7th Bangladesh Conference on Industrial Engineering and Operations Management
December 21-22, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/BA07.20240098
Published: December 21, 2024

Implementing Blockchain Technology in the Supply Chain of RMG Industries in Bangladesh

Syed Junayed Ahmed Niloy[1, *], Md. Iftekhar Alam[1], Shahed Karim[2], Mohammad Sarwar Morshed[1], Tahmim Alam[1], Nure Arfi[3]

[1]Department of Mechanical and Production Engineering
[2]Department of Computer Science and Engineering
[3]Department of Textile Engineering
Ahsanullah University of Science & Technology (AUST),
Dhaka, Bangladesh

[*]syedniloy1996@gmail.com, ornabmd@gmail.com, info@shahedkarim.com, m.morshed.mpe@aust.edu, sat.tahmimalam@gmail.com, arfiya.arfi17@gmail.com

Abstract

Bangladesh's ready-made garment (RMG) sector has substantial challenges in the areas of efficiency, traceability, and transparency across its intricate logistics and supply chain operations. This study investigates the use of blockchain technology, in order to address these issues, particularly the Hyperledger Fabric framework, which provides a transparent, tamper-proof, and decentralized platform for monitoring the flow of products from manufacturing to distribution. This work demonstrates the advantages of blockchain over traditional systems through a performance analysis based on metrics such as latency, throughput, and security vulnerabilities. These benefits include enhanced data integrity, process optimization through smart contracts, and stakeholder trust. A more resilient and scalable RMG supply chain can result from the incorporation of blockchain and its capacity to accelerate transportation, minimization of fraud, and drastically reduce third-party audit expenditures. By developing a model for implementing blockchain technology into logistics and supply chains, particularly in emerging markets like Bangladesh, this study broadens our comprehension of the non-financial aftereffects of the technology known as blockchain.

Keywords

Supply Chain and Logistics, Blockchain, Hyperledger Fabric, Performance Analysis, Smart Contracts.

1. Introduction

Blockchain technology has been a game-changer in addressing several logistics inefficiencies, especially in Bangladesh's Ready-Made Garments (RMG) industry, which is distinguished by complex and frequently opaque supply network. By giving users access to a shared and immutable record of every transaction, blockchain serves as a decentralized ledger that guarantees security, transparency, and traceability. From raw materials to ultimate delivery, blockchain technology can assist merchants, transportation businesses, and manufacturers in tracking products over their whole lifecycle. This capability could address enduring issues in the logistics sector, including fraud, delays, and the exorbitant expenses linked to intermediaries (Queiroz and Fosso Wamba 2019; Wang *et al.* 2018). Consensus techniques including Proof of Work (PoW) and Proof of Stake (PoS) are used by the system to validate transactions and ensure uniformity among all involved nodes. These mechanisms guarantee that transactions are confirmed by multiple participants, thereby preventing fraud and mitigating the risk of double-spending.

As Bangladesh is one of the global pioneers in the RMG sector, supply chain transparency and reliability might be greatly enhanced by implementing blockchain. Blockchain enables a single, reliable source of truth, which minimized the need for third-party audits in logistics, speeds up verification procedures, and reduces discrepancies according to Wang et al. (2019). Logistics operations can streamline processes including payments and other activities through the implementation of smart contracts, which are self-executing agreements encoded in the blockchain. These contracts are activated when certain circumstances are satisfied criteria, such as delivery confirmations. In addition to cutting down on delays, this automation fosters trust with foreign clients, which is key to Bangladesh's RMG export expansion (Dobrovnik *et al.* 2018).

Blockchain is a cutting-edge invention as it ensures data immutability and make data streams publicly accessible. In addition, it gets around the drawbacks inherent in traditional centralized systems, which are susceptible to challenges with trust such as data manipulation, fraud, and corruption. Since they only have one weak point, centralized systems are similarly liable to catastrophic collapse. The distributed and decentralized design of blockchain, on the other hand, enhances resilience and security. While blockchain technology has enormous potential, it is still in its early stages, and there are numerous barriers to overcome prior it can be used in supply chain and logistics applications. The literature currently in publication appears to be deficient in research that discuss blockchain's non-financial applications in these industries (Perboli *et al.* 2018) Blockchain's decentralized, immutable, and transparent nature supports uses beyond cryptocurrency, such as smart contracts, supply chains, identity checks, and IoT. It reduces costs and improves trust by removing intermediaries. Nevertheless, there are issues with scalability, privacy, and energy consumption while actively working with blockchain. Ongoing research and advancements in consensus algorithms and scalability solutions are actively addressing these limitations, thereby facilitating broader adoption and innovation within the field.

Blockchain integration in logistics may enhance data accuracy while lowering transaction costs by up to 20%, claim Queiroz and Wamba (2019). By eliminating middlemen and streamlining record-keeping, blockchain lessens the chance of fraud and human error—two problems that are common in traditional supply chains. By enabling customers to verify the legitimacy of goods and ensure that all rules are adhered to properly, this could help the RMG sector. Blockchain technology streamline the certification process for textile exports while tackling issues like sustainability and labor standards. Furthermore, they suggest that for organizations to reap the benefits immediately, blockchain adoption ought to begin with crucial supply chain processes such tracking and verification. In massive operations industries like RMG, where careful integration of new technologies is required to safeguard against disruption, this stepwise approach is crucial (Saberi *et al.* 2018).

This paper aims to examine whether blockchain technology could alter Bangladesh's RMG sector's logistics. Particularly, it looks at how blockchain can enhance transparency, streamline operations, and reduce costs while highlighting the obstacles to its efficient implementation along with offering alternatives. And figure 1 illustrates the potential benefits of blockchain technology in logistics, highlighting its ability to enhance transparency, streamline operations, ease paperwork processing and identify counterfeit products, thus improving efficiency and security in the supply chain.

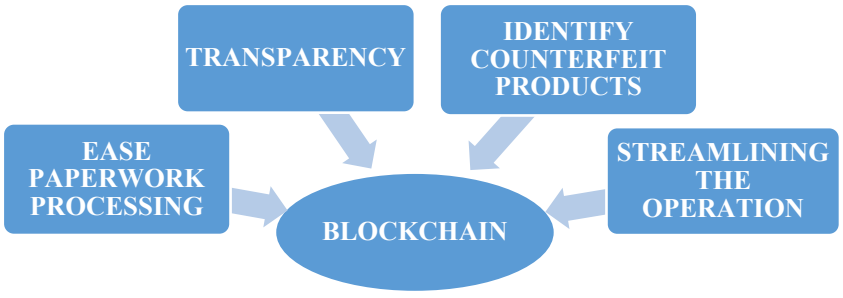

Figure 1. The Potential of Blockchain Technology in logistics.(Tijan *et al.*, 2019)

1.1 Objectives

To streamline the RMG sector's supply chain in Bangladesh, this research outlines several key objectives for implementing blockchain technology in logistics. Each objective targets critical pain points in the industry, promising improvements in transparency, efficiency, and security.

