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# Blockchain-based Manufacturing Supply Chain Management using HyperLedger Fabric

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**Abstract.** Production of goods has reached record numbers in the last decades as it became more efficient and effective than ever before due to the automation and digitalization of the production process. This gave customers more choice and the delivery process became faster and more satisfying. However, supply chain management remains a bottleneck due to the limitations of the supply chain management systems which suffer from poor traceability, product tampering, lack of timely information sharing, and delays. These issues can be addressed by the blockchain as a digital platform with features like immutability, transparency, and decentralization of information. In this paper, we propose a case study for improving the manufacturing supply chain management through a blockchain-based solution. The proposed system would provide a more transparent supply chain with improved product traceability because of the tamper-proof and decentralized nature of blockchains.

**Keywords:** Blockchain, Manufacturing, Supply Chain, Transparency, Traceability, HyperLedger Fabric.

## 1 Introduction

To reach the hands of the consumer, a product often goes through a long chain of participants which might include suppliers, manufacturers, transporters, distributors, retailers, and storage companies. Billions of products are manufactured daily through this complex supply chain that could stretch across continents starting from raw materials such as cocoa beans in the Ivory Coast to the hands of a customer in Japan in the form of a nicely packaged chocolate bar [1].

The supply chain participants combine their efforts to design, produce, market, and deliver the final product. This long journey from an idea to a final product is in most cases not visible in a holistic way for a single viewer. Each actor in the manufacturing supply chain of a product uses his private information system and the information is

exchanged between the actors if necessary either through system integration, manual paperwork, or informal channels such as emails [23]. This would create fragmented silos of systems that are under the control of the supply chain actors with minimal traceability and visibility capabilities. This leads to several issues that include but not limited to data error and discrepancy, information tampering, delay, and lack of real-time information sharing in the supply chain. These issues cause significant risk in terms of reputation and environment which could impact any brand's profitability, equity, and operational capabilities [2].

Additional consequences of these issues are unethical labour environmental damage, end of life wastes and counterfeit products. Another consequence of the defragmentation of the systems and their databases is the difficulty of tracking the origins of the products as the supply chain is stretched and the product travels through a vast network of different parties. Information of where and when the product is manufactured is often obscure. This effect is compounded by the fact that most companies relocate their manufacturing facilities to developing countries [3]. Although recent technologies such as Internet of Things (IoT) devices and wireless sensor networks have started to be used to improve visibility and tracking [4], there remains a major issue in the supply chain which is lack of trust.

The information that is shared between parties in the supply chain either in a central database or in one-to-one information exchange is not trusted. Any party can tamper with the data. Having a centralized information source in a monolithic system without strong protection is a major flaw in the network and any individual or organization who have access to the database can tamper or falsify information to gain an advantage. These actions would result in a complete loss of trust between parties which would often lead them to fall back to more traditional and manual transaction processing [5].

This problem of centralized non-trusted information sources happened to have been solved in another completely different domain which is the digital currencies where information is shared by distributing it between the parties in a decentralized network of nodes. Any further modification for the data once it is committed and distributed between the nodes is not allowed. This is the essence of the blockchain technology which have turned out to be a revolutionary idea that is touching almost all domains. This immutability feature improves traceability, visibility, and most importantly restores trust in the supply chain information systems [6].

In this paper, we propose a decentralized blockchain-based system that implements a manufacturing supply chain use case as opposed to a traditional information system with an RDBMS database. The Fabric Ledger is selected as the suitable platform for the domain for reasons that will be discussed later, and the resulting solution is compared to a non-blockchain based solution in terms of functionality and performance. The goal of the system is to prove that such a system is feasible to implement as a blockchain and investigate the advantages and disadvantage of such a system.

The remainder of this paper is structured as follows: In section 2, we present a state-of-the-art overview of related works on blockchain-based manufacturing supply chain management applications. In section 3, we cover the impact of blockchains on manufacturing systems and the Product Lifecycle Management (PLM). The next section provides an overview of the system. Section 5 covers implementation aspects of the system

including its evaluation. We draw our conclusion in section 6 highlighting a set of future challenges.

