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Blockchain Technology for Enhancing Traceability and Efficiency in Automobile Supply Chain—A Case Study

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Abstract: A robust traceability system would help organizations in inventory optimization reduce lead time and improve customer service and quality which further enables the organizations to be a leader in their industry sector. This research study analyzes the challenges faced by the automotive industry in its supply chain operations. Further, the traceability issues and waiting time at different nodes of the supply chain are considered to be priority issues that affect the overall supply chain efficiency in the automotive supply chain. After studying the existing blockchain architectures and their implementation methodology, this study proposes a new blockchain-based architecture to improve traceability and reduce waiting time for the automotive supply chain. A hyper ledger fabric-based blockchain architecture is developed to track the ownership transfers in inbound and outbound logistics. The simulation results of the proposed hyper ledger fabric-based blockchain architecture show that there is an improvement in the traceability of items at different nodes of the supply chain that enhances the Inventory Quality Ratio (IQR) and the mean waiting time is reduced at the factory, wholesaler, and retailer, which thereby improves the overall supply chain efficiency. The blockchain embedded supply chain is more capable to eliminate the risks and uncertainties associated with the automotive supply chain. The benefits of adopting blockchain technology in the automotive supply chain are also described. The developed blockchain-based framework is capable to get more visibility into goods movement and inventory status in automotive supply chains.

Keywords: automotive supply chains; blockchain; simulation; case study; Industry 4.0

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1. Introduction

As industries around the globe expand, their supply chains have become complex and defragmented [1–3]. Despite enormous investments being made to improve the part tracking or value tracking in supply chains, most companies still have a limited amount of part tracking mechanisms [4–6]. Many organizations have a significant gap between systems employed within a company and across companies. A traceability system is necessary to obtain a reduction in costs, waiting time, and an overall improvement in quality and customer service, which would further enable organizations to develop a competitive advantage [7,8]. Moreover, consumers nowadays are also interested in knowing whether the product they received comes from an ethical background. In recent days the importance of automation within the supply chain process has increased [9]. To automate the supply chain process, multiple systems need to be integrated which essentially means the volume of data produced. This data is essential to track the products and their status at each point to ensure quality [10].

The automotive industry is an important sector that also drives the economy of a nation [11]. Today, organizations are facing different challenges in this sector. Similar to many sectors, the automotive industry also increased its global presence which resulted in frequent part movements across the globe. Firstly, manufacturers are finding difficulty in tracing the in-transit parts, in-house production, and out for delivery products [12,13]. It remains an important challenge for the entire supply chain. Secondly, overcapacity is another problem that results in overspending that affects the overall efficiency of supply chain operations [14]. Customers are concerned about the sustainability of the parts and interested in knowing the origin of the parts. In the automotive industry, it becomes imperative to trace the components and semi-finished goods used in a particular vehicle or product family [15,16]. All the stakeholders of the supply chain lack a common information access framework, making this process difficult to execute in real-time as well as for them to exchange information in real-time [17,18]. The supply chain organizations also find it challenging to maintain the right Inventory Quality Ratio (IQR) across different nodes of the supply chain and that leads to traceability issues. Further, there is unplanned production downtime due to stock out of raw materials and machine breakdowns. The unplanned downtime affects the lead time and the waiting time for the customer is increased. Thus, impacts the supply chain efficiency [19,20].

One of the technologies that are emerging with Industry 4.0 is blockchain. Blockchain has the potential to address some of the issues faced by the automotive industry. Blockchain is a better solution for traceability issues as it can share information across supply chain networks with increased security of information. Each supply chain member can see the same information on a product's lifecycle [21]. Blockchain can potentially affect supply chain parameters such as waiting time, cost, risk reduction, speed, quality, dependability, flexibility, etc. [22,23]. With today's complex supply chain networks, the interactions and transactions among these stakeholders should exist on an immutable ledger/database system that is shared, secured, and can provide permission accessibility. A shared blockchain-based system facilitates increased transparency which enables seamless transactions and improved visibility [24]. One of the benefits of blockchain in the automotive industry is traceability that includes part provenance, vehicle tracking, improved inbound plant logistics, etc. [25]. However, blockchain adoption in the supply chain is still at its nascent stage.

The blockchain is a decentralized database with a collaborative network that functions as a ledger for maintaining secured transactional data [26]. While the applicability of blockchain technology showcases to have a considerably strong case for changing many aspects of the working of the automotive industry functioning, the automotive sector has just begun to scratch the surface of blockchain applications about its operations. Figure 1 shows a simple automotive supply chain depicting how product flow happens in the supply chain from suppliers to customers. Considering the volume of components involved in the automotive supply chain, blockchain can help manage its operations. Companies are still exploring ways to enhance the working of their supply chains as well as embrace the change that blockchain technology has to offer.

Figure 1. A typical automotive supply chain.

In the current supply chain, the trust among the supply chain partners is said to be less even though information systems are deployed. Organizations are focusing on a good relationship with other supply chain members to improve their trust however there is no guarantee to validate the information is accurate as some supply chain members may share false information with or without intention which impacts the entire eco-system. This article tries to implement blockchain technology in an automotive contemporary organization to improve supply chain operations. The literature shows that blockchain in the automotive supply chain is still in the initial stages and there is scope to study this technology and explore the opportunities to implement it in the automotive sector.

Based on the literature, the automotive supply chain with blockchain is not completely explored to overcome traceability issues and improve efficiency. Besides, the automotive supply chain requires a trustable eco-system as it involves multiple parties and stakeholders. Thus, the study on the automotive supply chain is essential to add more value to manufacturers and explore opportunities with blockchain technology. Therefore, this study intends to contribute to the blockchain literature for the automotive supply chain by addressing the following research questions.

RQ1. How an automotive supply chain traceability system based on blockchain technology can be established?
RQ2. What are the benefits of adopting a blockchain-based system in the automotive supply chain?

To address the mentioned research questions, the following objectives are defined:

- To identify different traceability issues at various nodes of an automotive supply chain.
- To develop a new blockchain architecture for the automotive supply chain and improve supply chain traceability issues and reduce waiting time, thereby improving supply chain operational efficiency.
- To explain the implications of implementing blockchain across the automotive supply chain.

By addressing the research questions and objectives, this article contributes to the blockchain literature by identifying the issues in the automotive supply chain. The result can help organizations to understand the impact of blockchain particularly for automotive manufacturers who work in a complicated supply chain network with a high volume of parts involved.

The article is constructed as follows. Section 2 provides the literature on the issues faced in the traditional supply chain, how blockchain applications help in the supply chain. Further, it discusses the research gap based on the literature study. Section 3 explains the research methodology. Section 4 describes the case organization details, application of the proposed framework, and presents the simulation results of the blockchain framework. Section 5 discusses the results obtained and explains the theoretical and practical implications. Finally, the key outcomes and conclusions are summarized in Section 6.

