How to Reduce Information Silos While Blockchain-ifying Recycling Focused Supply Chain Solutions?

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Abstract

Blockchain has already found applications in the supply chain domain to ensure transparency. Recently, blockchain has further been extended to support the circular economy. Existing literature can broadly be divided into product tracing (or track-n-trace) and anti-counterfeiting. Unfortunately, the information generated in existing supply chain applications has stayed in silos. The existence of information silos reduces the value of "blockchain-ifying" the supply chain. Proper data curation via blockchain secures the information and eases the information flow in the supply chain ecosystem, which can accelerate the implementation of the circular economy. In this paper, a blockchain-IoT-based supply chain management framework has been proposed that offers two primary features. They are i) reducing data sitting in silos while opening doors to circular economy-focused services (particularly recycling), ii) documenting suppliers' performances while delivering quality products focusing on sustainability. Thanks to such unification, relevant supply chain stakeholders will also have access to important events (ranging from the initial stage to the end of the product's life cycle).

Keywords: Blockchain, DMAIC, Information, Silo, Supply Chain

1. Introduction

Current supply chain (SC) solutions must offer faster delivery of quality products while adhering to social compliance (such as sustainability). Till now, the social responsibility within the circular economy (CE (Murray et al., 2017)) has been neglected (Upadhyay et al., 2021). A traditional supply chain management system manages multiple diverse supply-demand processes and further decomposes them into processes, components, and structures (Cooper et al., 1997). These processes generate a massive amount of data[1]. Digitalization of traditional SC is not easy because it depends on data quality and availability of relevant data. Moreover, we can enhance the digitalization of SC by incorporating the blockchain with other technology (such as Internet-of-Thing (IoT) and machine learning (ML)). Blockchain is a popular data structure for distributed ledger technology and secures distributed records of transactions (Kannengießer et al., 2020). It is a decentralized data store that combines robust features of data tamper resistance. Data blocks (or records) are added to the blockchain by applying consensus among blockchain network users.

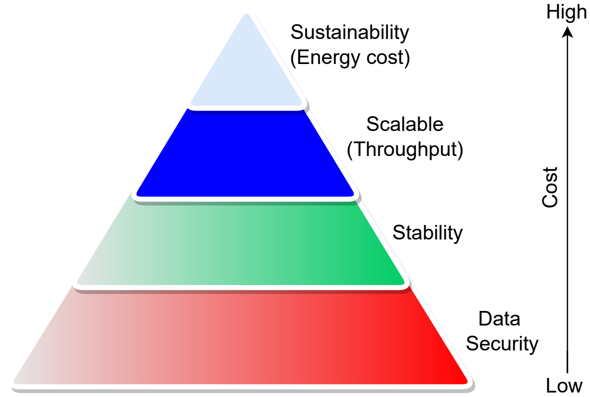

Figure 1: Four primary blockchain features with variable cost

From Figure 1, we can see that blockchain offers four primary features (with a variable cost) that are required for most applications. Thanks to cryptographic hashes and digital signatures, data integrity is strongly protected, while changes made to one record cause subsequent records to be invalid. Blockchain as a whole is not yet matured (Kamilaris et al., 2019; Wang et al., 2016) and standardised (Drljevic et al., 2020). However, it is quite stable due to the underlying mature

[1] Data and information are used interchangeably in the paper.

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technology stacks (such as peer-to-peer computing and cryptography). Still, scalability and energy cost are two primary challenges related to blockchain's existence. Traditional SC management studies focus on manufacturing and logistics phases but not the complete product lifecycle (Madenas et al., 2014). It has been found that most of the blockchain applications in the SC domain are primarily focused on traceability and anti-counterfeiting (Gonczol et al., 2020). The lack of a holistic approach to solving both the problems made information silos that cannot be accessed seamlessly across the SC processes. It has already been argued blockchain can help to incorporate sustainability across the industry by incentivizing CEs while reducing information asymmetry and improving process monitoring (Herweijer et al., 2018). Blockchain can support CE by lowering transaction costs and communication delays while improving the SC performance (Upadhyay et al., 2021). Blockchain combined with IoTs can capture events from a wide range of stakeholders (such as material suppliers, product manufacturers, transporters, retailers, service providers, and consumers) to ensure transparency (Dietrich et al., 2021). It is worth noting that blockchain only holds data while IoT devices are employed to collect related event data. Data collected by IoT devices are stored in the cloud, while only metadata or important events are stored in the blockchain. However, collecting and storing all-important context-specific events in the blockchain is not a trivial task.