## 2 Related Work

Various studies on the effects and applications of the blockchain technology in many fields have been conducted. We have focused on the research conducted on blockchain applications in Manufacturing supply chains.

Fu et al. [7] presented a solution for the emission trading schema that is based on blockchains for Industry 4.0 and an innovative emission link system that is capable of reducing emissions. Li et al. [8] proposed a blockchain-based framework that crosses enterprise boundaries for a high level of sharing services and knowledge in the manufacturing supply chain. They believe that because of blockchain, the manufacturing networks are going to move from traditional networked manufacturing to open manufacturing. Yin et al. [9] developed a secure blockchain-based machine-to-machine communication network to address the problem of securing the communication between the different machines in a cyber-physical system. To fulfil the requirement of checking the authenticity of components in additive manufacturing, Kennedy et al. [10] proposed an anti-counterfeiting method that is based on blockchains.

Lin et al. [11] proposed a framework that is composed of hierarchical four tangible layers and is designed to integrate vertically the inter-organizational value networks, manufacturing factories, engineering value chain, etc. They also developed a secure blockchain-based system for mutual authentication to enforce more fine-grained policies of access control. Lee et al. [12] presented a service for custom manufacturing with a peer-to-peer (P2P) network for customers and manufacturing as a blockchain-based IoT architecture. The architecture is composed of a manufacturer rating classification, a reputation assessment method, and a malicious evaluator identification. To improve the traceability of the components and products manufactured, Westerkamp et al. [13] proposed a blockchain-based method for generating non-fungible digital tokens for the products. Yu et al. [14] proposed a Blockchain-based framework (BSM) to support Cyber-Physical Systems.

The manufacturing industry is going through substantial changes as we are moving to the era of Industry 4.0, and smart manufacturing is becoming a reality through emerging technologies such as blockchains, Internet of Things (IoT), cloud manufacturing (CM), and artificial intelligence (AI). Manufacturing giants such as BMW and Ford are adopting blockchain technology to improve the efficiency of their supply chains and attain business innovation. Leading technology companies and innovative start-ups collaborated to create the Trusted IoT Alliance which aims to develop the necessary standards to integrate blockchains and IoT. The main goal of the standard is to develop smart contract interfaces that enable the exchange of data between blockchain-enabled systems. The alliance efforts are focused on using blockchains for the trusted identification of hardware and documentation immutability.

To encourage the adoption of blockchains by the industry, the cloud-based Blockchain as a service (BaaS) was proposed by various vendors. Businesses can use this

cloud-based solution to develop, host, and use their blockchain applications which include their smart contracts through a blockchain infrastructure that is developed by a vendor. It provides tools that simplify the management and deployment at scale. Similar to the increasing trend of Software-as-a-service (SaaS) where access to the software is granted on a subscription-basis, BaaS enables businesses to tap into a blockchain network using its configuration without having to invest in developing their blockchain infrastructure and without requiring inhouse expertise in the subject especially for resource-constrained enterprises [15].

The Mobility Open Blockchain Initiative (MOBI) is an initiative formed by giant automotive companies such as General Motors (GM), Ford, and BMW to help in making automobiles safer, more affordable, and accessible using blockchain technology. To give new cars a digital entity, MOBI specified the first blockchain-based car identity standard. This enables the tracking of significant events during the lifetime of the car. The blockchain digital identity can also be used to exchange information between cars such as location, speed, travel direction, driver behavior, and even driver intention predictions [16].