2. Literature Review

The existing literature was reviewed to identify different methods used for supply chain traceability and their limitations. The investigation was carried out using different keywords related to supply chain, supply chain, data management systems, traceability, synchronization, blockchain architecture, framework model, etc. in various databases such as a web of science, IEEE Xplore, Springer link, Scopus, Taylor and Francis, Science Direct, Wiley, Emerald. Concerning the reported domain of research, 60 research papers, four reports, and three white papers were shortlisted considering the aim and scope of the study from an enormous amount of literature available relevant to the above-stated keywords.

2.1. Issues in Traditional Supply Chain

Various supply chain issues related to automotive supply were reviewed. Bonilla et al., (2018) analyzed traditional supply chain issues and analyzed Industry 4.0 technologies to improve sustainability [27]. Di Vaio and Varriale (2020) reviewed the issues in the supply chain related to the airport industry and explored blockchain to improve sustainable performance [28]. Junaid et al., (2020) assessed supply chain risk using AHP and TOPSIS framework for the automotive industry [29]. González-Benito et al., (2013) conducted a bibliometric analysis of 404 publications which is focused on the automotive industry [30]. Maro et al., (2018) provided a comprehensive overview of the challenges involved in effective traceability as well as solutions in the automotive domain while contrasting them with those found in general literature [31]. Papetti et al., (2019) aimed at developing a platform for concurrently supporting supply chain traceability as well as eco-sustainability in the leather shoe supply chain [32]. Ferriols et al., (2013) proposed eight steps for developing a hierarchy in a supply chain company [33].

When multiple parties are involved, few manual processes happen across the supply chain which leads to incorrect data reconciliation and a drop in efficiency [34,35]. In addition, there are chances for mixing counterfeit products when there is no direct visibility for Original Equipment Manufacturers (OEM) with tier-2 suppliers [36,37]. The problem of differential pricing comes into the picture as they generally prefer concealing their pricing since this allows them to pay lower prices when outsourcing to developing countries [38–40]. As numerous parties are involved, mediating between these parties can pose a critical problem for logistics providers such as slowing down the delivery of services and creating a large overhead for logistics. Furthermore, a centralized mediator of these parties can misuse power to prioritize some parties over others. As quality and compliance issues occur, procuring a replacement for defective parts is long-drawn and unfeasible in some cases. Lean "on-demand" manufacturing falls flat in a situation where natural disasters and socio-economic problems are common. For example, Japan (frequently affected by earthquakes) has outsourced most of its supply chain logistics to other countries. Hence, it is safe to say that in some cases, companies rely on their disruptive network to function effectively. But as a central mediator for parties is required which centralizes power in the hands of a few may also be a gateway to misuse the resources. As the number of interacting parties increases, there is a proportional increase in middlemen. It may lead to fraud and slow down the supply without contributing to the network. In a centralized network validating identity vendors and checking for tampering by middlemen is cumbersome and, in some cases, outright impossible. Table 1 summarizes supply chain issues and descriptions.

Table 1. Typical supply chain issues and description.

Issue	Description	References
Tracking the history of any product	Validating identity vendors and checking for tampering by middlemen is not possible.	[2,41,42]
Differential Pricing	Companies prefer keeping their pricing a secret since this allows them to pay lower prices when outsourcing to developing countries	[43,44]
Numerous Parties Involved	Mediating between so many parties can be a big problem for logistics providers, slowing down the delivery of services and creating a large overhead for logistics. Furthermore, a centralized mediator of these parties can misuse power to prefer some parties over others.	[44–47]
Quality and Compliance Issues	Procuring a replacement for defective parts is a long-drawn and uncomfortable process.	[48–51]
Inevitable disruptions	LEAN "on-demand" manufacturing falls flat in a situation where natural disasters and socio-economic problems are common. For example, Japan (frequently affected by earthquakes) has outsourced most of its supply chain logistics to other countries.	[52–54]
Centralization	A central mediator for parties is required, which centralizes power in the hands of a few and is a gateway to misuse of resources	[55–57]
Fraud by Middlemen	As the number of interacting parties increases, there is a proportional increase in middlemen. They lead to fraud and slow down the supply without adding anything to the network	[58–60]

Özceylan et al., (2016) reported on the development of a linear programming model for handling reverse material flows and integrating them with forwarding supply chains [61]. Sher et al., (2018) developed a framework to synchronize activities in a supply chain for perishable products that require a careful storage system [62]. Al-aomar and Hussain

(2018) explored issues concerning lean and sustainability issues in service-based supply chains [63]. Kalverkamp and Young (2019) developed a framework for closed-loop supply chains. Case studies of Automotive remanufacturing are considered here [64]. Masoud and Mason (2015) developed a hybrid model using a hybrid simulated annealing algorithm (HSAA) which solves the NP-hard problem. A tier-1 automotive industry supply chain was considered for the same [65].

Borgstedt et al., (2017) studied alternative powertrain systems and justified the technology shift required in the automotive industry [66]. Mathivathanan et al., (2017) developed a framework for Sustainable Supply Chain Management (SSCM) practices within the automotive industry [67]. Ambe and Badenhorst-Weiz (2011) proposed a supply chain plan that provides standard rules for implementing in a demand-driven supply chain environment [68]. Sundarakani et al., (2012) conducted a worldwide economic analysis of the automotive industry to identify the potential factors that favor and also provided recommendations for the automotive industry based in Singapore [69]. Bhattacharya et al. (2014) examined subjective parameters such as visibility, innovation in the supply chain, and collaboration among supply networks [70]. Teucke et al., (2018) studied a system that affects the production planning stages in the supply chain [71]. Queiroz and Fosso Wamba (2019) have developed a framework built on the theory of acceptance [41].

2.2. *Blockchain Technology in Supply Chain*

The literature on blockchain application with the supply chain was analyzed. Li et al., (2018) developed a framework that employs blockchain for systems in injection mold redesign to improve qualitative aspects such as trust, brand value, etc [42]. A case study for developing and implementing blockchain architecture in a cloud manufacturing environment and it is found that the total time required for the transaction process is significantly reduced [43]. Muzammal et al., (2019) present an application platform with the capabilities of and fast processing of data [44]. Banerjee (2018) described the benefits of integrating ERP with blockchain to improve supply chain effectiveness [45]. Atlam and Wills (2018) provided information about blockchain and IoT [46]. Min (2019) analyzed various areas of risk management and security for employing Blockchain technology [47]. Xu et al., (2019) conducted a study on blockchain and how it can be implemented in various product traceability scenarios [48]. Casado-vara et al., (2018) developed a blockchain model is for integrating it with an existing supply chain in the agriculture sector by employing smart contracts [49]. Costa et al., (2017) discuss the visibility of internal logistical processes using Radio Frequency Identification (RFID) technology. Additionally, this study identifies and discusses the main obstacles that are associated with the implementation of its proposed solution. When compared to the data management frameworks of conventional traceability tools such as RFID tagging and E-Kanban, blockchain has the potential to overcome its limitations and significantly improve supply chain operations. The data management system considering RFID tagging needs to be updated frequently as surplus amounts of variable data are produced. The E-Kanban system is slower to adapt to this changing set of data [50]. Furthermore, this system does not work ahead of schedule. While these traceability systems need their infrastructure to be set up, the data management framework of blockchain can be integrated with conventional traceability tools.