Blockchain's data immutability and tamper resistance features, together with IoTs, offer the opportunity to combine product tracing (or track-n-trace) and product authentication processes with recycling while documenting the certificates of sustainable products. Here, the proposed generic blockchain-IoT-based framework primarily answers two research questions: *How can we reduce information silos among different stages of SC to support product recyclability?* and *how can we quantify quality product delivery by suppliers' while focusing on sustainability?* This paper first proposes one generic blockchain-IoT-based[2] unified framework (in Section 3) to reduce information silos while facilitating recyclability in the SC domain and then applies application design principles (in subsection 4.1) for efficient code development. Next, to implement the framework successfully, a five-stage application methodology has also been applied in subsection 4.2.

2. Related Literature and Methodology

This section presents related literature, followed by a brief description of the applied research methodology behind the working of the blockchain framework.

[2]Title does not contain IoT because IoT is just an event data collector. Blockchain is primarily bridging the gap for better information flow and data security. Event data can also be collected by others (sensors, QR codes or bar codes to a certain extent).

2.1. Related Literature

Employing blockchain in the SC domain is a prevalent research topic. From literature, many surveys are found that cover most of the blockchain-based SC research (Chang and Chen, 2020; Dietrich et al., 2021; Fraga-Lamas and Fernández-Caramés, 2019; Gonczol et al., 2020; Muessigmann et al., 2020; Vadgama and Tasca, 2021) and some primarily focus on CE (Böckel et al., 2021; Upadhyay et al., 2021). However, there is a lack of research on how blockchain can accelerate CE adoption (Upadhyay et al., 2021). Vadgama et al. analyze public data to discover how blockchain has been adopted in the SC domain (Vadgama and Tasca, 2021). Another survey focused on applied design choices and technical characteristics and tried to figure out the benefits of blockchain adoption in SC (Gonczol et al., 2020). Fraga-Lamas et al. survey how blockchain can help the automotive industry to distribute trusted and cyber-resilient information inside the organization. Additionally, Seebacher et al. proposed a layer-based model for capturing traceability and anti-counterfeiting use cases based on their business model, network composition, and technical implementation (Seebacher and Maleshkova, 2018). Abeyratne et al. proposed a hypothetical vision for manufacturing cardboard boxes that use blockchain to collect, store, and manage product details of each product throughout its life cycle (Abeyratne and Monfared, 2016). Casado-Vara et al. proposed a blockchain-based supply chain with CE support (Casado-Vara et al., 2018). While Upadhyay et al. surveyed to align the blockchain with the CE from the perspective of Industry 4.0 (Upadhyay et al., 2021), and Böckel et al. listed some potential research gaps for CE via a literature analysis (Böckel et al., 2021). Unlike others, this work proposes a generic framework that helps to develop a solution to support seamless information flow (across the SC processes) based on solid data security and access control policy thanks to blockchain. It also discusses the design principles required to develop solutions successfully while "blockchain-ifying" recycling-focused SC solutions.

2.2. Research Method

Blockchain can create value for the SC application domain with proper support from stakeholders. The success of a software project is a combination of project management and the project product (Baccarini, 1999). Here, the project product is the blockchain-ification of the supply chain. The proposed framework is primarily based on the blockchain research framework proposed in (Rossi et al., 2019). The employed research framework consists of a blockchain layer and an application layer. This research framework guides the core development of the proposed framework. The blockchain layer primarily focuses on how blockchain should be employed and communicated with the respective stakeholders. The application level focuses on the supply chain application with recyclability support. Furthermore, to develop the prototype, the action design research (ADR) methodology should be followed (Sein et al., 2011). ADR further extends the methods of design, science research, and action research (Cole et al., 2005). Multiple iterations of build, intervene, and evaluate (BIE) should be followed to develop a blockchain-based distributed application. The success of BIE requires proper knowledge transfer from one iteration to the next. The successful implementation of such a framework requires the collection of relevant events by the stakeholders and deciding what to keep per the application's requirements. Overall, the blockchain network should map the network structure of the SC ecosystem with proper communication links.

Finally, to transform the first version of the prototype into a pilot and later into a production-grade implementation, the framework relied on Six Sigma (Montgomery and Woodall, 2008). Six Sigma follows a five-stage problem-solving methodology called DMAIC which can be an effective framework for improving SC processes. In DMAIC, 'D' means to define, 'M' means to measure, 'A' means to analyze, 'I' means to improve, and 'C' means to control (discussing more in subsection 4.2). It is a generally four to six-month-long development and improvement process.

3. Proposed Framework

Generally, SC without CE support has four primary stakeholders. They are suppliers, product manufacturers, transporter, and distributor, considering re-seller and consumers[3] as non-primary stakeholders. Currently, SC with CE support considers re-sellers, end-users (or buyers or consumers), and service providers (can be the third party) as primary stakeholders. These new categories are essential for generating and submitting event data to support recyclability. Overall, the SC ecosystem can be divided into two primary components, i.e., SC application and enabling technology (following the blockchain research framework). Furthermore, we can divide the application domain into stakeholders and primary supply chain events or processes. Human stakeholders primarily represent the decision-making and data management parts. Stakeholders can decide which features fall into the must-have, should-have, nice-to-have, and unnecessary categories (optional). The technology stack is to digitalize SC. Knowing how primary data can be collected and added to the blockchain for digitalization is essential. This generic framework allows blockchain to hold data securely and access secure information based on the applied rules encoded into the smart contract while leaving the data collection part to IoTs.