- To enhance transparency in raw materials sourcing.
- To Implement Smart Contracts to make documentation and compliance safer and more efficient.
- To improve the accuracy of real-time tracking and inventory control.

2. Literature Review

Supply Chain is the overall management of a network of stakeholders of a company, firm and other related business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and other related organizational structures that has a key role in accelerating transport of resources both reverse and forward, services, finances and information exchange from the producing organization to final customer with the benefits of adding monetary value by maximizing profit margin through efficient dealing of product, quality control and being punctual leading to customer satisfaction (Queiroz *et al.*, 2020) (Azzi *et al.*, 2019). Though the whole world is shifting towards a paperless digital era, many sectors of the supply chain management is still stuck in the old paper-based style. (Sangeerth and Lakshmy, 2021). The general supply chain management work view in Bangladesh RMG sector given the Figure 2.

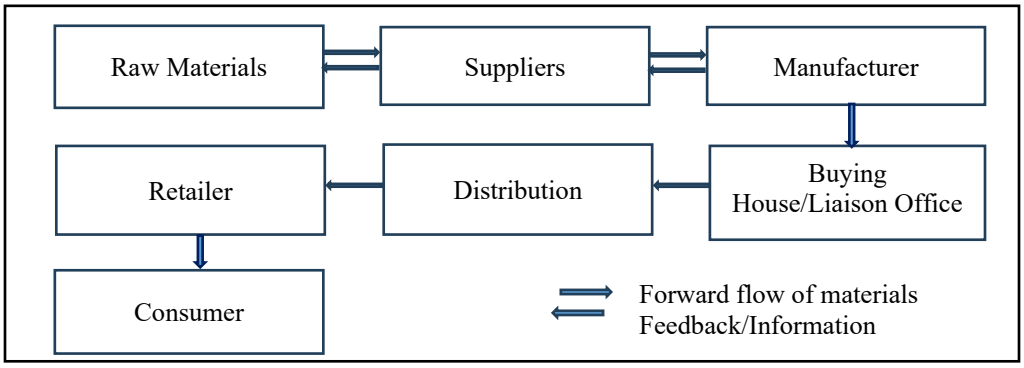

Figure 2. In general, SCM work view in Bangladesh Garment Industry.(Tanvir and Muqaddim 2013)

With advanced technology like blockchain, the old school paper-style can be easily transferred into a digitalized ledger system. Blockchain can be described as a network where there is no central authority among peer-to-peer network(Sangeerth and Lakshmy 2021), every node (computer) connected to the network can share data without any server monitoring required. The nodes can be either of a mining device, a storage device or any other functional participant which performs a different function in the Blockchain network. Using other data transfer software to maintain the information transfer is expensive compared to the comparatively cheaper blockchain technology. Blockchain is a type of distributed ledger technology. Mentionable features of it includes decentralization and trustworthy ledger of records which are tamper proof once entry of data is done. The way the blockchain keeps its data safe from tampering is by keeping a record of any type of data entry including transaction records using cryptographic hashes (Queiroz *et al.* 2020) The smallest unit in a blockchain network is a transaction. A block stores successful transactions along with metadata, including the timestamp, nonce, root hash, and previous hash. The timestamp indicates when the block was created, and the nonce is a random number used in proof of work and mining. The root hash is derived from a Merkle tree of transaction hashes.

The previous hash stores the hash of the previous block's header. These cryptographically linked blocks from the blockchain in chronological order across the network (Sangeerth and Lakshmy 2021). Blockchain has become one of the most emerging technologies to mitigate prior problems in sector like the financial services, supply chains, healthcare, energy, and public services with its capabilities to support a publicly distributed ledger whose copies are available to every stakeholder of the blockchain. Anonymous and automated transaction without a need of centralized authority or a middleman is also a unique feature of this technology (Kuzlu *et al.* 2019). The active use of blockchain technology in sharing information has been seen in many scenarios like storing and sharing personal health

information (Kuzlu *et al.* 2019), electric power industries (Queiroz *et al.*2020), automotive industry (Alhajjaj *et al.* 2023; Itohan Oriekhoe *et al.* 2024; Yuksel *et al.* 2021), Medicine manufacturing companies (Itohan Oriekhoe *et al.*, 2024) and many more. The key features of a blockchain technology are transparency, integrity, security, stability, and decentralization(Azzi *et al.* 2019; Batta *et al.* 2020; Chaker and Damak 2024; Hellani *et al.* 2020; Perboli *et al.* 2018). There are three principal categories of blockchain platforms: public chains, private chains, and consortium (or hybrid) chains. Public chains permit unrestricted participation, whereas private chains limit access to authorized entities and consortium chains are managed collaboratively by multiple organizations.

Bangladesh's economic growth is significantly supported by the RMG (Ready-Made Garments) sector. To modernize this sector and increase profit margins, various challenges need to be addressed. As Bangladesh's RMG sector prepares for Industry 4.0 (Rahman *et al.*, 2023) one of the major obstacles it will be facing is information digitalization and sharing (Rahman *et al.*, 2023). In the logistics sector alone, enhanced transparency and faster information sharing can accelerate processes and mitigate the bullwhip effect (Blossey *et al.* n.d.). Blockchain enables secure, transparent, and cost-efficient tracking and direct transactions throughout a product's lifecycle, eliminating intermediaries and building trust among stakeholders (Habib *et al.* 2024). Game theory (Manzoor *et al.* 2022) is often used for blockchain implementation in industries, while TOE (Technology-Organization-Environment) theory (Manzoor *et al.* 2022) is utilized for pre-adaptation assessments. According to Nash Equilibrium concept, in game theory, players' payoff functions exhibit interdependence, meaning the outcome for one player depends on the strategies chosen by others, creating indirect interactions.

Each player's decision directly influences the payoffs of others. When binding agreements are possible, the complexity of these interactions often results in closed-form solutions. Solving such problems involves computing or approximating the Pareto frontier, which represents solutions where no player can improve their payoff without negatively impacting another. For TOE we assess the data of technology, organization and environment to get an idea of possibilities of implementation and its success rate (Keysers *et al.*,2016; Tian, 2024).
Overall RMG sector of Bangladesh faces various time management issues due to wasteful activities occurring along the logistics of the supply chain. Eight such wastes can be identified in TIMWOODS which are Transportation, Inventory, Motion, Waiting, Overprocessing, Overproduction, Defects, and skills. Other than these regular challenges are faced in transportation through Air Cargo, Land Ports and Sea Ports due to custom issues and lateness in paper clarification related to goods, which is true for any industry in Bangladesh (Aziz *et al.*, n.d.). Successful integration of Blockchain will reduce time delays in sectors like Waiting of TIMWOODS and also in custom clearance and transportation.