With the advent of disruptive technologies, conventional data management systems could be replaced or integrated into modular and scalable systems. The blockchain, being immutable, distributed, and decentralized in nature with its scalability and modularity, could prove an effective alternative for the replacement of data management systems of conventional traceability tools. Furthermore, it could also be integrated with them, if required. Table 2 shows the summary of data management methods used in various traceability tools.

Table 2. Summary of data management methods used in various traceability tools.

	RFID	E—Kanban	Blockchain
Features	Provides relatively accurate location over a certain range	Allows visual management	Distributed, decentralized, A system with immutable, tamper-proof nature
	Can be integrated with Enterprise resource planning (ERP) systems	Improves visibility in plant and paperless operation	Enables real-time information and enhances visibility through the entire supply chain
	Improves accuracy in logistical operations	Supports lean and helps to reduce waste	Can be integrated with RFID and E-Kanban
Limitations	Limitations in operating conditions	Need for financial investment	Requires adaption to new tech
	Less accurate/faulty detection	Centralized system	Need for financial investment
	Security and privacy issues	Can easily be tampered/modified	A seamless digital-physical link
	Can be tampered/modified	Limited scalability	Needs acceptance by every supply chain partner

Different techniques have evolved which facilitate the live tracking of parts and goods in a supply chain. However, data management frameworks of current traceability systems such as RFID and E-Kanban are centralized and lack the distributed and scalable architecture that can be used for real-time secure data sharing with all supply chain partners. While the current research on various applications of blockchain technology is still evolving, there is a limited amount of research being carried out on blockchain implementation in an automotive supply chain. Although a variety of relevant blockchain applications are being proposed, the pertinent discussions are mostly conceptual expositions, with very little or no empirical evidence of how to employ this technology at the organizational level. Blockchain-enabled supply chain, if successfully implemented, would have potential advantages because of its tamper-proof nature, the distributed structure which would further enable improvement in visibility on the inventory of the organization. Hence there is a need to develop a framework to embed blockchain in the automotive supply chain.

2.3. Research Gap

Based on the literature review, it is observed that some of the research work has been carried out on traditional supply chain issues and the application of blockchain technology. The use of blockchain for traceability issues and reducing waiting time are not reviewed for the automotive supply chain. There is a need for organizations to focus on these issues to improve overall operational efficiency. Kamble et al., (2021) reviewed blockchain technology's impact on the automotive supply chain and summarized the relationship between blockchain and sustainable supply performance [51]. Khanfar et al., (2021) reviewed the application of blockchain technology in manufacturing and suggested opportunities for new directions of research [52]. Rejeb et al., (2021) reviewed blockchain technologies in logistics and supply chain management and summarizes the existing gaps and potential research directions for future research in the blockchain [53]. Further, it appears that there are not many studies earlier that performed simulation-based analysis for traceability issues and waiting for time problems with the focus on improving operational efficiency in the automotive supply chain. Thus, studies unveil that the research on blockchain for the automotive supply chain is slightly limited and suggest exploring a more practice-oriented approach. The mentioned factors are considered as the literature gap for the present study.

3. Methodology

To formulate the methodology, different use cases concerning various traceability breaches in food and automotive manufacturing industries were reviewed and common problems faced by stakeholders especially in areas on the tracking of the component/parts were identified. Furthermore, various solution methodologies like the use of IoT sensors were reviewed. However, to govern the system and ensure the reliability of data from these sensors and different methodologies, a virtually unbreachable model is required. Hence, blockchain as a potential solution for the aforementioned problem is proposed in this study. The blockchain technology applied on various applications is reviewed to develop a solution approach by simulating a supply chain. Weak nodes or links that possess potential threats to traceability are identified within the supply chain. A blockchain model is developed to understand the risks posed by these critical nodes, thus, enabling effective integration of technology in the automotive organization. Figure 2 shows the flowchart of steps involved in the methodology.

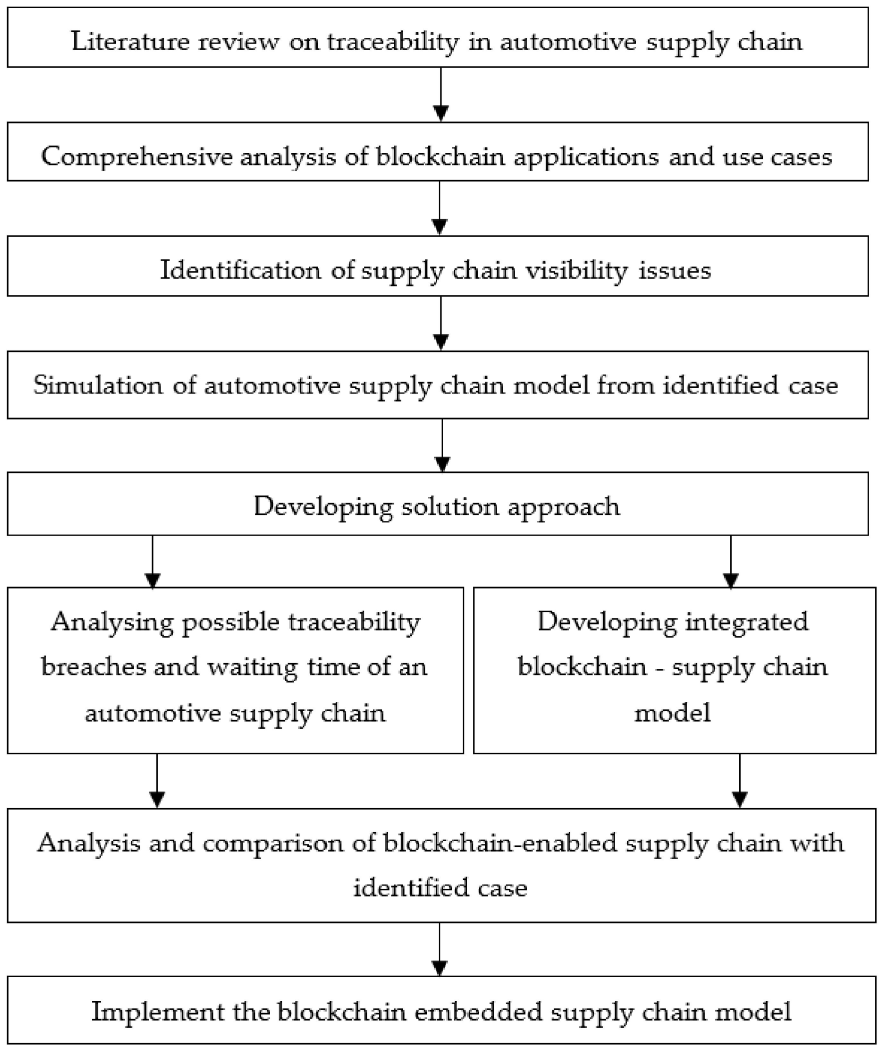


Figure 2. Research methodology framework.

