A Tracking and Tracing System for Supply Chain

Miguel Palma, ***Instituto Superior Técnico – Lisboa***

Abstract – **Traceability systems can improve the overall operations efficiency and logistics, improve brand reputation, and are resilient against counterfeiting products. However, most traceability systems do not cover the entire supply chain or have systems that only cover the product information. Sometimes this can lead to trust issues between the stakeholders and the consumers.**

On this work, we classify these systems into three levels according to the type of tracked information. Furthermore, we propose a general architecture for tracking and tracing (T&T) systems for a supply chain that contains several applications related to different stakeholders. We will analyse this architecture under the perspectives of security, privacy, transparency, performance, among others.

We focused on the decentralised case, more precisely, using blockchain. Blockchain is the right candidate for different applications and areas because of its features such as immutability, data integrity, and many others. Blockchain brings to supply chain a solution with useful features such as security, auditability, transparency and privacy.

To the best of our knowledge, there is no level three T&T system for a supply chain that covers a wide range of products. All known experiences are strict with a specific type of product. We believe that the absence of a system like this is because of the implementation costs and a lack of confidence of the participants. Besides those obstacles, we think that the big obstacle is to convince all entities to participate in the proposed architecture. Future research suggests a practical implementation and analysis of the proposed architecture.

Keywords: **Traceability; Supply Chain; Blockchain; Architecture Analysis**

I. INTRODUCTION

Most businesses, if not all, have a supply chain. A supply chain involves all the processes and activities from which the material flows, ranging from raw materials to the end-consumer [1]. Traceability systems are an essential component in any supply chain. According to GS1 Global Traceability Standard (GTS) [2], *traceability* is defined as "the ability to trace the history, application, or location of an object. When considering a product or service, traceability can relate to the origin of materials and parts, the processing history, and the distribution and location of the product or service after delivery". These systems identify units of products with the ability to register information about when and where these units were moved or transformed, and they are able to link and transfer all the relevant information about the product to the next stage of the supply chain [3].

Traceability systems bring a set of benefits to the supply chain, such as **(i)** improvements in logistics and overall operations efficiency, **(ii)** brand reputation, and **(iii)** resilience against counterfeiting, tax evasion and others. They meet stakeholder's increasing demands ensuring product authenticity [4].

Nowadays, it is possible to observe a proliferation of these systems with logistic traceability solutions for specific contexts. For example, when someone sends a package using the courier, both the sender and the receiver are able to know the package's location at any given point in time. When a company buys raw materials or distributes a manufactured product, it may want to know who is involved in the transportation and where this product is, and supervise some characteristics of the product. This process gives the company more control over the supply chain, improving production, managing and storage planning, which, in turn, improves efficiency and reduces costs. The increased efficiency and cost reduction can imply a price reduction. Additionally, information transparency is essential to strengthening the relationship between a consumer and the product. Both aspects collaborate to improve brand reputation. Also, traceability systems can improve supply chains' resilience against counterfeiting by significantly reducing the proliferation of counterfeit products.

In this work, we consider three levels for traceability systems. The higher the level, the more complete the traceability system will be. Also, there are several initiatives for implementing traceability systems for supply chains of levels two and three. Nevertheless, all of them address specific solutions [5].

These initiatives and the traceability system levels bring us to the research question: Why there is not any solution for a level three traceability system that can be applied to any supply chain? In this research, we are showing that the technology is mature enough to have such a solution (both for the centralised and for the decentralised case). The centralised case is widely studied and known. We look to better evaluate the decentralised case to see if it is also mature by focusing on blockchain technology. Therefore, we propose a *tracking and tracing* (T&T) system architecture for a supply chain that goes beyond the GS1 solution. The proposed architecture is a justification that we have the needed technology to create a global solution that includes a level three traceability system.

II. RELATED WORK

GS1, a non-profit organisation founded in 1974, with the role of Issuing Agency for unique object identifiers [6], introduced a Global Traceability Standard (GTS) [2] with the aim of assisting organisations and industries in the implementation of traceability systems.