[3]Consumers, end-users and buyers are used interchangeably in the paper.

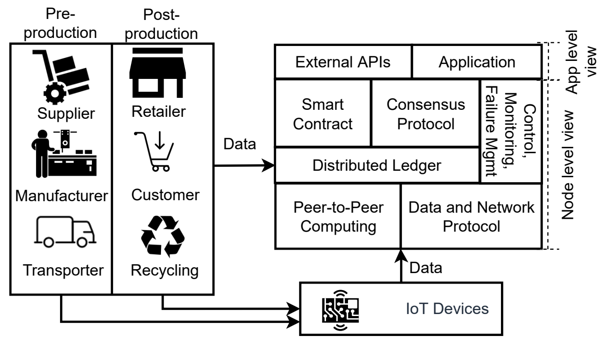


Figure 2: Proposed blockchain-IoT framework to reduce information silos while supporting recyclability

3.1. Blockchain-ifying of Supply Chain (BSC)

Dietrich et al. showed via a survey that no holistic framework covers the events starting from the raw materials to the final products (Dietrich et al., 2021). The current blockchain solution lacks the mapping of assembly processes, including asset auditability features. The proposed framework is presented in Figure 2 and is aimed to be a step toward filling the gap. The framework can be implemented at large enterprises[4] and also at small enterprises[5]. The blockchain layer can work on top of existing legacy systems for large enterprises. It can also work as a standalone solution for small enterprises. Important event-related 'read-only' data can be retrieved from legacy systems using external APIs, while IoT collects data from events generated during both pre- and post-production stages. IoTs pass data to the blockchain based on the applied rules.

In Figure 2, we can see three primary components of the framework. They are SC ecosystem, blockchain, and IoT devices. Further, the SC ecosystem is divided into pre- and post-production stages to support recycling, generating multiple important events-related data. Blockchain works closely with the SC ecosystem and IoT devices to collect and delegate data when needed. Blockchain reference architecture (right-side of Figure 2) can be divided into node and application levels. The two bottom blocks of the blockchain platform are primary computing resources, while the distributed ledger is the primary on-chain storage. Each blockchain node keeps its local synchronized copy while applying a consensus protocol to add new data blocks to the ledger. Business logic and rules are encoded into the smart contract. There is also a platform management unit to overall monitor the blockchain platform. Hyperledger Fabric (or HLF (Androulaki et al., 2018) platform can be used for implementation because it has an overall lower failure rate than Ethereum platform (Vadgama and Tasca, 2021). HLF also allows a secure private mode of communication inside the network, which can be dedicated to each

[4]who have already invested a large amount of money in their IT infrastructure.

[5]who have just started their journey or generally outsource IT services.

stakeholder.

3.2. Information Flow in Framework

The proposed framework aims to reduce the information silos. Such silos are generated due to the lack of a holistic solution approach, resulting in solving the problem in parts (such as having a different solution for traceability and anti-counterfeit) (Dietrich et al., 2021; Gonczol et al., 2020). Figure 3 shows how the framework can support three use cases (of product 'X'), i.e., product track-n-trace, product authentication, and product recycling, while not creating unnecessary information silos.

Block creation. Each data block holds the relevant transactions for all used components (such as parts numbers) at each manufacturing stage for product 'X'. Overall, each data block represents the metadata of a product. If applicable, then certificates related to sustainability and authentication can be stored as off-chain while a hash entry related to certificates will be added to the blockchain. Later, making changes to these certificates cannot go unnoticed. In general, blockchain suffers from scalability issues. Thus, storing unnecessary data in blockchain can reduce its throughput. During the application definition phase (refer to subsection 4.2), wise decisions should be made related to on- and off-chain data storage. However, multiple solutions are also being proposed to improve the solution quality (Xie et al., 2019).

Product track-n-trace. First, stakeholders (such as product manufacturers, suppliers, retailers, service providers, and transporters) should agree on what are the important events that need to be collected to support: *i)* tracking, *ii)* product's authenticity verification and *iii)* product recycling. Such events will vary across applications (such as food, automotive, healthcare, and e-commerce). Key blockchain characteristics (such as shared, append-only ledger (for holding transactional history), cryptography-based data security, and distributed platform) help to achieve the stated goals. Blockchain provides verifiable proof of the existence of a transaction using digital signatures. Time stamping of its data using hash functions offers security and is verifiable at any time. Using the external APIs (refer to Figure 2), data exchange among other blockchain platforms, legacy systems, and IoT devices is possible. The green lines in Figure 3 represent that stakeholders at various stages can upload and download product-related data from the blockchain (based on agreement).