3. Methodology

With the help of blockchain a distributed ledger may be formed in order to share data and information with active stakeholders of the RMG sector.

Table 1. Comparison of Layered Architecture Across Bitcoin, Ethereum, and Hyperledger.

Layer	Bitcoin	Ethereum	Hyperledger
Application layer	Bitcoin trading	Ethereum trading	Enterprise blockchain
Network layer	TCP-based P2P	TCP-based P2P	HTTP/2-based P2P
Contract layer	Script	Solidity/Script EVM	Go/Java Docker
Consensus layer	PoW	PoW/PoS	PBFT/SBFT
Data layer	Merkle tree	Merkle Patricia tree	Merkle Bucket tree

Among a number of Consensus mechanisms, Proof of Work (PoW) and Proof of Stake (PoS) are employed to validate and incorporate transactions into the ledger Smart contracts serve to automate and enforce agreements, thereby eliminating the need for intermediaries and enhancing operational efficiency. The nodes participating in the network include full nodes, which maintain complete copies of the blockchain and validate transactions, and light nodes, which depend on full nodes for data. The process of tokenization facilitates the creation of digital assets or cryptocurrencies,

thereby introducing an additional layer of value to blockchain systems. Interoperability solutions, exemplified by Polkadot, enable communication between distinct blockchains. Furthermore, scalability solutions such as sharding and layer-2 technologies address performance-related challenges.
A few well known and well-established structures are :1) Bitcoin. 2)Ethereum. 3)Hyperledger. And the table 1 compares the layered architectures between them. Each platform has distinct components at various layers, such as application, network, contract, consensus, and data layers, highlighting differences in functionality and design.

3.1 Block Structure in a Blockchain:

The structure of blocks in a blockchain includes several essential components that work together to ensure the integrity, security, and transparency of the data. The Prev Hash element connects each block to its predecessor by storing the hash value of the previous block's data, creating a continuous and unbreakable chain. Because of this link, any modification to a block's data will result in a change to its hash value, disrupting the chain and indicating possible manipulation. Miners modify this value and repeatedly recalculate the block's hash until it matches the designated difficulty level. The Nonce is a random number used in the mining process. This procedure, called Proof of Work (PoW), enhances the security and reliability of the blockchain by validating each block before it is added to the chain. The Timestamp demonstrates the specific moment when a block is generated, facilitating the chronological ordering of blocks and delivering proof of the existence of data at a particular point in time. The Merkle Root is derived from a Merkle tree, a type of binary tree in which each leaf node includes a hash of transaction data, while non-leaf nodes represent hashes of their respective child nodes. The root hash allows for rapid verification of all transactions within the block without obliging an individual examination of each transaction.

The Target parameter sets the network's difficulty level for mining new blocks, dynamically adjusting based on the time taken to mine previous blocks. This mechanism ensures that blocks are mined roughly every ten minutes, keeping the network's consistency intact. Additionally, Smart Contract Transactions act as self-executing agreements with rules built in, automatically triggering actions whenever specific conditions are met. These transactions are stored on the blockchain, providing transparency, immutability, and automated business logic. Together, these elements build a secure and efficient blockchain system that supports decentralized applications and ensures data integrity.

The below figure 3 shows a blockchain structure beginning with the Genesis block, followed by subsequent blocks (N and N+1) linked in sequence. Each block contains essential data, including the previous block hash, nonce, Merkle root, timestamp, target, and smart contract information, ensuring secure and sequential data storage.

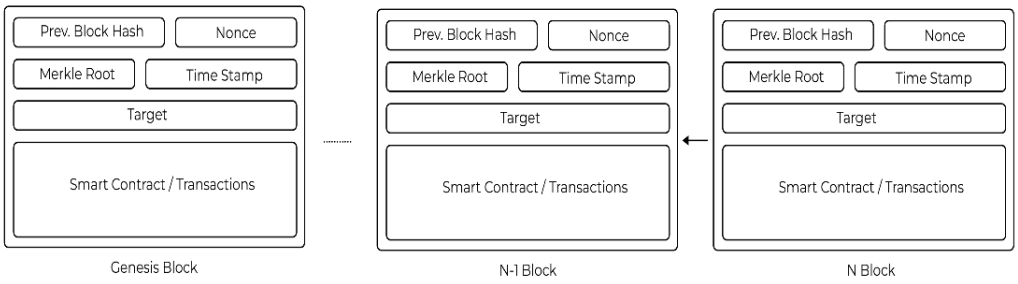

Figure 3. Genesis Block

3.2 Consensus Mechanisms in Blockchain

Different methods of Consensus Mechanisms are actively used in order to create and add a new block of Information to the chain with different mechanisms having different pros and cons. Some of the Prominent and Widely used Consensus Mechanism are:

a) **Proof of Work (PoW):** Participants (miners) compete to solve complex mathematical puzzles to add a new block to the blockchain. Miners try to find a nonce (a random number) that, when hashed with the block's data, produces a hash value below a certain target. The condition for a valid block is, H (block data||nonce) <target. where H is the hash function (e.g., SHA-256), block data represents the block's contents, and nonce is the value miners adjust to meet the difficulty target (Nakamoto, n.d.).

b) **2. Proof of Stake (PoS):** PoS selects validators to create new blocks based on the amount of cryptocurrency they stake (lock as collateral). The more coins staked, the higher the chances of being selected. The

probability P of a validator V being selected is proportional to their stake S and the total network stake T: **P(V)=S/T**. Validators earn rewards based on their staked amount.

c) **3. Delegated Proof of Stake (DPoS):** Evolution of PoS, where stakeholders vote for delegates (also called witnesses) to validate transactions and create blocks. The delegates are responsible for maintaining the blockchain. Each voter's voting power W is proportional to their stake S: **W=S/T**. The delegates are chosen based on the weighted votes of stakeholders.

d) **4. Practical Byzantine Fault Tolerance** (PBFT): designed to tolerate up to f faulty or malicious nodes in a network of 3f + 1 nodes. Nodes communicate in rounds to agree on the order of transactions and maintain consensus. For a network with n nodes, it can tolerate up to f faulty nodes if: **n≥ 3f+1**. The protocol requires that at least 2f + 1 correct nodes must agree for a decision to be made.

e) **Proof of Elapsed Time (PoET):** relies on participants waiting for a randomly chosen amount of time. The node that waits the least amount of time is selected to create the next block. The probability of being selected is inversely proportional to the waiting time: **P(V)=1/T (min.)**. where T (min.) is the minimum wait time.

The below figure 4 illustrates the types of consensus mechanism.