4. Application of Proposed Framework in the Case Organization

4.1. Case Details

The case organization is selected based on its supply chain maturity level and present IT systems. The case organization is a leading automotive manufacturer in South India and leading manufacturers of steering and suspense systems, valve train components, friction material products such as brake linings, disc pads, clutch facings. This organization utilizes modern technologies to provide the clients a perfect fit in a variety of industry segments such as passenger vehicles, commercial vehicles, and farm tractors. The organization has put into practice world-class approaches such as ISO 9001:2015 for quality management systems and also won the prestigious 'Deming Grand Prize' for their supply chain quality practices. The contemporary organization is in the digital transformation phase to get real-time visibility on their supply chain to make quicker decisions. The organization is interested and willing to explore blockchain technology for improving supply chain operational efficiency. The organization thus selected is best suited for the study as they are positive about adopting new technologies and distinguish themselves as a global leader in the automotive sector.

4.2. Current Supply Chain Operational Challenges for Case Organization

The case organization faces challenges in maintaining the correct Inventory Quality Ratio (IQR). IQR is an approach for managing inventory to find the fast-moving items, and review the slow-moving and non-moving items. The focus is to track the active inventory and reduce the slow-moving and non-moving inventory at different nodes of the supply chain that improves the IQR. Additionally, they are times the production is stopped due to the non-availability of materials and tool breakdowns. Hence the organization is keen on improving IQR and also reducing the waiting time so that the overall operation efficiency is improved.

Based on the traceability and efficiency issues reported, the data is collected on Key Performance Indicators (KPI) for calculating IQR and Waiting time. IQR is calculated by measuring active inventory divided by the total inventory. The total inventory comprises active, slow-moving, excess, obsolete inventories. In addition, the waiting time is calculated based on the number of stops per shift and the average time lost per shift. Based on the computation, Table 3 is formulated. The calculated KPIs are validated with the stakeholders who are expertise in the area of supply chain operations belonging to production, logistics, and inventory departments.

Table 3. Evaluation on factors affecting IQR and Waiting time for the automotive supply chain.

KPI	**Factors**	**Last 12 Months (until June 2021)**											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
IQR (Active Inventory/Total Inventory)	Active, Slow, Excess, Obsolete Inventory (%)	62	67	72	68	65	69	74	70	63	64	71	68
Waiting time	Number of stops/shift	4	5	6	2	3	8	6	7	6	8	5	5
	Average Time lost/shift (Minutes)	10.3	12.6	15.1	5.6	7.5	20.4	13.5	16.7	14.56	20.5	12.7	13.8

Based on the analysis, a model is proposed as illustrated in Figure 3 nonetheless similar to the general automotive supply chain as depicted by Figure 1, and can be considered as an abridged version of the same. Here the first three blocks of Figure 1 are replaced by a factory, wholesaler acts as a dealer, and retailer as a customer. On arrival, the customer demands a product from a retailer and purchases the available products. In case the demand exceeds the supply, the excess is backlogged. The respective inventory levels of the retailer and wholesaler are reviewed every day. Upon reviewing the order from the customer, every member in the supply chain determines the overall demand which needs to be fulfilled like how many items are to be ordered. Different types of costs, such as carrying cost, shortage cost, and ordering cost, are calculated. Information for the simulation is given according to the case study identified, wherein the demand is randomized. The output shows the mean daily cost for all parties, as well as the distribution of waiting times for customers. The variation plots for waiting time and mean cost with max and min stock level for each party are also obtained to understand the magnitude of the variation. Anylogic software v8.4 was used to simulate the case study.

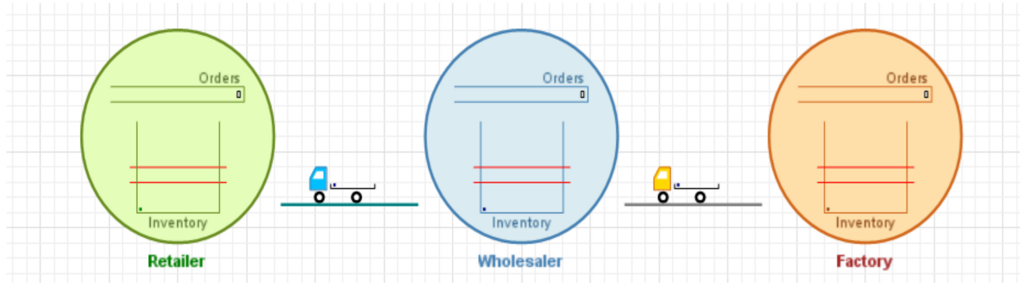


Figure 3. Auto part supply chain model.

4.3. Application of Solution Framework

The proposed framework is multi-layered, in that it connects various technologies as well as technical components [54]. As illustrated in Figure 4, the blockchain architecture of the distributed ledger consists of various sub-networks, each associated with specific orders and partners. In this case, the transactions are termed as per their usage in Hyperledger composer which is discussed further. It has four stakeholders namely person/customer, manufacturer, supplier, and regulator who are involved in inventory management, two assets such as order/part and vehicle that impacts the logistics, and two different transactions such as Place Order and Update Order Status that are associated with two events Place Order Event and Update Order Status Event are considered. The stakeholders in the sub-network are the parties that engage in transactions. This can also be expanded to employ an interoperable network of networks at a global scale that would be open to every supply chain partner and third-party logistics (3PL) provider. Thus, it can serve to audit the events associated with each transaction, monetary or non-monetary. There are four participants involved in the solution architecture: an index server, peers (stakeholders of the supply chain), administrative nodes, and external monitors. Considering the contemporary case organization supply chain complications, it is recommended to use a flexible blockchain framework. Thus, IBM Hyperledger Fabric is proposed for the automotive organization.