Product authentication. The functionality of the framework is to inform the buyer about the product's authenticity or quality (denoted by red lines in Figure 3). Blockchain helps buyers get immutable product history, and the process can be improved by fitting proper IoT devices into the products. In Figure 3, the consumer (buyer or end-user) is also denoted as a stakeholder of the blockchain who generally has read-only access to the product data. From Figure 3, we can see that an interested buyer scans the product 'X' QR-code, generating a web search request to the blockchain. After a successful product search, the prospective buyer (or consumer) receives the product's information. The buyer gets relevant information if the product is authentic (depending on smart contract implementation). Otherwise, the prospective buyer will get a proper message. It will also report the 'fake-product' incident to the manufacturer.

Product recycling. It is worth noting that CE leads to better sustainable business models. The amount of recycled materials vary due to multiple dynamic factors (such as wear and tear, material decay, and other relevant chemical properties), which makes it very hard to recycle the material thoroughly. Apart from that, the amount of recyclable material is also related to the quality of the primary materials used to manufacture the primary product. So, it is essential to collect relevant data to support recycling, and the framework is capable of doing it. For some products (such as wooden furniture or metal furniture), a good amount of recycled materials can be reused, but it is not true for all cases (such as clothes). Suppose the product (denoted as Product 'X') supports recycling. In that case, the product manufacturer should update the smart contract with relevant details (such as recyclable after 'Y' years and update information as per sale date). Suppose, after 'Y' years pass, an alert is sent to the current owner of the product 'X'. Relevant stages are denoted by blue lines in Figure 3. Based on the purchase time agreement, the transporter can be informed to collect the product and deliver it to the product manufacturer or other stakeholders. Apart from material quality, product maintenance is also important for the recycling stage. It means the entries related to product servicing and maintenance made by the service provider can play a vital role in deciding the worthiness of recycling the product. A quantification method can be advantageous to keep track of whether a supplier is supplying raw material as per agreed quality and in the correct quantity or not.

Ranking suppliers. The primary aim of using the 'Rank' (denote as $Supplier_{Rank}$) concept is to reward a good supplier and also to identify the overall quality of a supplier in a transparent way. It is worth noting that sustainability should be incorporated into the quality, and it is implementation-dependent. For instance, sustainability can be related to higher quality products or a sustainable mechanism that has been followed while generating raw materials. So, it is very hard to embed sustainability directly into the model. However, it is supported by the concept directly or indirectly through a certificate issued by a relevant institution. Such ranking can also be translated to reputation (or certificate of excellence), which the supplier can further use for its marketing purpose. A high rank means the supplier maintains both quality and quantity. Ranking

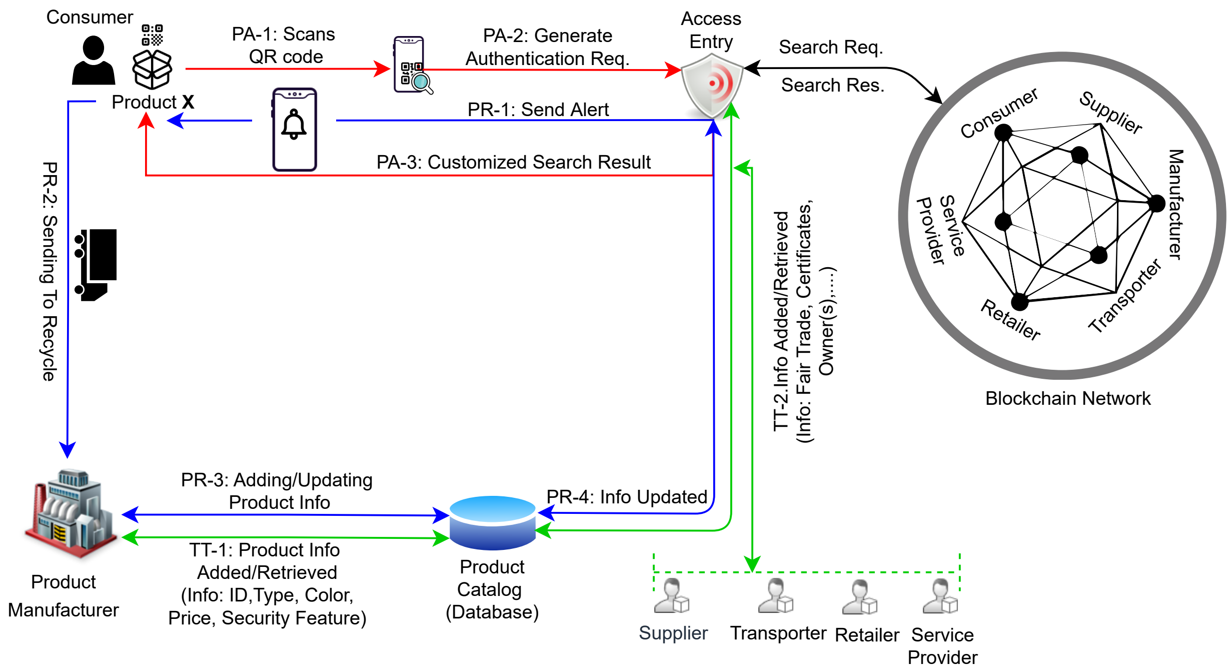
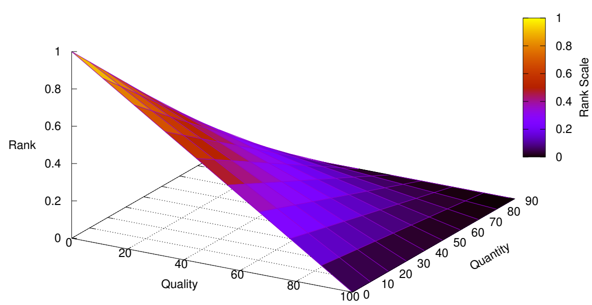
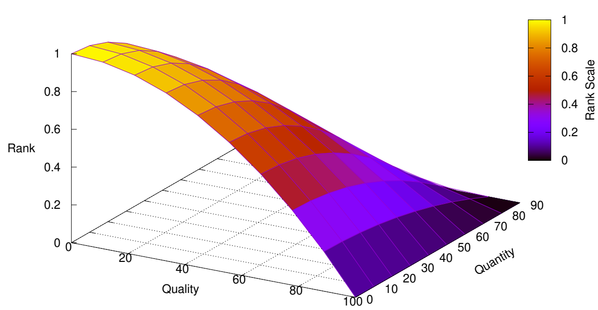