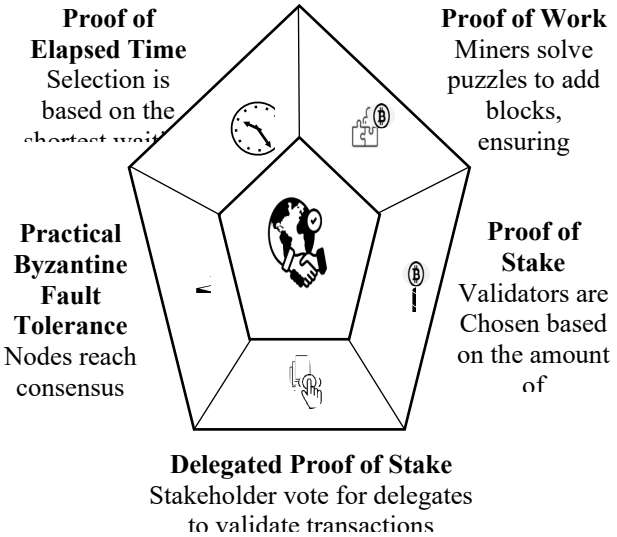

Figure 4. Types of Consensus Mechanisms (Zhai *et al.* 2019)(Zheng *et al.* 2017)

3.3 Hyperledger Fabric, a consortium blockchain framework:

Hyperledger Fabric is a permissioned blockchain framework specifically designed for enterprise applications, offering a modular architecture characterized by features such as confidentiality, scalability, and flexibility. This framework is one of the initiatives under the Hyperledger umbrella, which is endorsed by the Linux Foundation. Hyperledger Fabric enables businesses to develop blockchain-based applications or solutions customized to particular use cases by facilitating private and secure transactions. The platform's modular design allows for the customization of consensus mechanisms, membership services, and the integration of pluggable components, including various databases and communication protocols (Androulaki *et al.* 2018).

3.3.1 Hyperledger Fabric Architecture:

Hyperledger Fabric operates using specific methodologies that enable data integration onto the blockchain while controlling access so only designated parties can view certain information. It follows an Execute-Order-Validate Paradigm. Unlike traditional blockchains that use an "order-execute" model—where transactions are first ordered and then executed—Hyperledger Fabric uses an execute-order-validate approach. This model starts with simulating transaction execution (execute), then arranges the transactions in order (order), and finally validates them to ensure consistency across all nodes (validate). This approach boosts performance by allowing transactions to be processed in parallel, with only certain peers needing to endorse transactions rather than every peer, which improves scalability.

Additionally, Hyperledger Fabric uses channels and private data collections to divide data and control access, making sure that sensitive information is only visible to authorized parties. Identities and permissions are managed by a Membership Service Provider (MSP), which enables secure access control. Also figure (5) shows the Hyperledger Fabric Architecture.

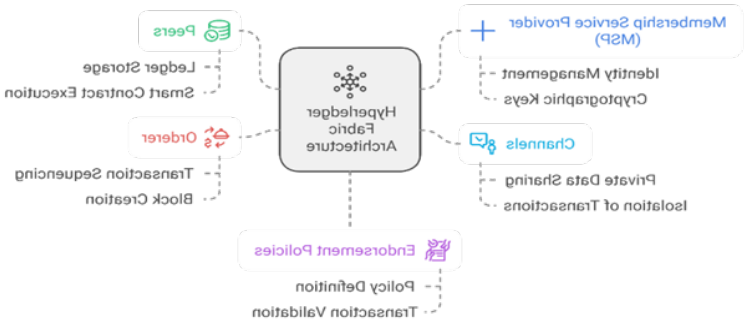

Figure 5. shows the Hyperledger Fabric Architecture**.**

3.4 Proposed Model:

Figure 5. Architecture of Hyperledger Fabric.

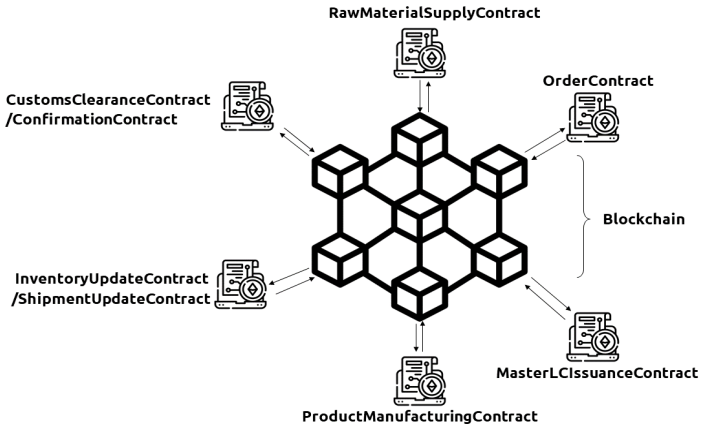

Figure 6. Structure of Blockchain Using Smart Contract.

The overall system is initiated once a client places an order for the required product. The order will contain details of required factors like product type, size, and delivery date. The details provided are then saved in the blockchain via the **OrderContract**, this saved data is immutable and secured. All relevant information is automatically created in a new block by the contract, which the RMG factory and other authorized organizations can access. A Master Letter of Credit (LC), which confirms to the fulfilment of the terms set forth between the organizations is requested by the RMG sector once the order has been accepted and verified. The **MasterLCIssuanceContract**, which provides security and transparency concerning payment terms and production variables, is used to record the LC in a new block after the client provides the master LC. F**i**gure 6 shows interaction between smart contact and blockchain.

After the LC is confirmed, the next step is sourcing and processing the raw materials required for production criteria. The **RawMaterialSupplyContract** is then used to connect the provided LC directly to the blockchain. The licensed and authorized suppliers of raw materials then assess the requirements of the product and provide their opinion regarding the demand and specifications, including both pros and cons, which is saved in the blockchain. This method ensures transparency and accountability in the process of sourcing while retaining safe access to information about fulfilment of orders, including the availability of materials. Following receipt of the raw ingredients, the RMG factory begins manufacturing, which is closely monitored by the **ProductManufacturingContract.** This contract ensures that all stakeholders receive real-time information by documenting all essential production details, such as output amounts, manufacturing status, and quality checks.

Inventory management plays a crucial role in the supply chain, especially in the case of raw materials and produced goods. The **InventoryUpdateContract** tracks and updates inventory levels dynamically as the raw materials are used and finished goods are made. Through this contract, the RMG factory and material suppliers can keep track of the current inventory levels, thereby reducing the possibility of either a deficit or surplus of stock.The RMG plant uses the **ShipmentUpdateContract** to provide shipment data as soon as the items are manufactured and ready for shipping. All parties concerned may track the status of shipments in real time thanks to this contract, that stores the shipment identification number, carrier information, and expected arrival dates.