4.3.1. Blockchain Implementation Using IBM Hyperledger

Hyperledger Fabric is an open-source blockchain infrastructure, which offers a modular architecture to develop distributed systems, with an emphasis on the improvement in the reliability and performance of these distributed systems. It provides a solution approach facilitating performance at scale and simultaneously ensuring required privacy for the provision of an interoperable network of networks. The network has four participant types, two asset types, and three transaction types. The model file that defines assets, participants was developed using Hyperledger Composure Modelling Language (HCML). The script file that defines the logic of transaction executions was developed using JavaScript. A permission access control file was created to decide the access level for each stakeholder.

The index server manages the details of the participant nodes involved in the blockchain. Every participant is given a unique ID as well. The second partner comprises sub-partners or trading partners such as suppliers, manufacturers, and customers. The application node acts as a transmitter node. Essentially, it means that the application node receives the communication and transmits it to ERP. It helps to maintain the proper exchanges of information happening and minimize communication errors. Third-party systems validate the respective status of the orders and communicate them to the public ledger. This third party may also act as a regulator monitoring the transactions and handling queries. All the peer nodes deliver information to the ledger, in the form of a timestamped record of transaction events. The architecture maintains different types of events to record the status of an order as discussed below.

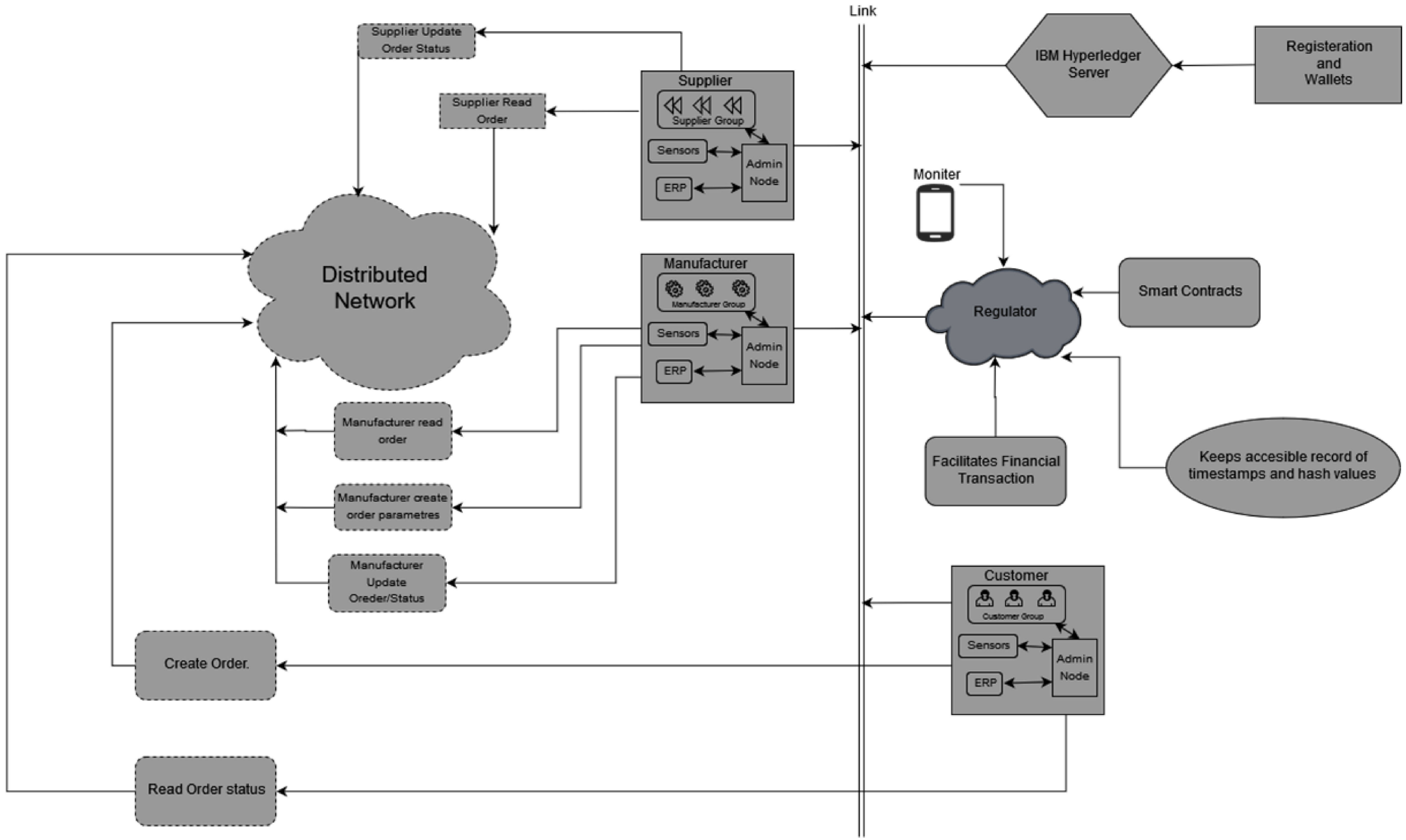


Figure 4. Architecture for blockchain integration.

4.3.2. Inception Event

The inception event shows the initiation of an order which is similar to a bitcoin transaction. This event is triggered by the customer administrative node and communicated to other members. The supply chain partner stores the information and communicates it internally. This document, however, can be tampered with in case of a security breach but the order placed in the network cannot. The information in the inception event is available only to supply chain partners. A hash value generated from this event can be verified by the customer. This specific hash value is visible to all partners.

4.3.3. Custody Event

This event is used to maintain the status of the order. It shows the current status of the order and who is responsible for it. It also shows the communication events happening between the participants. This event maintains the information in a private ledger and shares the information among supply chain members. The generated hash value is visible to all partners.

4.3.4. Monitoring Event

The monitoring event also denotes the location of the order. This event tracks the order and provides the information shared between the manufacturer and logistics provider. The generated hash value by monitoring the event is visible to all partners through a public ledger.

4.4. Simulation Results of Blockchain Framework

Figure 5 shows inventory variation (on the Y-axis) with the number of days (on the X-axis). Here a random input is given to the model which simulates for one year. As seen from Figure 5, even though the inventory at the factory is changed there is a lag before which the inventory at wholesaler and retailer is changed. This can be attributed to uncertainties occurring during information sharing between respective partners.

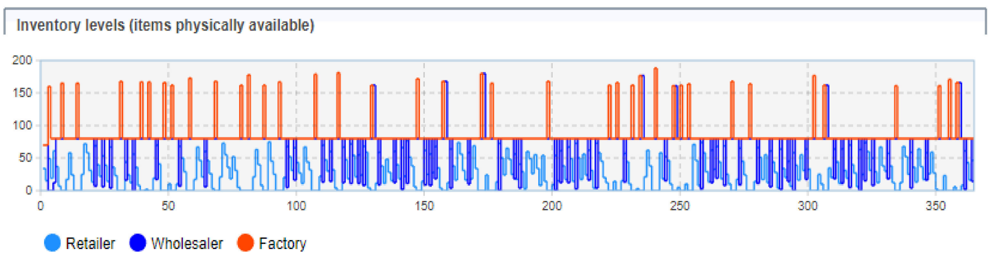


Figure 5. Inventory level before blockchain integration.