Figure 3: Representation of how proposed framework is working (NB: PA - product authentication, TT- track-n-trace and PR - product recycling)

the suppliers is based on two values: delivered quantity and a ratio between quality and delivered units. The fraction (ranging from 0 to 1) has been calculated based on the actual delivered number of items and the total supposed to receive items (raw materials).



(a) Rank method setting α and β to one



(b) Rank method setting α and β to two

Figure 4: Visualization of Ranking

- Delivered quantity is denoted as Qty_D and total quantity as Qty_T. Therefore, the usage fraction is $Qty_{frac} = \left(\frac{Qty_D}{Qty_T}\right)$, where 'D' and 'T' represents delivered and total respectively.
- Similarly, we can derive the quality as $Qlt_{frac} = \left(\frac{Qlt_D}{Qlt_A}\right)$, where 'A' denotes actual delivered quantity.

$$Supplier_{Rank} = \left(1 - \frac{Qlt}{1.0}\right)^{\alpha} * \left(1 - \frac{Qty}{0.9}\right)^{\beta} \quad (1)$$

From Figure 4, we can see how changing the values of α and β changes 'Rank'. In other words, the higher the rank value, the better the supplier is (represented by the yellow colour shades). Quality and quantity parameters are normalized on a scale of 0 to 1, while tunable parameters (α and β) should be customized based on the preference of the product manufacturer. For representation, the quality threshold is set to 100% (means no negotiation over quality) while setting the delivery threshold to 90% (also implementation-dependent). Maintaining low values for α and β reflects the product manufacturer's strict quality control policy. Overall, the supplies are expected to stay in yellow shade areas.

3.3. Reduction of Information Silos

Now Figure 5, shows how the proposed framework supports the seamless flow of information related to all SC processes. Here, information flow can be logically