### **3 Blockchains Impact on manufacturing systems and Product Lifecycle Management (PLM)**

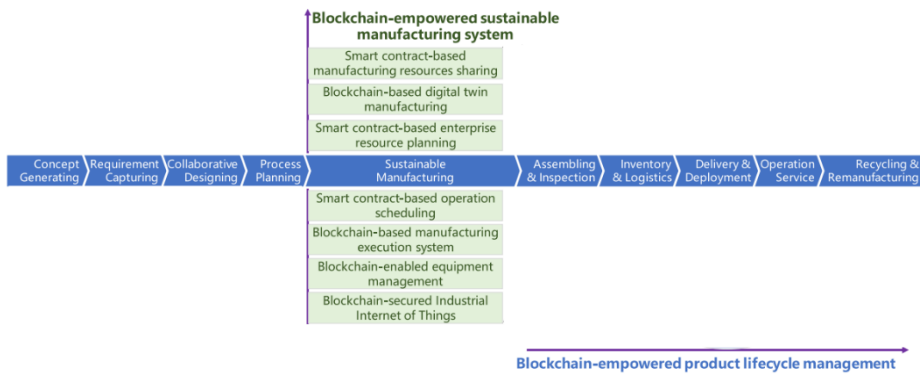
The impact of blockchains on manufacturing supply chains can be seen from two perspectives: the manufacturing systems perspective and the product management lifecycle perspective [17]. From the perspective of manufacturing systems, blockchains can be considered as an enabling driver for existing information systems in the manufacturing domain such as the manufacturing execution systems (MES) and the traditional enterprise resource planning (ERP) (Fig. 1 – vertical axis). In an industrial workshop, the blockchain can act as an indexing server for tracking manufacturing parts to speed up manufacturing automation. At the higher level of enterprise, blockchains can enable distributed manufacturers to create a trusted environment that self-manages the service transactions and interconnection between them over a transparent and decentralized credit mechanism. In this setting, smart contracts improve the efficiency of the manufacturing process by automatically executing planning and scheduling processes. Also, due to the tamper-resistant nature of blockchains, data such as order information and transaction history can be exchanged safely between manufacturing nodes for a more convenient product traceability.

On the other hand, and from the perspective of product management, the lifecycle activities (starting from concept generating all the way to the final stage of recycling & remanufacturing) as shown in (Fig. 1 – horizontal axis) are increasing in complexity. This is mainly due the increase of stakeholders, socialized resources, and advanced technologies that are involved in the lifecycle of the product. Moreover, the challenge of managing and exchanging product information is increasing because of the requirements of security, intellectual property protection, and other trust issues.

Blockchains can be the tool that would provide the community of lifecycle management (designers, manufacturers, suppliers, etc.) with a unified and shared database. This

database is the medium by which the community share product information, enable untrusted manufacturers to freely change requirements and capabilities, and eventually make deals. Blockchains allows manufacturers to search for more efficient approaches to connect with each other and with the end customers as well. With blockchains, decisions on these aspects can be taken by consensus algorithms and smart contracts instead of management boards. Likewise, the process of making deals in product life management, which includes bidding, payment, resources management, usage tracking, and final services can be automated through smart contracts with the input from IoT devices for instance.

**Fig 1.** A bi-dimensional impact of blockchains on manufacturing [17]



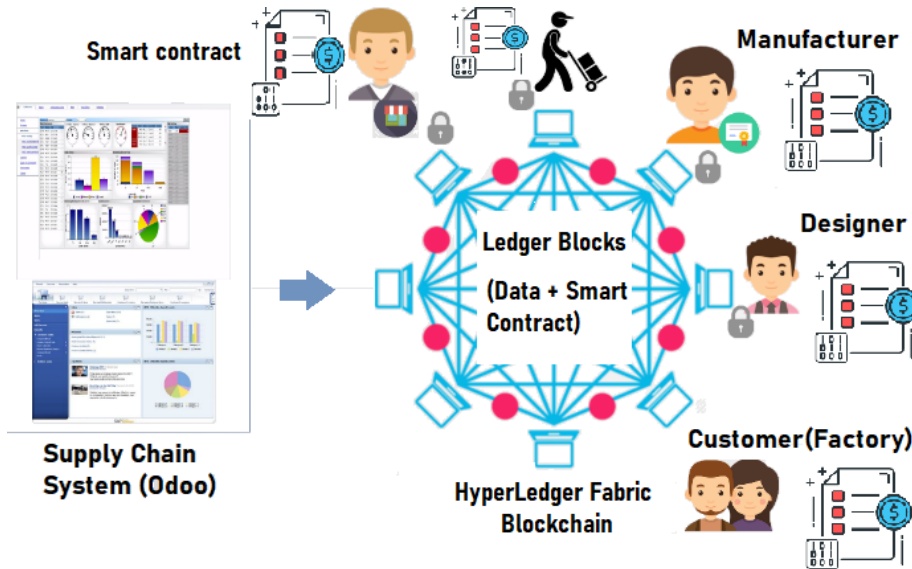
In manufacturing, the systems managing the supply chain consists of several entities such as people, knowledge, physical items, contracts, processes, and transactions that enables suppliers to provide products to customers. Manufacturing supply chain systems are typically large which makes it challenging to get a complete picture of all the transactions in the supply chain [18]. Information is usually scattered in multiple systems and sometimes it is duplicated in multiples locations with no warranties for data consistency. The final consumer who is an individual or a company typical will have only very limited access to the overall supply chain information [19]. In most cases, the reason for this is the suppliers who treat this information as a commodity which results in a low level of transparency. Consequently, the tractability of transactions depends on the trust between the different actors of the system.