In this paper, we propose a traceability system for a supply chain that can be implemented using blockchain. Blockchain is a distributed ledger technology (DLT) capable of recording transactions in a chain of blocks, well known for its immutability, transparency and data integrity properties, which highlights the security of this technology. Currently, blockchain is being used in many areas and fields such as financial, healthcare, insurance, supply chain and many more. As stated by Singhal et al. [7], developing blockchain applications is only limited by our imagination, which means that more blockchain applications will be created to serve our daily basis in the future.

GS1 [6] has focused on improving traceability in supply chains, has a global solution that enhances the supply chain's visibility with improved traceability and transparency. It is an international identification standard that helps in identifying and authenticating a product in real-time.

There are different known initiatives for implementing different types of traceability systems for supply chains. Nevertheless, all of them address specific solutions: a supply chain for a specific product, or even only part of the chain for a specific product.

Some of these solutions use auto-ID technologies and other IoT tools to measure different properties of the tracked product [5]. As for the blockchain, different authors have been implementing blockchain technology to supply chain traceability systems. For example, Feng Tian [8] applied blockchain technology in an agri-food supply chain traceability system. Besides the implementation of blockchain technology, Venkatesh et al. [9] proposed a system architecture that integrates blockchain, internet-of-things (IoT) and big data analytics for supply chain social sustainability. Casado-Vara [10] proposed a new supply chain model via blockchain, where it explained how blockchain could improve the current supply chain models.

The contributions of this work are inspired by the current GS1 T&T solutions and by the mentioned blockchain supply chain articles. Besides having the same ideology, there are differences between this work and the blockchain supply chain papers. In this work, we implement blockchain technology to enhance the proposed T&T architecture, instead of creating a global solution for every supply chain. Another crucial point that makes this paper different from the others is the proposal of an alternative solution to the entire blockchain solution. We called this solution off-chain supply chain, which uses both the blockchain and centralised system. This solution overcomes obstacles presented by blockchains such as costs, limitation of knowledge, legacy systems, and others.

III. TRACKING AND TRACING SYSTEM

Traceability can be divided into two processes*: tracking* and *tracing*. These two terms with different meanings, but both are important in a supply chain system. *Tracking* is the process where the product details of each production stage are recorded. *Tracing* is the inverse process of tracking, where the history and the responsibilities at different stages of the cycle (ranging from the producer to the client and vice versa) are accompanied.

A. Classifying Traceability System in three levels

In this work, traceability systems are classified into three different levels, where the higher the level, the more complete the traceability system is. A system in the first level is able to identify the product. Product identification is a significant feature, widely used, from factories to retail, but it is not broad enough to cover the entire supply chain [11]. An example is the barcode containing an identification of the product, where this identification is unique per product batch. It could also be achieved using RFID, simplifying the product identification process. Another example would be identifying the product in different stages of the supply chain only by reading the barcode attached in the product. Many distributor companies do this type of traceability.

The second level adds to product identification a track of the product flow over the supply chain. This track consists of the geographical position or the entity that holds the product at a specific time. This additional feature could be achieved, for example, by technology like GPS, plugged in the product. Another option is to add an RFID in the product, which is automatically scanned by a geographically referenced system, for example, if this system runs in a transportation truck [11]. This track has a broad application in the supply chain and allows tracing the nodes where the product flows, leading to better security against counterfeit products in the supply chain.

The third level is the most complete. It allows tracing of product materials properties or any other product features (besides identification and position) along the supply chain. This level extends the control and transparency of the traceability system, which can be beneficial, for example, in an agri-food and health systems. To reach this goal, IoT technologies can be a handy tool. For example, smart IoT sensors can gather information about the products in real-time [12].

Nowadays, it is considered necessary for global manufacturing companies to monitor and manage logistics and supply chain networks. The monitoring is related to tracking and tracing the logistics and delivery network, which is considered one of the motivating factors to build trust among manufacturers, suppliers, potential customers, and customer satisfaction.

B. The Trust Chain

There are several examples of T&T systems for supply chains in all three levels [11], [12]. However, there is no universal system that contains wide traceability of the products (the third level of traceability). The higher the traceability level, the smaller the supply chain.