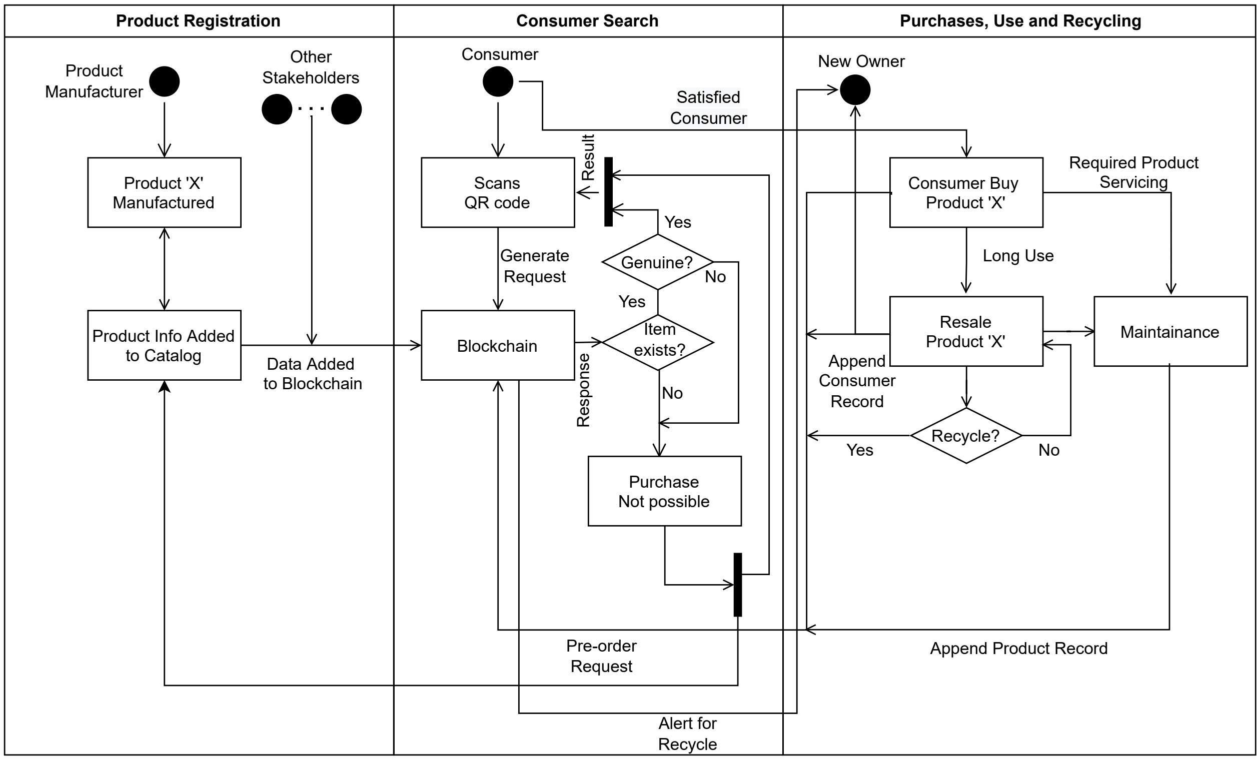


Figure 5: Information flow using the unified blockchain-IoT framework.

separated into three phases. However, the information is fluid. The first phase (product registration) is primarily related to event collection, while the consumer search phase is about data delegation. The last phase is delegating and collecting product purchases, re-sale, and recycling-related information. From Figure 5, it can be seen that stakeholders, including the product manufacturing company, can add relevant product data. A prospective consumer can have the option to find product X's authentication. Upon satisfaction, the consumer can buy the product. A pre-order request can be made if the product does not exist. Purchase-related information is also added to the blockchain. Current product users can use the product for a long time or may sell it to another buyer. The product's maintenance history is also recorded in the blockchain, which can help to determine the product's current state and the future quality of recyclable material. Moreover, if the product's lifeline is over, the current owner will get an alert from the blockchain (initiated from the smart contract) for recycling.

4. Application Development

The focus point of this section is: *How to develop a good quality blockchain-IoT-based SC application while strictly adhering to the eight application design principles followed by the five-stage development methodology called DMAIC?*

4.1. Application Design Principles

The framework is required to fulfil eight software qualities for successful implementation. The qualities are *compatibility, functional suitability, maintainability, performance efficiency, portability, reliability, security*, and *usability* (ISO, 2011). On the other hand, selecting an optimal blockchain platform is not trivial (Farshidi et al., 2020), and most of these platforms are not mature (including the HLF). Thus their offerings can also vary. Blockchain-IoT-based platform publishes its features while the application subscribes to them. A prototype should include many of the primary features of SC and is very important for the success of the final solution.

1. **Compatibility** is one of the important features, primarily when most of the existing SC solutions are based on legacy systems. As already said, the framework can work on top of legacy systems, so selected blockchain platforms should be compatible with each other for seamless data flow. Primarily, interoperability between legacy systems and blockchain is essential. It can hugely impact success when multiple stakeholders have their blockchain platforms. The framework supports interoperability via external APIs. Due to feature differences, there is no standard interface to connect two popular blockchain platforms (i.e., Ethereum and HLF). For instance, Ethereum is based on cryptocurrency, while HLF does not support it. However, very few interfacing libraries exist, but neither are they complete

nor standardized. Using non-standard interfaces can lead to data leaks. Moreover, blockchain's ongoing standardizing and benchmarking process is very slow (Drljevic et al., 2020).

2. **Functional suitability** can be further divided into functional completeness, appropriateness and correctness (ISO, 2011). Such application-level features must be used to validate whether or not the BSC application supports stakeholders' multiple different requirements. Collecting relevant event data and registering it into the blockchain is highly important to achieve better functional suitability. However, most popular blockchain platforms have limitations irrespective of the use cases (Gräbe et al., 2020) and offer features specific to cryptocurrency and IoTs.

