, April, 3444-3449.
https://doi.org/10.1109/WCNC.2014.6953138

[5] CouchDB. https://www.couchdb.apache.org

[6] Corda. https://www.corda.net

[7] Deloitte. Digital Procurement: New Capabilities from Disruptive Technologies, Deloitte Development LLC: Stanford, CT, USA, 2017.

[8] Dobrovnil, M., Herold, D. M., Furst, E., Kumer, S. Blockchain for and in Logistics: What to Adopt and Where to Start, Logistics, 2018, 2, 18.
https://doi.org/10.3390/logistics2030018

[9] Ethereum. https://www.ethereum.org

[10] Fadi, S., Joaquin, B., Ordieres, M., Giovanni, M. Smart factories in Industry 4.0: A reviewof the concept and of energy management approach, In Proceeding of the IEEE International Conference on Industrial Engineering and Engineering Management, Bandar Sunway, Malaysia, 2014, 679-701.

[11] Finextra. Everledger secures the first bottle of wine on blockchain, 2016, (online – https://finextra.com/pre article/6738/everledger-secures-the-first bottle-of-wine-on-the-blockchain).

[12] Goo, Y. L., Kyung, J. C., Hwa, J. K. Designing the GDPR compliant consent procedure for personal information collection in IoT environment. In Proceeding of the International Congress on Internet of Things, IEEE, Milan, Italy, 2019, 79-1.

[13] Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M. Internet of Things (IoT): A vision, architectural elements, and future directions, Future Generation Computer Systems, 2013, 29: 1645-1660.
https://doi.org/10.1016/j.future.2013.01.010

[14] Hulseaapple, C. Block Verify uses blockchains to end counterfeiting and making world more honest, 2015 (online – https://finextra.com/presarticle/67381/everled ger-secures-the-first-bottle-of-wine-on-the-blockchain).

[15] Hyperledger. https://www.hyperledger.org

[16] Inera, A. Bosch, Cisco, BNY Mellon other launch new blockchain consortium, 2017, (online – http://www.reuters.com/article/us-blockchain-iot-idUSKBN15B2D7).

[17] Kim, N. IBM pushes blockchain into the supply chain, Wall Street Journal, July 2016.

[18] LevelDB. https://github.com/google/leveldb

[19] Nakamoto, S., Bitcoin: A Peer-to-Peer Electronic Cash System, 2008.

[20] Nora, N. L. A port in data -sharing storm: the GDPR and the Internet of Things, Journal of Cyber Policy, 2019, 4(2), 178-196.
https://doi.org/10.1080/23738871.2019.1635176

[21] Pal, K. Information Sharing for Manufacturing Supply Chain Management Based on Blockchain Technology, In Cross-Industry Use of Blockchain Technology and Opportunities for the Future, Dr. Idongesit William (eds), Chapter 1, May 2020, IGI Global Publication, Hershey, PA, USA.
https://doi.org/10.4018/978-1-7998-3632-2.ch001

[22] Pal, K. Algorithmic Solutions for RFID Tag Anti-Collision Problem in Supply Chain Management, In the proceeding of 9th International Symposium on Frontiers in Ambient and Mobile Systems (FAMS), 29 April – 2 May 2019, Leuven, Belgium, Procedia Computer Science, 929-934.
https://doi.org/10.1016/j.procs.2019.04.129

[23] Pal, K. Supply Chain Coordination Based on Web Services, In Supply Chain Management in the Big Data Era, H.K. Chan, N. Subramanian, and M. D. Abdulrahman (eds), Chapter 9, 2017, 137-171, IGI Global Publication, Hershey, PA, USA.
https://doi.org/10.4018/978-1-5225-0956-1.ch009

[24] Pal, K. Ontology Assisted Enterprise Information Systems Integration in Manufacturing Supply Chain, in Handbook of Research on Development and Trends in Industrial and Material Engineering, Prof. Prasanta Sahoo (eds), January 2020, Chapter 5, IGI Global Publication, 70 E Chocolate Avenue, Hershey,PA, USA.
https://doi.org/10.4018/978-1-7998-1831-1.ch005

[25] Shrouf, F., Ordieres, J., Miragliotta, G. (2014), Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm, in Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management, Bandar Sunway, Malaysia, 9-12 December 2014, 679-701.
https://doi.org/10.1109/IEEM.2014.7058728

[26] Yan-e, D. Design of intelligent agriculture management information system based on IoT, in Proceedings of the 2011 Fourth International Conference on Intelligent Computation Technology and Automation, Shenzhen, China, 28-29 March 2011, 1: 1045-1049
https://doi.org/10.1109/ICICTA.2011.262

[27] Samaniego, M., Deters, R. Virtual Resources & Blockchain for Configuration Management in IoT, in Journal of Ubiquitous Systems & Pervasive Networks, 2017, 9(2): 1-13.

[28] Rahmani, R., Li, Y. A Scalable Digital Infrastructure for Sustainable Energy Grid Enabled by Distributed Ledger Technology, in Journal of Ubiquitous Systems & Pervasive Networks, 2020, 12(2): 17-24.