Projected Effect of Blockchain Implementation on Case Identified

Integration of blockchain would improve daily supply chain operations. Secured real-time data sharing would help to increase the level of consensus among supply chain partners, resulting in frequent order and inventory updates. This would help to lower daily costs for all the stakeholders viz. factory, wholesaler and dealer as well as lower their respective mean waiting time. Additionally, the waiting time for end customers would decrease due to the fast and responsive nature of the blockchain-enabled supply chain. The optimized simulation for a period of 1 year was carried out that produces a plot of inventory levels against the number of days. Figure 6 shows the simulation results after the integration of blockchain. It can be seen from the graphical results that though the inventory is changing randomly, the inventory of the wholesaler and retailer changes almost simultaneously as that of the factory. This can be attributed to the improved information sharing achieved by the integrated model of blockchain into the supply chain.

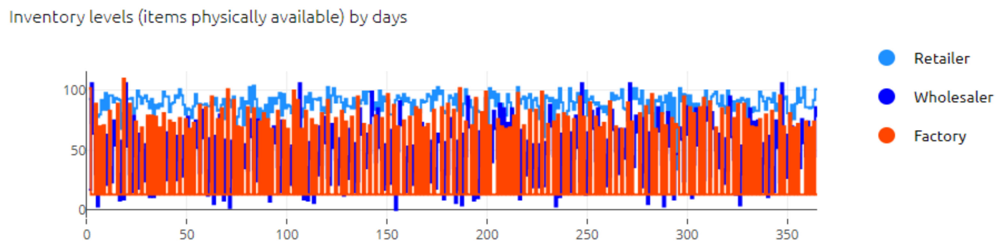


Figure 6. Inventory level after blockchain integration.

After comparing Figures 5 and 6, it is evident that there is less lag in inventory update for all the supply chain partners after blockchain implementation. This shows signs of improved communication and traceability.

Figure 7a shows more simulation results depicting the costs associated with inventory. Here, ordering, holding, and storage costs are associated with the retailer, wholesaler, and factory; the mean waiting time and the total daily cost of the supply chain are shown. Figure 7b shows the simulation result after the integration of blockchain.

Figure 7. (**a**) Overview of daily operational costs means waiting time and total daily costs before blockchain implementation; (**b**) Overview of daily operational costs mean waiting time and total daily costs after blockchain implementation.

It can be inferred from Figure 7a,b that storage cost for the retailer is drastically decreased, however holding costs have increased. Moreover, holding costs for wholesaler and factory have decreased significantly. The mean waiting time has decreased from 0.279

to 0.1 days (i.e., 61.29% reduction in mean waiting time). Moreover, daily costs have decreased from USD 851.87 to USD 796.39 (i.e., a 6% reduction in daily costs).

Furthermore, to show the variation of factors such as daily costs and mean waiting time against the minimum and maximum costs levels, three-dimensional plots were plotted before and after the integration of blockchain. Figures 8a, 9a, 10a, 11a, 12a and 13a represent the simulation results of daily costs and mean waiting time before integrating blockchain at factory, wholesaler, and retailer. Figures 8b, 9b, 10b, 11b, 12b and 13b represent the simulation results of daily costs and mean waiting time after the integration of blockchain at factory, wholesaler, and retailer.

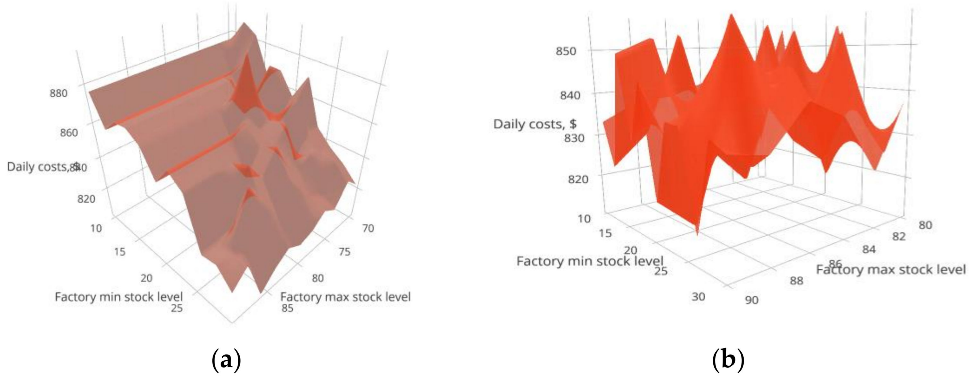


Figure 8. (**a**) Factory daily costs. (**b**) Factory daily costs.

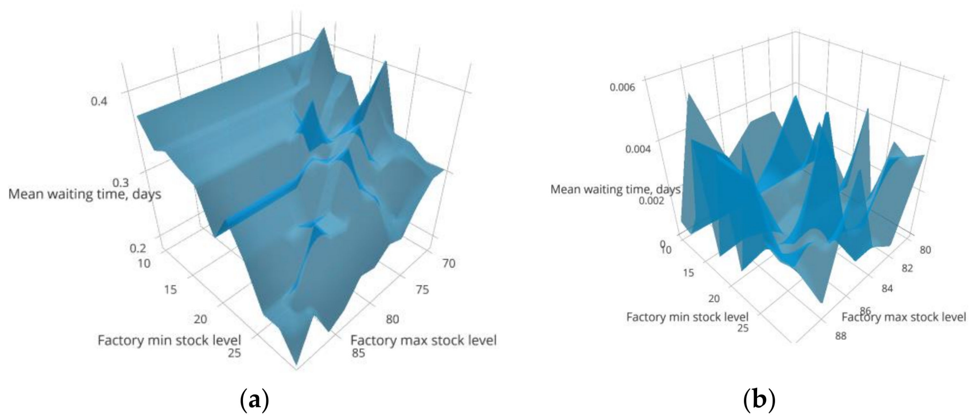
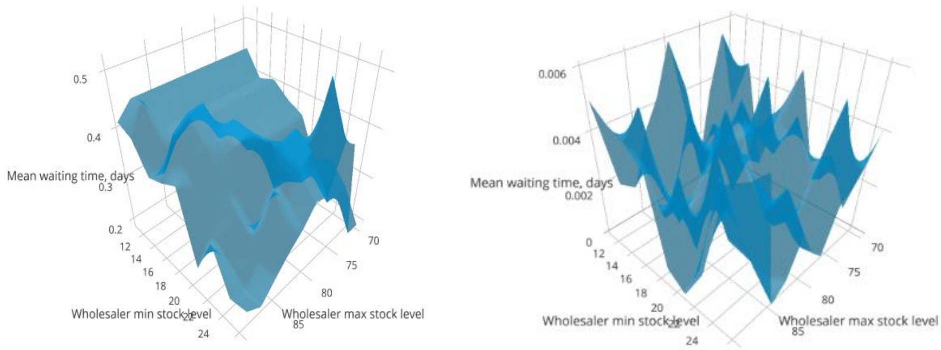