The traceability and transparency issues in the manufacturing supply chain can be addressed using blockchain technology through controlled user access, decentralized data storage and most importantly immutable data records. In the next section we present a blockchain-based system for the manufacturing domain. We explain the actors in the supply chain network, how they interact with each other through the blockchain and how smart contracts are used to control and govern their interactions. Finally, we cover how data privacy between groups of supply chain actors is achieved and how a token-based model is used for financial transactions in the blockchain.

## 4 Blockchain-based Manufacturing Supply Chain System

An overview of the proposed blockchain-based supply chain system for manufacturing is shown in Fig. 2.

Fig. 2. Supply chain system for manufacturing blockchain



The central component of the system is the decentralized blockchain where each actor has a complete copy of the information. All the data collection, storage, and management of the product lifecycle are performed in the blockchain. Throughout the life cycle of a product, its ownership is potentially transferred between the actors of the supply chain, for instance, customers, designers, retailers, suppliers, producers, manufacturers, and distributors. These actors play an important role to fulfil the goals of the system (traceability and transparency) as they supply the product information during each phase of its lifecycle. Each product has a distinctive digital profile that is updated constantly as it moves through the supply chain. This provides a real-time view of its status in the blockchain and consequently in the supply chain. To link the digital profile with the physical product, an information tag needs to be attached to the product. This tag could be an RFID, QR, or barcode. This tag is considered as the digital cryptographic identifier that is linked with the digital profile which is the virtual identity of the product in the network. The use case developed to evaluate the system involves a customer who needs to design a factory machine.

### Case study scenario

The scenario of the case study consists of the following actors:



- *Customer*: a food factory that needs a new machine to improve its efficiency and increase its production.
- *Designer*: a design firm specialized in industrial machines design.
- *Manufacturer*: bespoke machine manufacturing company.
- *Supplier*: raw materials supplier
- *Transporter*: goods transportation company.

The supply chain starts with a food factory that has an increase in demand and needs to increase its production. It formulates its requirements in a document and sends it to several design companies for quotations. Design companies then evaluate the financial standing of the customer and upon satisfying a certain rating, they prepare the design and send it to the customer. If the customer accepts a design, the typical transactions between him and the designer take place (Quotation, invoice, etc.). Once the design is finished, it is delivered to the customer who will in turn send it to a manufacturer with the same interaction patterns. The presentation of the case study focused mainly on the interaction between the customer and the designer where the following aspects are highlighted:

- The smart contracts representing the different actors in the blockchain such as the customer, designer, and manufacturer.
- The smart contracts representing the transactions between actors such as the one representing the relation between the customer and designer.
- The representation of the domain entities such as design and quotation.
- Asset transfer in the blockchain for instance transferring the ownership of the design from the designer to the customer and vice versa.
- Create and transfer fungible tokens using an account-based model for payment aspects.
- Establishing private channels between groups of actors in the blockchain.