Lastly another key role player for consideration is custom clearance. The **CustomsClearanceContract** ensures that crucial Customs Documentation, including Bill of Lading (BOL), Transaction Invoice, List of Packing, Import Permit/Import Registration Certificate (IRC), Certificate of Origin, Insurance Certificate, Letter of Credit (L/C) or Purchase Order, Customs Declaration Form, Tax Identification Number (TIN) (ITA, 2022), is recorded on the blockchain. This contract accelerates the custom clearance process by reducing paperwork time and guaranties that all necessary documents are readily available for inspection by custom authorities. This Contract ensures that all documents are accessible by the authorized parties in real time ensuring transparency and mitigating delay. Following the confirmation of the shipment being done through successful Custom Clearance, the initiation of The **ConfirmationContract** is done marking the end of processes from RMG's end according to contract and the below figure 7 is our proposed model.

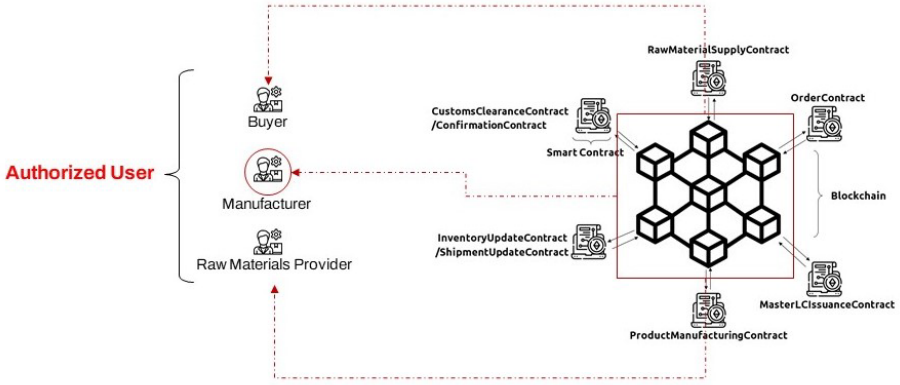

Figure 7. Proposed Model

4. Performance Analysis and Discussion:

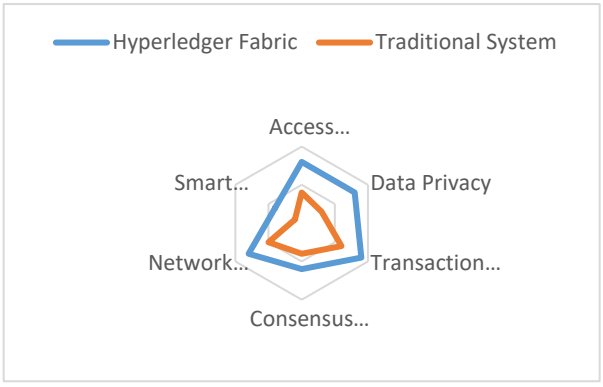

Figure 8. Vulnerability Comparison: Hyperledger Fabric vs Traditional System

The hypothetical data used in the radar chart in figure 8, comparison between Hyperledger Fabric and traditional systems was based on general characteristics and common security features of each system. Here's a more detailed

explanation for how these values were determined based on a scoring system (on a scale from 1 to 10, where 1 is the least secure and 10 is the most secure):

a) **Access Control:** Because of its permissioned blockchain model, which strictly regulates both participants and their actions, Hyperledger Fabric offers a more secure and strict access control system. Compared to older systems, which may have different levels of access control based on their architecture, this results in improved security and stops unwanted access. Traditional Systems 4 and Fabric 8 have been updated. In contrast to traditional systems, which are more likely to have weaker settings, Fabric uses predefined access rules and permissions, which results in greater access control, as indicated by the updated score.
b) **Data Privacy:** Hyperledger Fabric excels in securing data privacy with strong encryption and isolation algorithms, ensuring transactions are confidential and secure. Traditional systems sometimes rely on simple or centralized security mechanisms, making them more susceptible to intrusions. Fabric 8, Traditional System 3. This modification showcases Fabric's greater privacy features and resolves the previous scoring anomaly.
c) **Transaction Integrity:** Fabric's usage of blockchain's inherent immutability renders transactions very resistant to tampering or manipulation. Traditional systems, on the other hand, are vulnerable to corruption caused by external meddling, such as SQL injection or data breaches. Fabric 9; Traditional Systems 6. This grade demonstrates blockchain's unsurpassed integrity when compared to centralized alternatives.
d) **Consensus Protocol:** Hyperledger Fabric relies on complex consensus methods to assure transaction validation. However, the increasing complexity and resource requirements of these protocols might cause operational issues. Traditional systems, on the other hand, usually provide simpler transaction processing but are more prone to fraudulent entries. Fabric 6; Traditional Systems 4. The grades represent Fabric's balance of security and complexity while considering the trade-offs.
e) **Network Security:** Fabric's permissioned structure improves network security by minimizing vulnerability to threats such as DDoS and man-in-the-middle assaults. Traditional systems are considerably weaker because they lack such strong safeguards. Fabric 8; Traditional Systems 5.
f) **Smart Contract Vulnerabilities:** While Fabric allows smart contracts ("chaincode") for automated transactions, they can be vulnerable if they are badly written or incorrectly set. This is less relevant in conventional systems that do not employ smart contracts.Fabric 4; Traditional Systems 1.

Detailed description of each of the three graphs and what they reveal about the relationship between **Throughput** and **Latency** across varying third parameters:

- **Throughput vs. Latency with Varying Nodes:**
  This line chart in figure 9 is plotted with Throughput (TPS) on the y-axis and Latency (ms) on the x-axis, with each data point labeled by the Node count (e.g., 10 Nodes, 20 Nodes). With increasing latency, throughput generally decreases. This trend illustrates how adding nodes to the system may increase latency and affect throughput. Initially, with fewer nodes, throughput is high, but as more nodes are added, latency begins to increase, causing a decline in throughput. The chart indicates that while adding nodes can provide some initial benefits (possibly for redundancy or fault tolerance), there's a trade-off with throughput at higher node counts.

- **Throughput vs. Latency with Varying Transaction Rate:**
  The scatter plot in figure 10 presents Throughput (TPS) on the y-axis and Latency (ms) on the x-axis. Different transaction rates are represented by color intensity, with darker colors indicating higher transaction rates. The graph shows that as transaction rates increase (darker points), both latency and throughput tend to vary. Here, higher transaction rates might increase the system strain, which is reflected in the increased latency and potentially decreased throughput. This visualization demonstrates the effect of transaction rate on system performance, which shows that high transaction rates can create bottlenecks that impact latency, which can reduce throughput efficiency.