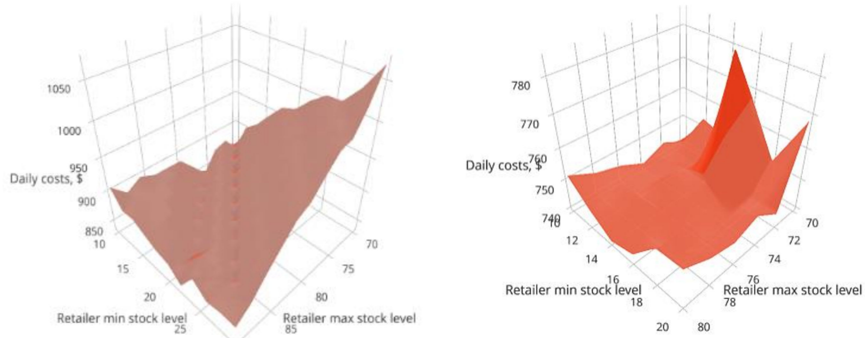
Figure 9. (**a**) Factory mean waiting time. (**b**) Factory mean waiting time.

Figure 10. (**a**) Wholesaler daily costs. (**b**) Wholesaler daily costs.



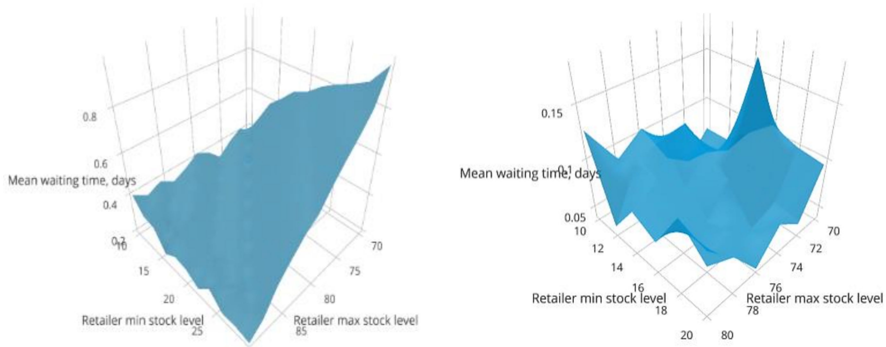
(**a**) (**b**)

Figure 11. (**a**) Wholesaler mean waiting time. (**b**) Wholesaler mean waiting time.



(**a**) (**b**)

Figure 12. (**a**) Retailer daily costs. (**b**) Retailer daily costs.



(**a**) (**b**)

Figure 13. (**a**) Retailer mean waiting time. (**b**) Retailer mean waiting time.

Figure 8a,b depict plots that show a variation of factory daily costs before and after the integration of blockchain, respectively. Figure 9a,b illustrate the variation of mean waiting times before and after the integration of blockchain with minimum factory stock level and maximum factory stock level, respectively, which helps to measure IQR.

Figure 10a,b depict plots that show a variation of wholesaler daily costs before and after the integration of blockchain, respectively. Figure 11a,b illustrate the variation of mean waiting times before and after the integration of blockchain respectively with minimum wholesaler stock level and maximum wholesaler stock level that helps to measure IQR.

Figure 12a,b depict plots that show a variation of retailer daily costs before and after the integration of blockchain, respectively. Figure 13a,b illustrate the variation of mean waiting times before and after the integration of blockchain with minimum retailer stock level and maximum retailer stock level, respectively, which helps to measure IQR.

5. Discussion

After comparing Figures 8–13, it can be inferred that the maximum limit of mean daily costs and mean waiting time for factory, wholesaler, and retailer after employing a blockchain has significantly decreased with minimum retailer stock level and maximum retailer stock level that helps to measure IQR. The deployment of the blockchain model improves the data and information sharing between different stakeholders in a secure environment. Thus, blockchain integration improves the traceability of items and reduces the waiting time, thereby improving supply chain operational efficiency. All the information is stored in a centralized immutable digital ledger with varying levels of access for different parties. If implemented on a global scale, this network has the potential to improve the overall supply chain operations of the automotive industry.

Implementation of blockchain can potentially overcome the issues faced by the automotive industry such as traceability issues at various nodes of an automotive supply chain. Differential pricing can be availed by using a permission ledger for confidential transactions between parties. Consensus between multiple parties is maintained through Smart Contracts which helps to intimate required information between different mediating parties [55]. The disruptions are rather promoted by blockchain as the digital ledger is free of geographical constraints such as natural disasters and socio-economic issues. Furthermore, the smart contract only lets out payments once both parties are satisfied, and the risk of fraud is mitigated by using nodes for checking delivery status. Due to using doubly signed smart contracts, no financial fraud by middlemen can occur in the system. Table 4 describes how the proposed solution helps in solving common organizational-level supply chain problems.

Table 4. Solution description.

Problems	How the Proposed Solution Solves Them
Tracking supply-chain history of each part	Every party has access to their respective order status where they can track the product in real-time.
Differential Pricing	Permission ledger for confidential transactions between parties
Numerous parties involved	Consensus between multiple parties is maintained through Smart Contracts
Quality and Compliance issues	Smart Contract stores money while all solutions are checked and tested
Inevitable disruptions	The digital ledger is free of geographical constraints like natural disasters, socio-economic issues
Procuring replacements for defective pieces	The smart contract only lets out payments once both parties satisfied
Centralization	The risk of fraud is mitigated by using nodes for checking delivery status
Fraud by Middlemen	Due to using doubly signed smart contracts, no financial fraud by middlemen can occur in the system

5.1. Theoretical Implications

The focus on the blockchain is seen more in areas of financial services, food, consumer services, and healthcare [56–59]. This article provides multiple theoretical contributions to the existing literature on the blockchain. The major challenges of the automotive supply chain such as traceability issues and waiting time issues are not focused on earlier. First, the study is made based on an analysis of a contemporary organization that looks for digital technologies to overcome traceability and waiting time issues. Secondly, a blockchain architecture is proposed for an automobile supply chain that can be used by other industries facing similar problems. Further, a simulation-based study is conducted for integrating blockchain that was not focused on earlier. This study is intended to contribute to the blockchain literature with the objective of how hyper ledger fabric-based blockchain can help the automotive industry to reduce daily operational costs, mean waiting time, and improve responsiveness. In this context, the article aims to contribute to Industry 4.0 literature as well.