3. **Maintainability** denotes how easily the application can be managed after deployment. Maintenance can include application extensions via modifications. It is very much needed as blockchain platform upgrades are frequently happening. Some of the frequent HLF platform (from version 1.0 to version 2.1) updates are user interface improvement, bug fixes, securing data flow, extending access control, validation logic, data query support, developer support, transaction ordering, complex network creation support, data security, and more smart contract features for further rule customization. Such additional/updated features must be tested. In addition to that, the impact of code changes must be assessed before adding to the existing application. Similarly, during application debugging, modifiable code portions should also be checked.

4. **Performance efficiency** related to blockchain includes throughput and energy cost. Throughput can be impacted by the scalability issue of blockchain, and the amount of on-chain data can impact scalability. Off-chain data storage (such as cloud storage) should be preferred over on-chain storage to get consistent throughput. It is worth noting that blockchain has been shown to be a non-enabler of sustainability due to its vast energy consumption, thanks to its proof-of-work consensus protocol (Delliere and Grange, 2018). However, there exist a few less power-hungry consensus protocols (Bach et al., 2018). The selected HLF platform applies a traditional crash fault-tolerant consensus protocol that does not require mining. It is one of the few platforms for developing enterprise-level applications.

5. **Portability** is a big concern to the SC stakeholders as they have invested extensive resources (primarily money and human resources) into their existing systems. The blockchain platform must be stable, compatible, and offer functional suitability for a smooth transition. Generally, traditional applications are implemented on a specific platform. Thus, moving to blockchain should be as smooth as possible. The proposed framework can work on top of legacy systems to reduce technical intricacies. The framework can also support system replaceability as each node of a blockchain network has its local ledger copy; thus, replacing an errant node with a new node is less problematic.

6. **Reliability** means the application should be available and can recover from failure. The peer-to-peer computing infrastructure-based blockchain is a distributed network. It is more reliable than old legacy systems, which primarily have a single point of failure. Overall, storing data in a blockchain is more reliable (mainly secure) than many traditional database systems.

7. **Security.** The primary idea of using the blockchain for this framework is to secure information and bring trust among stakeholders. One of the primary reasons for blockchain's popularity is to ensure data integrity and protect confidentiality. Blockchain offers tamper-resistant distributed ledgers by combining digital signatures and hash functions. Blockchain is less vulnerable to the traditional six security threats (termed as STRIDE) model compared to legacy systems (Kohnfelder and Garg, 1999).

   From Table 1, we can see that data tampering and repudiation is very hard to achieve due to the hashing and the distributed transaction records maintained by a consensus protocol. Changes made to one record cause subsequent records to be invalid. Thus unwanted changes can easily be detected in the blockchain network. To take down the blockchain platform, an attacker must have colossal computing power (as a worst-case scenario). Blockchain-based solutions offer better features (except for spoofing) over legacy systems. However, it is worth noting that spoofing-related events can also result from low physical security measures for a node. Apart from that, some of the features can further be improved if the blockchain platform is a permission-enabled network and strict access measures are in place. In comparison, blockchain is the preferred way to solve the security challenge in SC applications.

8. **Usability** is one of the primary factors of high acceptance of application among all stakeholders. Usability can represent appropriateness, user interface quality, and feature accessibility. Appropriateness shows how much an application is appropriate for the needs. Thus, the higher the

STRIDE Model	Threat	Legacy Systems	Blockchain-based SC
Spoofing of stakeholder identity	Breaching stakeholder's authentication information	Possible	Possible to some extent
Tampering with information	Modifying system/data with/without detection	Possible	Not possible
Repudiability	Undetected illegal operation by un-trusted user	Possible	Not possible
Information disclosure	Data compromising	Possible	Very tough
Denial-of-service	System temporarily unavailable	Possible	Very tough
Elevation of privilege	Unprivileged user access system to do harm	Possible	Possible

Table 1: The STRIDE model: comparing legacy systems with blockchain

application's usability, the faster the stakeholders' acceptance.

4.2. Application Development Methodology

Madenas et al. mentioned that most traditional SC-related studies focus on exchanging engineering data rather than selecting the information type that can be critical and beneficial for the product development phase (Madenas et al., 2014). A five-stage methodology called DMAIC (already mentioned in subsection 2.2) can help to develop a good quality application adhering to the above eight design principles. A prototype should be built to begin with; later, it can be extended to a pilot stage and later to production after the prototype's success. In these transition stages, we must answer most of the questions with the help of DMAIC. Some of the questions can be: *i)* Which features are important? *ii)* How can we collect these feature data? *iii)* How much data do we need? *iv)* Where will the data be stored (on-chain and off-chain)? *v)* What are the relevant data quality checks? *vi)* Who will host the solution? *vii)* Who will have access to the application? *viii)* How much access will a stakeholder have to the solution?