The system has been implemented using the Hyperledger Fabric platform as the most suitable of the problem domain where the access to the blockchain is not open to the public besides other features that will be highlighted in the next section.

### **HyperLedger Fabric**

The system was implemented using the Hyperledger Fabric platform which is one of the blockchain projects within Hyperledger. Like other blockchain technologies, it has a ledger and smart contracts [20]. The following are the main characteristics of Fabric:

#### *Privacy features*

Unlike most other blockchain systems, Hyperledger is a private and permissioned blockchain allowing only known and registered entities to participate in the network. Members of the network gain access through a trusted Membership Service Provider (MSP). This property of the Hyperledger makes it suitable for the supply chain management domain where access is only open for the SC members and not open for the

public. The pluggable architecture of Hyperledger Fabric allows some parts to be exchanged such as the data formats, the consensus mechanism, and MSPs.

Another requirement in the supply chain domain is the need for privacy between certain actors in the SC. For instance, some participants in the network might be competitors and they do not want their all transactions to be visible to everyone in the network. Some of these transactions could be a special price for client that should not be known to the competitors. The solution to this requirement is through channels that allow a group of participants to have their exclusive shared ledger of transactions [21].

#### *Shared Ledger Data Store*

The ledger subsystem of the Hyperledger Fabric is a combination of two main components: the world state and the transaction log. Each node in the network has a copy of the ledger. The world state component is a snapshot of the ledger at any given point in time. The transaction log is a record of all the transactions that took place in the blockchain and led us to the current world state. The default data store for the world state is a LevelDB key-value which can be replaced by another data store. As for the transaction log store, it is not pluggable as it only persists the before and after values of the ledger database.

#### *Smart Contracts.*

Smart contracts in Fabric are written using chaincode which can be implemented in several programming languages. Currently, Go, Node.js, and Java chaincodes are supported. Chain code can be called by external applications that are outside the blockchain boundary to interact with the ledger. The most common interaction scenario is the interaction between the chain code and the world state component of the ledger to query for data.

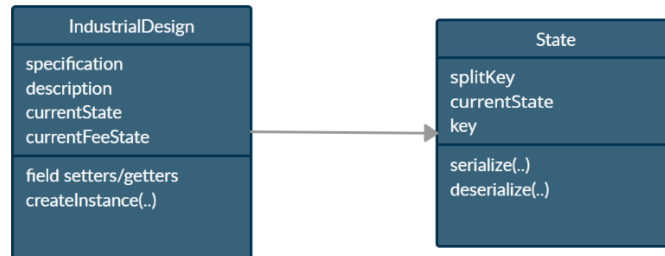
## 5 Implementation

For the proof-of-concept implementation, we used JavaScript as the implementation language for smart contract and hosted the HyperLedger Fabric on Linux as it uses Docker extensively which is recommended to run on Linux to avoid technical issues. The different aspects of the implementation are presented in the next sections.

### 5.1 Domain Entities

The use case consists of the domain concepts such as design, design request, quotation, invoice, receipt, etc. So how are these concepts created in the blockchain? All concepts in the blockchain are inherited from a class called *State* predefined in Fabric (**Fig. 3**). It has a unique key and a lifecycle current state of the concept where the key and current state are determined by the specific subclass. The class has also helper functionality to convert to and from the JSON format. An example domain concept in the system is the *IndustrialDesign* concept. To define it, we inherit from the *State* class and add the entity-specific properties. The *currentState* and *currentFeeState* are defined as enumerated values. The *createInstance* method is used to generate instances of the entity.