Nevertheless, if we evaluate the technological scenario, it seems we have everything necessary: IoT tools to acquire data, cybersecurity for safe data transmission, storage and processing power to handle the business rules, and the software engineering knowledge to design these systems. So, it raises the question: why do not we have a level three traceability supply chain system? A deep investigation of this question is out the scope of this research. However, we will state a hypothesis: this system does not exist due to a lack of trust between the stakeholders of all different markets (since it does not seem to be a technological issue).

In this direction, we can post a second question: how can we build this trust? We see two main directions: a managerial and a technological. The first one is out of this work scope, but we can exemplify the GS1 work in the past to convince countries and industry to adopt the barcode product identification. On this work, we will focus on the second one.

We will present an architecture for a level-three traceability system for a supply chain. We will also analyse this system components from the security, auditability, privacy, transparency, scalability, and performance perspectives. Furthermore, a traceability system enhances the knowledge of all the flow, allowing the stakeholders to improve their production planning, the final consumers to have a better knowledge about the tracked products, decrease the counterfeiting, and more. These facts enhance the trust in the system and goodwill to adopt it (which helps the managerial task).

C. Traceability Flow in Supply Chain

Figure 1 shows an example of a product flow in a T&T system. Afterwards, the product flows through *n* distribution entities, and each one updates the information until it reaches the end-customer [13].

This product flow can be aggregated into multiple product flows, where each one represents an interaction between two main entities (Figure 2). A product flow could start from a supplier and end in the producer, where the producer is the end-customer because it receives the raw materials to manufacture the product. Another product flow would start from the producer and end in the consumer, where retail stores would act as an intermediary of the product flow. On multiple product flows, the traceability information goes from the supplier to the consumer. It is essential to mention that there is an absence of a broad traceability system like the one presented. However, as mentioned earlier, there are already partial solutions capable of reaching some extent [11], [12]. It may be desirable the proposal of a broad solution capable of being integrated into these partial solutions.

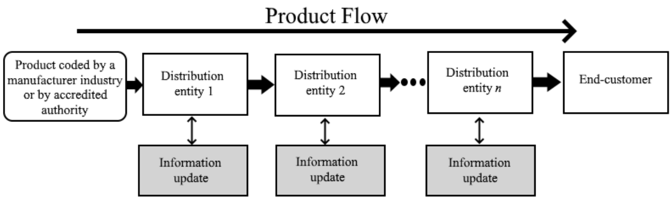

Figure 1 - Product flow in a supply chain [13]

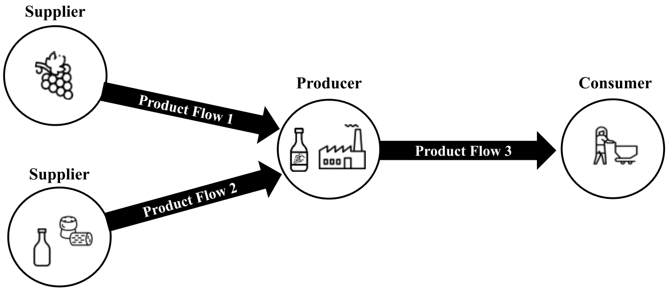

Figure 2 - Multiple products flow across the supply chain

D. Auto-ID Technologies and their applications

Auto-ID technologies are technologies that provide all the available solutions for tracing and tracking the logistics network. This type of technology enhances the management and control of products, making life easier for logistic services [14]. There are various auto-ID technologies for tracking and tracing such as the Bar Code, Quick Response Code (QR Code), Radio Frequency Identification (RFID), Radio Frequency Data Capture (RFDC), Real-Time Location Systems (RTLS), and Global Positioning System (GPS) [14].

Each auto-ID technology has its features, and in Table 1 we compare all the technologies mentioned above against the following a set of features.