- **Throughput vs. Latency with Varying Transaction Number:**

The bubble chart in figure 11 Throughput (TPS) is on the y-axis, Latency (ms) on the x-axis, and the size of each bubble represents the Transaction Number (larger bubbles indicate higher transaction numbers). As transaction numbers increase (larger bubbles), the chart shows a similar pattern where latency tends to increase while throughput decreases. A higher workload is indicated by a higher transaction volume, which may cause throughput decreases and latency increases. This figure is helpful for illustrating how transaction load affects system performance because it demonstrates how high transaction volumes which are frequently linked to peak loads may impair throughput as the system tries to manage the additional load.

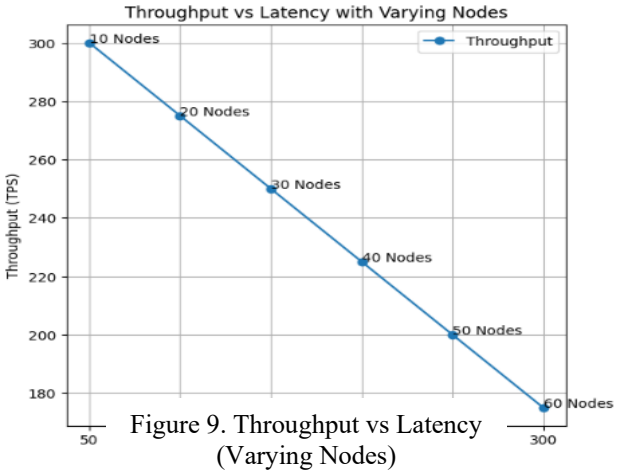

Figure 9. Throughput vs Latency (Varying Nodes)

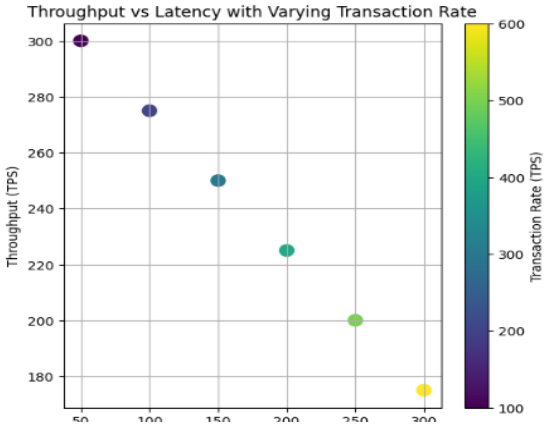

Figure 10. Throughput vs Latency (Varying Transaction Rates)

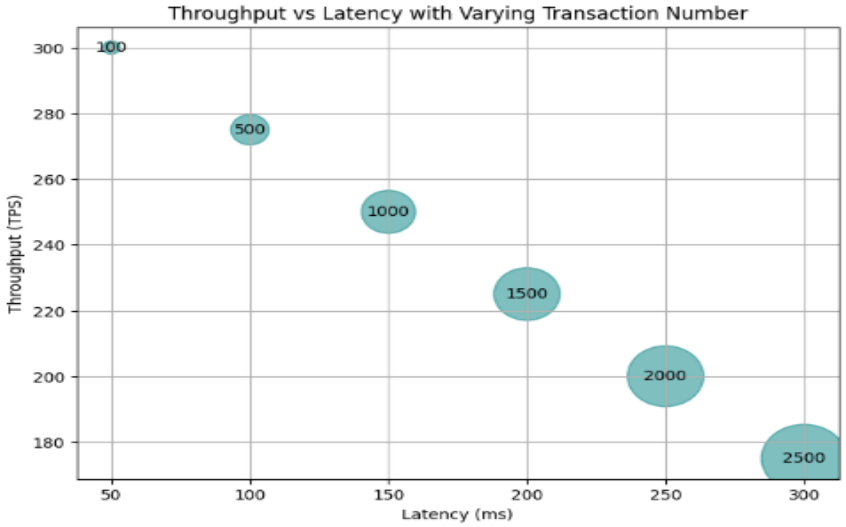

Figure 11. Throughput vs Latency (Varying Transaction Number)

4.1 Comparative Analysis:

Table 2 is the comparative analysis of existing and proposed improvements.

Table 2. Existing vs. Proposed Improvements

Aspect	Existing Process	Proposed Improvement with Blockchain
Tracking and Visibility	Limited visibility on shipment status; reliance on manual updates leads to delays in information.	Implement a blockchain-based tracking system for real-time updates accessible to all stakeholders, enhancing visibility throughout the delivery process.
Data Accuracy	Manual entry leads to errors and discrepancies in delivery records.	Utilize blockchain's immutable ledger to ensure accurate, tamper-proof records of all transactions, reducing discrepancies.
Delivery Issues	Lack of transparency in handling delivery issues; disputes can arise without clear records.	Enable a transparent system where all parties can access the delivery history and status, allowing for swift resolution of disputes.
Cost Management	High costs associated with delays, disputes, and inefficiencies in the delivery process.	Reduce costs through improved efficiency and reduced delays by providing clear visibility into the supply chain, enabling better decision-making.
Compliance and Auditing	Manual compliance checks can be inefficient and prone to errors.	Utilize blockchain's transparency for automatic compliance tracking, making audits easier and reducing the risk of non-compliance.
Inventory Management	Limited insight into inventory levels during transit, leading to overstock or stockouts.	Implement a blockchain system to provide real-time visibility into inventory levels, enhancing overall inventory management.
Stakeholder Collaboration	Poor collaboration between stakeholders, leading to inefficiencies and misunderstandings.	Foster better collaboration by providing all stakeholders with access to a shared blockchain ledger, improving trust and cooperation.

4.2 Summary of Improvements

By integrating blockchain technology into the product delivery process, the RMG industry can achieve significant improvements in transparency, traceability, and overall efficiency. These enhancements will not only streamline operations but also build trust among stakeholders and improve customer satisfaction, ultimately leading to a more robust supply chain. The proposed blockchain solution can address existing challenges, allowing RMG companies to adapt to market demands and improve their competitiveness in the industry.

4.3 Validation of the work

The performance analysis and proposed model for integrating Hyperledger Fabric into Bangladesh's RMG supply chain demonstrate tangible benefits in transparency, security, and operational efficiency. This validation is supported by similar research highlighting the value of blockchain in complex supply chains. For instance, Queiroz et al. (2020) emphasize the role of blockchain in enhancing traceability and data integrity in supply chains, pointing out that a decentralized ledger reduces errors and provides a reliable, tamper-proof record of transactions (Queiroz *et al.*, 2020).