5.2. Practical Implications

The study offers practical implications for supply chain stakeholders such as OEM, 3PL/Freight Forwarder, Dealer, and Customer. The emerging technology blockchain in industry 4.0 aids organizations to overcome operational challenges by ensuring secured and authentic information. Typically, manufacturers can own and manage the blockchain network. Transparency is achieved by various nodes acting as individual participants of the supply chain. In some cases, the blockchain can be exclusive to the company itself or the blockchain network can be distributed among various stakeholders and company partners. In this study, a hyper ledger fabric-based private blockchain is employed wherein certain parts of the information can be accessed by certain entities considering the complexity involved in sharing information.

When compared to the data management frameworks of conventional traceability tools such as RFID tagging and E-Kanban; blockchain has the potential to overcome other tool's limitations and improve supply chain operations. A blockchain will improve supply chain operations by enabling an interconnected network of the supply chain. There are several studies done with public and consortium blockchain. For public blockchain, the immutability is good, but the efficiency is low. It takes much time to transmit the data when the volume increases [60,72,73]. For consortium blockchain, the efficiency is good, but it is partially decentralized which makes it difficult to control by primary supply chain members [74–76]. In this article, a new blockchain architecture is proposed based on private blockchain where efficiency is high. Moreover, it is entirely centralized so that primary supply chain members can control it. Hyperledger Fabric blockchain is a private blockchain that can be implemented in a wide range of automotive industries. It maximizes confidentiality and scalability. It uses Smart Contracts where supply chain members can manage their transactions and collaborate with the supply chain network. Table 5 shows the limitations faced by different stakeholders in a global supply chain without blockchain implementation and how the same can be overcome with our proposed blockchain architecture.

Table 5. Comparison of supply chain with and without our proposed blockchain architecture.

Stakeholders	Without Blockchain	With Blockchain
OEM Adds value to the raw materials into other consumables and finally the end product	Has a limited ability to control as well as to verify the flows coming from its suppliers? (e.g., proper compliance to standards and requirements)	Benefits from an integrated and distributed ledger that enables them to control the inputs and keep track of their production
3PL/Freight Forwarder Responsible for transporting materials and products between stakeholders	Reliable but the one-sided tracking system Limited certification ability and complex tracking (e.g., heat or pressure variations) Difficulty to certify a code of conduct	Shared information system The client can benefit from a distributed and certified system The client can make sure his goods are transported in the right conditions and timing
Dealer The link between the OEM and the end consumer	Difficulty to certify the origin and path of the goods bought and sold	Can easily check the origin of the goods and their transformation path on the blockchain. With sealed IoT devices put on the goods, the broker can check and prove their authenticity and provenance
Person/Customer The end consumer of the product	Difficulty to verify the total compliance, origin, and composition of the goods to be bought	Has a full view of the goods bought (i.e., provenance, transformation process, transportation) directly on the blockchain

Based on the discussion with the case organization, they are keen on expanding the pilot study in other plants as well considering the value the blockchain features offer in terms of improving traceability and reducing waiting times thereby increasing the supply chain operational efficiency. In addition, supply chain members believe that the resources can be effectively managed with technology and are keen on investing in new technologies to improve operational efficiency thereby savings costs. The outcome from the blockchain technology study will gain practitioners' attention who are looking for a technology-based solution that impacts their organization and connected supply chain members. The improved traceability in inventory and reduced waiting time and costs impact the financial revenues for the organization. Thus, the management is keen on implementing blockchain based on the simulation study. In addition, transforming into a digital organization gives them a competitive advantage in the automotive sector that improves their reputation, thereby increasing its customers.

6. Conclusions

The need for blockchain integration is being endorsed by some organizations, however, this view is still not shared by many companies. This study aimed at identifying traceability issues at various nodes of an automotive supply chain. A new blockchain architecture for the automotive supply chain is proposed. The results were obtained after optimizing the current supply chain by considering blockchain integration. The results seemed to be promising, as there was improved communication between the partners indicated results in improved traceability in inventory that improves IQR and reduction of mean waiting time thereby improving overall supply chain efficiency. Mean daily costs of the whole supply chain were also seen to be reduced and the traceability on waiting time, inventory can be improved with the help of hyper ledger-based blockchain. The blockchain embedded supply chain is more capable in eliminating the risks and uncertainties associated with the automotive supply chain. These are the benefits of adopting blockchain technology in the automotive supply chain.

Five blockchain experts were further consulted to compare the supply chain and blockchain functionalities identified. Here, traceability was found to be the second most important factor and its blockchain readiness value was significantly higher than supply chain readiness which suggests that the current traceability system can be effective if blockchain is implemented. Blockchain offers a peer-to-peer network with cost-effective transaction and data security, thus making its integration with newer technologies all the more desirable. This would inherently assist any organization in making its supply chain cost-effective in the long run.

In conclusion, this study offered a new perspective on implementing blockchain and further digitizing the organization as reviewed by industry and business experts. However, one limitation of this study is that it offers insight only into the automotive sector. Moreover, the industry experts consulted were also predominantly from a manufacturing background. Further research may include the study of how cloud services may accelerate the integration, blockchain's integration capability with other tools, and the system's isolation from inevitable disruptions. The unique contributions of the study are

- A framework for blockchain is developed for the automotive supply chain where stakeholders get visibility into goods movement, inventory status, and waiting time.
- A hyper ledger fabric-based blockchain architecture is designed for an automotive supply chain to track the ownership transfers in inbound and outbound logistics, order readiness to fulfill the demand.

The implementation process for blockchain-enabled supply chain architecture mostly revolves around capital issues, network infrastructure issues, and legal aspects of implementation. Except for bitcoin, other use cases for blockchain have not been explored to an adequate level. For example, there is a limited amount of work done to address supply chain-blockchain integration keeping global context in mind. There is an opportunity to study the effectiveness of blockchain on a variety of supply chain operational parameters. The four core values of blockchain are still being closely researched and more functionalities may also be added in the future. Many governments around the globe have not made any laws or regulations for blockchain implementation. The decentralized database will provide more trust for regulators, and it improves the visibility among supply chain members. Researchers can focus on the security and legal aspects of blockchain-enabled supply chain implementation. With disruptive technologies coming into play and technical advancements being conducted with Industry 4.0, a comprehensive study can be performed to address any possible loopholes and issues in the blockchain network. The hyper ledger architecture developed in this study can also be expanded for advanced features such as geofencing and live location sharing with the help of sensors and IoT integration. It is evident that blockchain is evolving and thorough analysis on limitations also needs to be studied before implementation. This may help the practitioners and academia for further research on it.

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