- *Line of sight* relates to how technology can read or scan a product;
- *Reading work* indicates whether the reading or scanning is performed manually by the user, or whether it is automatic, without the user's intervention;
- *Ambient lighting arrangement* evaluates the need for light in the area to read or scan;
- *Durability* describes how resistant to adversary conditions or harsh environments the technology is;
- *Ability to store information* refers to whether it is only possible to read information about the product, or if it is possible to read and write;
- *Cost* of each technology is compared descriptively but without a specific value;
- Each technology's *security* is vital feature, and it is evaluated by comparison with other technologies;
- The last feature compared in the table is *device support*, which describes which devices support the mentioned technology.

From Table 1, it is possible to observe that each technology has its advantages and disadvantages. When using these technologies, it is possible to use more than one at a time, but this solution comes with higher costs. Organisations might choose one or more technologies that can be combined for better quality and efficiency of the T&T system.

In terms of applications, the auto-ID technologies share in common the tracking and tracing of assets in a business environment. However, each one of them may differ in terms of applicability in a real-world context.

Barcode technology finds applications in inventory control, production control and monitoring attendance [15]. The QR Code was created for tracking items and is used in many areas such as retailing, healthcare, transportation, and manufacturing. It has also been applied in other fields such as electronic payment, tampering detection, electronic ticket, coupon, and many others [16]. RFID is used for assets management to determine an item's presence. The RFDC is used in tracking commercial goods, although there is a lack of bibliography around this type of technology [14]. An application of RTLS is the use of this technology to monitor material flow, providing a view of weak spots in production processes. For example, it can be used to determine the cause of production delays [17]. Lastly, GPS technology has become more of a consumer product [14]. GPS can be used to evaluate road traffic congestion, for terrorism where it can be possible to determine a terrorist attacker's location, and for tourism where it is possible to gather points of interest based on a location instance. [18].

E. T&T Use Cases

Before presenting the proposed solution, it is essential to mention two different use cases for comparison with the proposed solution. The first use case includes a supply chain with one central entity responsible for the T&T system, and the second use case is based on multiple entities responsible for the T&T system. Both use cases can be either a centralised or decentralised system. However, the second use case is more achievable in a decentralised case scenario due to increasing trust on this approach. In both use cases, there is a set of supply chain entities. Those entities can be summarised as a supplier, distributor, producer, retailer, and consumer.

The supplier is responsible for providing raw materials to the producer. The producer acquires the raw materials from the supplier, uses the raw materials to produce the product, and sells it to the retailers. The distributor is the middle man of transferring goods between the seller and the buyer. The retailer purchases a batch of products and sells directly to the consumer in the retail. For last, the consumer buys and uses the product.

Case one is based on a central entity is responsible for the T&T system. As an example, Figure 3 shows a wine supply chain, where the producer is the central entity responsible for the supply chain system. The producer is a trusted entity in the system, which means that it can make decisions considering all the business entities that are participating in the supply chain [19]. Therefore, this entity can assure the other network participants that this solution is reliable, whether this solution is centralised or decentralised. This central entity plays a vital role in the management of this network.

As for case two, Figure 4 presents a juice supply chain example. There are multiple producers on this case, where each producer is treated as a separate business unit. Each producer makes their own decisions focusing on their own business, working locally and independently, increasing local control, and increasing local appearance [19].

In this way, the task of bringing all network participants to a unified solution is much more complex. A decentralised and highly reliable system would benefit the managers of each entity to embark on the solution.

In both use cases, it is possible to observe different product flows. A traceability system should be able to cover the whole supply chain, more precisely, it should cover all the product flows of the supply chain.