1. During **define** stage, the stakeholders must define how blockchain will improve the functional suitability compared to existing implementation. Understanding the technical know-how of blockchain by the relevant stakeholders is very important. Stakeholders must select a suitable blockchain platform from the existing list, and relevant stakeholders must be aware of SC processes that will benefit from blockchain-ification. Three primary challenges of blockchain-platform selection are data structure types (linear and non-linear), network types, and consensus protocols. There is a trade-off between selecting the permission and permissionless network.

2. In **measure** stage, stakeholders must know how event data should be obtained to support application features. Here, two primary technical challenges are: *Which features are important?* and *how can we collect such feature-rich data?* Proper understanding of the data generation and collection process is essential. IoT devices' technical know-how can help collect and store relevant important event data.

3. In **analyze** stage, the application should be properly analyzed to find the primary reasons why design principles are not met. The situation can differ based on how blockchain has been implemented. The solution can be implemented as a layer on top of existing legacy systems or as a standalone system. Existing open-source blockchain platforms (such as HLF) are not properly tested, while the non-standardization and non-existence of benchmarking complicate the analysis phase. Here, the application code quality should be checked rigorously. Pre-production and post-production support for open-source software from the community is essential for higher success rates of blockchain-based SC solutions.

4. In **improve** stage, the developed solution should be improved or extended for higher functional suitability. Feedback collection from all stakeholders is essential in this stage. Thorough testing can be done with relevant test cases. The availability of third-party software (such as libraries and packages) support is also critical during the improvement process.

5. In **control** stage, features should be verified which are identified during the define stage and monitored whether they are performing well or not for better maintainability. All critical events must be logged so that root causes can be traced in failure, which can also aid in compatibility.

5. Discussion

Almost all popular, expensive products are prone to counterfeiting. Due to the lack of transparency and shortage of raw materials, there is an imminent need to develop a unified blockchain-IoT-based SC framework that supports product provenance, authentication and product recycling while not creating any information silos. In today's competitive world, manufacturers must document product quality, identity, originality, and compliance with standards (such as sustainability) to become more transparent. It can make consumers more informed about their products. Producers also use blockchain to document products and market themselves. Blockchain adds benefits such as transparency, automation, and validation to the SC applications (Blossey et al., 2019) and can also protect a product manufacturer's intellectual property rights by securing product information. We must collect data at the required stages and delegate it to the appropriate stakeholders. However, selecting a suitable blockchain platform for the SC solution is also difficult, and the selection process can be translated as an instance of a multi-criteria decision-making (Farshidi et al., 2020).

Implementing product track-n-trace using permissioned blockchain does not offer any advantage compared to existing technologies. In contrast, permissionless blockchain can provide new functionalities (such as read-write-verify) but in pseudonymous mode (Straubert et al., 2021). There will be no perfect match between the offered features and the required application support. That means application developers can either extend the existing blockchain platform or add third-party libraries or packages to support the application. In the beginning, blockchain platforms (such as HLF and Ethereum) were not stable, which resulted in many applications failing. Besides, technological understanding among SC stakeholders and developers was low (quite an expected scenario). Later, as blockchain started to become popular, the number of features began to increase (but not complete). However, the development stages are long. Moreover, blockchain is not mature enough and requires extensive feasibility studies before implementation (Kamilaris et al., 2019; Wang et al., 2016). Overall, application requirements should be prioritized to identify needs for a blockchain-based collaboration platform (Herm and Janiesch, 2021). However, multiple practical implications exist for a collaboration platform in the SC ecosystem.

Madenas et al. already mentioned a lack of focus in the literature on selecting the information type that can optimize the product development phase (Madenas et al., 2014). The proposed framework based on a five-stage method answers such questions. Not all SC applications will get the same benefits from the framework. DMAIC ensures that the overall solution maintains quality and relevance to the requirements. The success of the solution based on this framework is primarily based on *i)* the know-how of the stakeholders of complete SC application (addressing functional suitability), *ii)* selecting the relevant events (addressing data quality issue), and *iii)* how such event data are collected and submitted (addressing data integrity issue)?

6. Conclusion

In this paper, a generic unified blockchain-IoT framework has been proposed to reduce the information silos. The framework supports three important use cases (such as product trace-n-trace, product authentication, and recycling). The proposed framework can reduce the information silos that existing SC solutions face. Blockchain is not a perfect technology and suffers from interfacing problems, high energy costs, and scalability issues. Thus, selecting an ideal platform is not trivial. It is worth noting that energy consumption can be improved by changing to a simpler consensus protocol and running a permissioned blockchain platform which the companies quite prefer. Seamless information flow also helps to add the recycling feature by adding a few more stakeholders. The proposed framework has been explained together with the design principles which should be applied during the application development phase. The application development methodology has also been discussed to make the solution more acceptable among all stakeholders while listing the essential questions to be answered.

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