Fig. 3. Concept Representation in Fabric

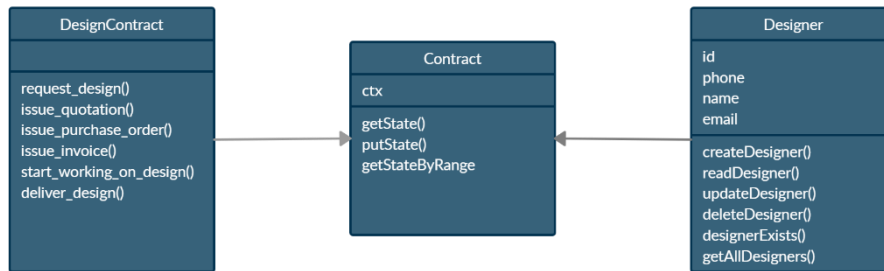


Domain entities are typically initiated in smart contracts either to create a new instance such as a new *Invoice* or retrieved as an existing instance from the database for further processing. The definition of entities can be nested, for instance, the *Invoice* is composed of a list of *LineItems* with is also defined in the same manner by extending the *State* class.

## 5.2 Smart Contracts

Smart contracts in the blockchain are used in our case study to represent two concepts: the actors in the system such as the customer and the relation between actors such as the relation between the customer and the designer. All smart contracts inherit from the *Contract* class as shown in (Fig. 4). The smart contracts for the actors in the system contain mainly the Create, Read, Update, Delete (CRUD) operations

Fig. 4. Smart Contracts in Fabric



All the *Designer* methods take as a first argument a *ctx* variable that represents the blockchain context. This variable is used to manipulate the entity in the blockchain for instance to store a *Designer* in the blockchain we invoke the `ctx.putState()` method. The relation between actors of the system is governed by smart contracts which are defined in Fabric as a regular class where the methods of the class represent the contract clauses that should be honored (Fig. 4). For instance, the relation between the *Customer* and the *Design* is defined in the *DesignContract* class as follows:

---

**Smart Contract 1: Request an IndustrialDesign from a Designer**


---

```

1  Input: ctx, requester, designer, design_code, spec, description, requestDate

2  Retrieve the customer(requester)
3  Create design request(requester, designer, design_code, spec, de-scription, request-Date)

4  If customer_credit_rating > 3 then
5    Set design state(ACCEPTED)
6  end
7  else
8    Set design state(REJECTED)
9  end
10 Store the design(contract_id, design)

```

---

As with entities, the smart contract functions also require the passing of the blockchain context variable *ctx* to access the blockchain database. Another example is the *design delivery* smart contract which is defined as follows:

---

**Smart Contract 2: Deliver the design to the Customer**


---

```

1  Input: ctx, contract_id

2  design ← retrieve the design contract(contract_id)
3  job_days ← get the difference between the request date and today(contract_id)
4  fees_reduction = Update fees based on delay(contract_id, job_days);
5  design.fees = fees + fees_reduction

6  store_the_design(contract_id, design)

```

---

This design delivery smart contract calculates the delay in the delivery of the design and based on that update the agreed-upon fees. If there is no delay, the *Designer* will be paid full fees, otherwise, his fee will be deducted according to the length of the delay.

### 5.3 Asset Transfer

Transferring assets between supply chain members in the blockchain is just a matter of changing an attribute in an entity to represent the owner. The *pay design fees* smart contract changes the owner of the design from the designer to the customer after settling the payment as follows:

---

**Smart Contract 3: Pay design fees**


---

```

1  Input: ctx, contract_id, customer_id
   financial transaction logic [Details in Smart Contract 4]

2  design ← retrieve the design contract(contract_id)
3  design.owner = customer_id

4  store_the_design(contract_id, design)

```

---

## 5.4 Financial transactions

The financial transactions between supply chain members are implemented using the ERC-20 account-based model [22]. A smart contract can either create or transfer fungible tokens using an account-based model. In this model, there is an account for each participant that holds a balance of tokens. A *mint* transaction creates tokens in an account, while a *transfer* transaction debits the caller's account and credits another account. To test the model, we allowed all the participant to call the *mint* function to create a certain limited amount in their account. The smart contract *mint* function takes the client certificate as the client identity through an API and credits their account with the requested number of tokens. To transfer money to another account, a *transfer* function is called to transfer the requested tokens to the account of the recipient. The recipient should provide their client ID to the sender to complete the transfer. The following is an example of a financial interaction between the *Customer* and the *Designer* where the customer calls the *mint* function to generate 7000 tokens then transfer 300 to the *Designer*:

---

### Smart Contract 4: Transfer money

---

```

1  Input: ctx, designer_id, customer_id

    mint(customer_id, 7000)
2  customer_balance ← get available mints (customer_id) // output: 7000
3  designer_balance ← get available mints (designer_id) // output: 0

4  accountId = get account id(designer_id)
    transfer from customer to designer(customer_id, accountId, 300);

5  customer_balance ← get available mints (customer_id) // output: 6700
6  designer_balance ← get available mints (designer_id) // output: 300

```

---

## 5.5 Private Channel Transactions

Hyperledger Fabric uses an immutable ledger for each channel in addition to the chaincode that manipulates the state of assets. This ledger can either be visible to all the network participant or can be limited to a specific subset of participants. In the latter case, participants will have their segregated transactions and ledger. To balance between total transparency in the network and the needed privacy between subgroups of participants, we created dedicated channels for subsets of participants and authorized them to use their private data. We further obfuscated the data by encrypting the values in the chaincode using the AES cryptographic algorithm before sending it to the ordering service which will append it to a block in the ledger. The encrypted data in the ledger can only be decrypted using the user key that was used to encrypt the data.

## 5.6 Evaluation and Discussion

To evaluate our proof-of-concept, we developed a test client that simulates the complete use case of manufacturing a machine by engaging all the actors that are required to complete the use case. In terms of functionality and when compared to a traditional information system, we did not find any difficulty in implementing the features required by the use case as the programming languages used to implement the smart contracts are Turing-complete languages and do not have any limitations. Also, the supported peer databases LevelDB and CouchDB are satisfactory for most business applications. The LevelDB stores chaincode data as simple key-value pairs and CouchDB which is the alternative state database supports rich queries and chaincode data values are modeled as JSON.

To test the performance of the blockchain network, we calculated the average time it takes to complete a single business transaction. The average delay from the first smart contract invocation requesting a design and the last call which settles the financial payment after delivering the design was around 7 seconds where the single call takes between 0.5 and 2 seconds. This time is slightly higher than a traditional Java application storing similar information in a MySQL database where the single call to manipulate the database take an average of 100 and 200 milliseconds. However, the reaped benefits from implementing the solution as a blockchain could outweigh the performance penalty of the blockchain complexity in many business domains. By design, our system as a blockchain solution has achieved all the benefits of the blockchain technology namely: immutability, durability, and transparency. These features as discussed are the solution to many of the manufacturing supply chain challenges such as the lack traceability and transparency. However, to enable blockchains to be applied to more industrial systems, more research is required in the performance area to close the gap between blockchain-based systems and traditional information systems.

## 6 Conclusion

Blockchain technology went beyond its original intended purpose as a cryptocurrency platform to become a major disruptive technology for numerous business fields and an interesting topic for academic research due to its attractive characteristics. Technology enthusiasts claim that it has the potential to completely transform our contemporary cultural, economic, legal, and political landscape. In this paper, we reviewed the impact of blockchain technology on the manufacturing supply management and how it could solve the various shortcomings of the current information systems used in the domain. Then presented a blockchain-based system implemented using one of the leading private blockchain platforms, the Hyperledger Fabric. We highlighted the main characteristics of Fabric that make it suitable for applications in this domain. As an example scenario, we proposed a hypothetical vision of a manufacturing supply chain of a factory designing a new machine. The business transactions between the customer and the designer were the conveyer that demonstrated how the main features of the chosen platform were used to create a solution that demonstrated the benefits of using blockchains to achieve transparency and traceability. The system protects information from public

access and provides privacy for subgroups of the supply chain participants. While blockchain platforms provide several benefits, their main known downside is their performance limitations compared to traditional storage systems such as RDBMS databases. In future, we will focus on exploring more features of blockchain platforms that apply to the supply chain management domain and perform a comparative study of the performance of the different available blockchain platforms.

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