In terms of system security and access control, Hyperledger Fabric's permissioned nature ensures that only authorized parties can view sensitive data. This framework is validated by similar findings in Azzi et al. (2019), who demonstrate that permissioned blockchain systems improve data privacy and prevent unauthorized access, making them particularly effective for supply chains that handle confidential information (Azzi *et al.*, 2019). The latency and throughput performance metrics, as analyzed in our paper are consistent with findings by Kuzlu et al. (2019), who analyzed Hyperledger Fabric's performance in varied transaction volumes and found it capable of maintaining low latency even as the number of nodes increases. This further supports the robustness of blockchain for large-scale supply chain applications in the RMG sector (Kuzlu *et al.*, 2019).

Furthermore, inventory management and transaction processing are done automatically through the implementation of smart contracts, which minimizes manual error and delays. This use of smart contracts aligned with studies by Sangeerth and Lakshmy (2021), which demonstrate the way automated contracts in logistics preserve costs by eliminating the need for middlemen and streamlining procedures (Sangeerth and Lakshmy, 2021).

In conclusion, this validation, that is backed up by different literature confirms that Hyperledger Fabric is a rational option for Bangladesh's RMG supply chain. Blockchain technology improves traceability, operational efficiency, and security. Pilot testing in an actual RMG supply chain setting might be used for further validation in order to evaluate performance in an operating setting.

5. Conclusion

The implementation of blockchain technology in Bangladesh's RMG sector represents a critical advancement toward addressing key supply chain inefficiencies such as transparency, accountability, and fraud prevention. This study underscores the effectiveness of Hyperledger Fabric as a permissioned blockchain solution tailored to meet the specific needs of the RMG supply chain, allowing for secure, immutable record-keeping and real-time visibility across stakeholders. Such implementation of the proposed prototype promises transparency in raw material sourcing as it can be used to document, enable the manufacturer to get opinions from suppliers as well as select from their proposed deals**.** By enhancing data accuracy, reducing reliance on intermediaries, and automating compliance through smart contracts, blockchain presents a robust alternative to traditional systems, paving the way for enhanced stakeholder trust and reduced operational delays. As for the proposed smart contracts, their implementation will make documentation and compliance safer and more efficient. The comparative analysis reveals that blockchain's distributed architecture minimizes risks related to single points of failure and upholds a streamlined, resilient supply chain that aligns with international compliance standards. Despite challenges such as initial implementation costs and technological integration, the study highlights blockchain's transformative potential in modernizing the RMG industry, ensuring both sustainable growth and competitiveness on a global scale. Future research should explore the integration of the Internet of Things (IoT) and artificial intelligence (AI) with blockchain to provide predictive insights and further enhance the responsiveness of the RMG supply chain. Although the proposed model has the potential to improve the accuracy of real-time tracking and inventory control, the lack of an implementation environment caused a partial part of the objective of real-time tracking and inventory control to be accomplished. Although after the full buildup of the prototype we can easily integrate it in RMG industries to check its accuracy regarding real-time tracking.

References

Alhajjaj, Y., Qatawneh, M., Abualghanam, O. and Almaiah, M.A. , "Using of Blockchain in the Context of Automotive Industry: A Survey", *2023 International Conference on Information Technology: Cybersecurity Challenges for Sustainable Cities, ICIT 2023 - Proceeding*, Institute of Electrical and Electronics Engineers Inc., pp. 519–523,2023, doi: 10.1109/ICIT58056.2023.10225958.

Androulaki, E., Barger, A., Bortnikov, V., Muralidharan, S., Cachin, C., Christidis, K., De Caro, A., *et al.* (2018), "Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains", *Proceedings of the 13th EuroSys Conference, EuroSys 2018*, Vol. 2018-January, Association for Computing Machinery, Inc, doi: 10.1145/3190508.3190538.

Aziz, T., Shahriar, S.T., Farhan, F.M., Farhan Faiyaz, M., Islam, A.N., Shahriar, S., Farhan Faiyaz, F.M., *et al.* (n.d.). *Lean Logistics Strategy for the Ready-Made Garments (RMG) Industry of Bangladesh: Review and a Proposed Enhanced Strategy*.

Azzi, R., Chamoun, R.K. and Sokhn, M. , "The power of a blockchain-based supply chain", *Computers and Industrial Engineering*, Elsevier Ltd, Vol. 135, pp. 582–592,2019, doi: 10.1016/j.cie.2019.06.042.

Batta, A., Gandhi, M., Kar, A.K., Loganayagam, N. and Ilavarasan, V. (2020), "Diffusion of blockchain in logistics and transportation industry: an analysis through the synthesis of academic and trade literature", *Journal of Science and Technology Policy Management*, Emerald Group Holdings Ltd., Vol. 12 No. 3, pp. 378–398,2020, doi: 10.1108/JSTPM-07-2020-0105.

Blossey, G., Eisenhardt, J. and Hahn, G.J. (n.d.). *Blockchain Technology in Supply Chain Management: An Application Perspective*.

Chaker, B. and Damak, C. , "Integrating blockchain technology for enhanced transparency and security in supply chains", *Strategic Innovations for Dynamic Supply Chains*, IGI Global, pp. 147–169,2024, doi: 10.4018/979-8-3693-3575-8.ch007.

Dobrovnik, M., Herold, D.M., Fürst, E. and Kummer, S. , "Blockchain for and in Logistics: What to Adopt and Where to Start", *Logistics*, MDPI AG, Vol. 2 No. 3, p. 18,2018, doi: 10.3390/logistics2030018.

Habib, Md.M., Sabah, S., Chowdhury, F., Raisa, R. and Shuvo, T.F. (2024), "Technology Enabled Ready-Made Garments Supply Chain Management: a Literature Review", *Revista de Gestão Social e Ambiental*, Vol. 18 No. 10, p. e08842, doi: 10.24857/rgsa.v18n10-188.

Hellani, H., Sliman, L., Samhat, A.E. and Exposito, E. ,Overview on the blockchain-based supply chain systematics and their scalability tools", *Emerging Science Journal*, Ital Publication, Vol. 4 No. Special Issue, pp. 45–69,2020, doi: 10.28991/esj-2021-SP1-04.

ITA (2022) The information about Tax Identification Number can be found in: https://www.trade.gov/country-commercial-guides/bangladesh-import-requirements-and-documentation

Itohan Oriekhoe, O., Bolawale Omotoye, G., Peter Oyeyemi, O., Tubokirifuruar Tula, S., Ifesinachi Daraojimba, A. and Adefemi, A. (2024), "BLOCKCHAIN IN SUPPLY CHAIN MANAGEMENT: A SYSTEMATIC REVIEW: EVALUATING THE IMPLEMENTATION, CHALLENGES, AND FUTURE PROSPECTS OF BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAINS", *Engineering Science & Technology Journal*, Vol. 5 No. 1, pp. 128–151, doi: 10.51594/estj/v5i1.732.

Keysers, C., Boyd, R., Cohen, J., Donald, M., Güth, W., Johnson, E., Kurzban, R., *et al.* (2016), "Explicit and Implicit Strategies in Decision Making", *Better Than Conscious?* The MIT Press, pp. 225–258, doi: 10.7551/mitpress/9780262195805.003.0011.

Kuzlu, M., Pipattanasomporn, M., Gurses, L. and Rahman, S. (2019), "Performance analysis of a hyperledger fabric blockchain framework: Throughput, latency and scalability", *Proceedings - 2019 2nd IEEE International Conference on Blockchain, Blockchain 2019*, Institute of Electrical and Electronics Engineers Inc., pp. 536–540, doi: 10.1109/Blockchain.2019.00003.

Manzoor, R., Sahay, B.S. and Singh, S.K. (2022), "Blockchain technology in supply chain management: an organizational theoretic overview and research agenda", *Annals of Operations Research*, Springer, doi: 10.1007/s10479-022-05069-5.

Nakamoto, S. (n.d.). *Bitcoin: A Peer-to-Peer Electronic Cash System*.

Perboli, G., Musso, S. and Rosano, M. (2018), "Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases", *IEEE Access*, Institute of Electrical and Electronics Engineers Inc., Vol. 6, pp. 62018–62028, doi: 10.1109/ACCESS.2018.2875782.

Queiroz, M.M. and Fosso Wamba, S. (2019), "Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA", *International Journal of Information Management*, Elsevier Ltd, Vol. 46, pp. 70–82, doi: 10.1016/j.ijinfomgt.2018.11.021.

Queiroz, M.M., Telles, R. and Bonilla, S.H. (2020), "Blockchain and supply chain management integration: a systematic review of the literature", *Supply Chain Management*, Emerald Group Holdings Ltd., 24 February, doi: 10.1108/SCM-03-2018-0143.

Rahman, C.M.L., Syed, M.U., Fahim, N.A. and Mia, M.R. (2023), "ASSESSING THE READINESS LEVEL OF RMG SECTOR OF BANGLADESH TOWARDS IMPLEMENTING INDUSTRY 4.0", *Khulna University Studies*, Khulna University, doi: 10.53808/kus.2023.20.02.965-se.

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L. (2018), "Blockchain technology and its relationships to sustainable supply chain management", *International Journal of Production Research*, Vol. 57, pp. 1–19, doi: 10.1080/00207543.2018.1533261.

Sangeerth, P.S. and Lakshmy, K. V. (2021), "Blockchain based Smart Contracts in Automation of Shipping Ports", *Proceedings of the 6th International Conference on Inventive Computation Technologies, ICICT 2021*, Institute of Electrical and Electronics Engineers Inc., pp. 1248–1253, doi: 10.1109/ICICT50816.2021.9358634.

Tanvir, S.I. and Muqaddim, N. (2013), 'Supply Chain Management' - Offering the New Paradigm for Bangladesh Garment Industry", *Journal of Economics and Sustainable Development*, Vol. 4, pp. 158–167.

Tian, T. (2024), *Analysis of the Principle and Application of Nash Equilibrium*, *Highlights in Science, Engineering and Technology AMMSAC*, Vol. 2024.

Tijan, E., Aksentijević, S., Ivanić, K. and Jardas, M. (2019), "Blockchain technology implementation in logistics", *Sustainability (Switzerland)*, MDPI, 1 February, doi: 10.3390/su11041185.

Wang, Y., Han, J.H. and Beynon-Davies, P. (2018), "Understanding blockchain technology for future supply chains: a systematic literature review and research agenda", *Supply Chain Management: An International Journal*, Vol. 24, doi: 10.1108/SCM-03-2018-0148.

Yuksel, H.B., Bolat, S., Bozkurt, H. and Yucekaya, A. (2021), "The Implementation of Smart Contract via Blockchain Technology in Supply Chain Management: A Case Study from the Automotive Industry in

Turkey", *Proceedings - 2021 International Conference on Artificial Intelligence and Blockchain Technology, AIBT 2021*, Institute of Electrical and Electronics Engineers Inc., pp. 90–94, doi: 10.1109/AIBT53261.2021.00022.

Zhai, S., Yang, Y., Li, J., Qiu, C. and Zhao, J. (2019), "Research on the Application of Cryptography on the Blockchain", *Journal of Physics: Conference Series*, Vol. 1168, Institute of Physics Publishing, doi: 10.1088/1742-6596/1168/3/032077.

Zheng, Z., Xie, S., Dai, H., Chen, X. and Wang, H. (2017), "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends", *Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017*, Institute of Electrical and Electronics Engineers Inc., pp. 557–564, doi: 10.1109/BigDataCongress.2017.85.

Biographies

Syed Junayed Ahmed Niloy obtained his undergraduate degree in Mechanical Engineering from Ahsanullah University of Science and Technology (AUST) in 2023. He worked as a Territory Officer at Robi Axiata Limited. His academic pursuits reflect a keen interest in a wide spectrum of disciplines, including Supply Chain, Blockchain, Operations Management, HVAC, Heat Transfer, CFD, Fluid Mechanics, Aerodynamics and Renewable Energy. He aims to pursue a career in Product Management, leveraging his technical and management skills to drive innovation.

Md. Iftekhar Alam is a recent graduate from Ahsanullah University of Science and Technology (AUST) with a bachelor's degree in Mechanical Engineering. He brings practical experience from internships at BITAC and a 225 MW power plant, which helped shape his technical and problem-solving skills. Currently, his research interests lie in Materials Science, Renewable Energy, and Blockchain.

Shahed Karim is a Software Engineer at Ridgeben IT Solutions. He holds a Bachelor degree in Computer Science and Engineering from Ahsanullah University of Science and Technology (AUST). His research focus is deep learning, blockchain and he also achieved a first runner-up in the Blockchain Olympiad in 2023 organized by Creative IT Institute.

Mohammad Sarwar Morshed, PhD is a distinguished Professor of Industrial and Production Engineering and currently serves as the Director of the Institutional Quality Assurance Cell (IQAC) at Ahsanullah University of Science and Technology (AUST). With over three decades of experience in academia and industry, he has made substantial contributions to advancing quality standards in engineering education and research.

Tahmim Alam is currently pursuing his B.Sc. in Mechanical Engineering from Ahsanullah University of Science and Technology (AUST). His research interest includes topic like Supply chain, Blockchain, Machine Learning, and Computer aided simulation (Thermal fluids, Fluids, and FEA).

Nure Arfi has completed her Bachelor in Textile Engineering from Ahsanullah University of Science and Technology (AUST). Major in Apparel Manufacturing. Currently working as a Development Merchandiser in Denim area. She is interested in Product Development and Washes of Denim. Her Interest area is Product Development, Dye processing and Sustainable fashion.