Table 1 - Adapted Table with comparative analysis of different T&T technologies [20]

Features	Barcode	QR Code	RFID	RFDC	RTLS	GPS
Line of sight	The scanner must physically see to scan the bar	The scanner must physically see to scan the bar [21]	Can only be used within the read range	Can only be used within the read range [14]	Can only be used within the read range [14]	Long read range
Reading work	Manual	Manual [21]	Automatic	Automatic [14]	Automatic [14]	Automatic
Ambient lighting arrangement	Works well in well-lit areas	Works well in well-lit areas [21]	No ambient lighting needed	No ambient lighting needed [14]	No ambient lighting needed [14]	No ambient lighting needed
Durability	Easily scratched and not readable if dirty, greasy, or wet	Damaged tags may work, 30% data recoverable [21]	Better protection and can withstand harsh environments	Depends if used with bar code or with RFID [14]	Adequate protection in general [14]	Can be kept inside a strong container
Ability to store information	Read-only	Read-only [21]	Read and writing tag	Read-only [14]	Read-only [14]	N/A
Cost	Cheaper than RFID	Cheaper than RFID, but higher than Barcode [21], [22]	Cheaper than GPS	Expensive	Inexpensive [14]	Most expensive option
Security	Highly secure	More secure than Bar Code [23]	Possible security risks due to wireless connections	Possible security risks due to wireless connections [14]	Possible security risks due to wireless connections [14]	Secure
Device support	Easy to support bar code in any camera-enabled-mobile	Any application that reads QR Code or the mobile phone camera [21]	Extra hardware needed	Extra hardware needed, such as a computer [14]	Extra hardware needed [14]	Supported by mobile devices

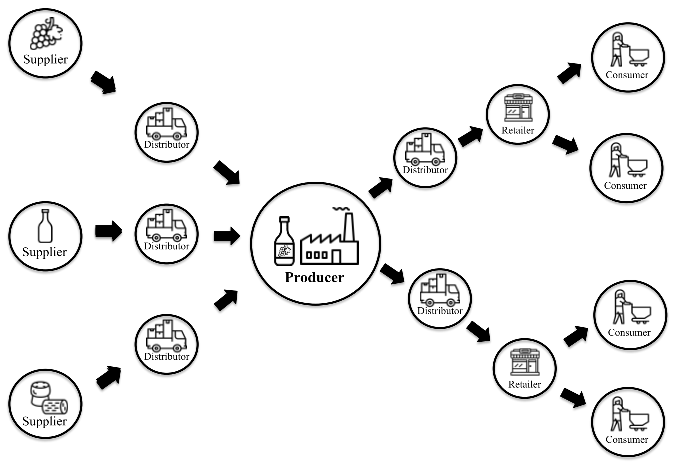

Figure 3 - Central entity supply chain example

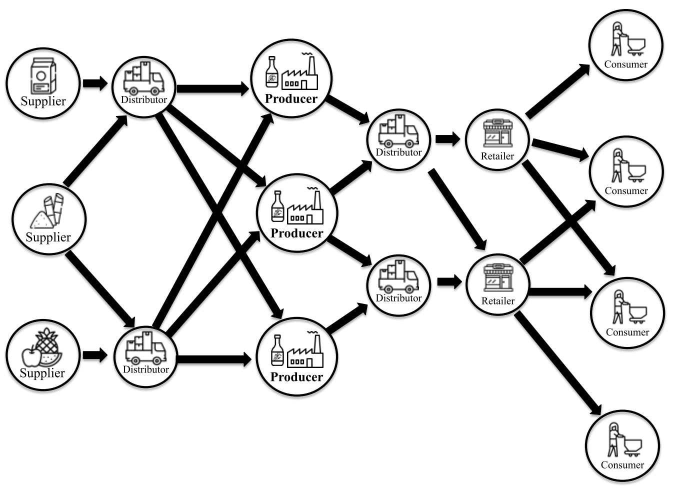

Figure 4 - Multiple entities in the supply chain example

IV. T&T ARCHITECTURE PROPOSAL

On this section, we will introduce a Tracking and Tracing architecture that can be used mostly for a supply chain system on levels two and three (level one can be implemented without connecting parts).

A. *Proposed T&T Architecture*

The proposed architecture is composed of two main elements: the kernel and the applications. The kernel processes the business rules and stores the system information, and the applications are responsible for acquiring data and displaying information. The data captured by the different applications are sent to the kernel that will process them and eventually return a response. Also, the applications are used as an entry to consult the stored data. It is considered as an integral part of the kernel the activities intrinsically related to the traceability of the product and its properties. Secondary tasks such as the inference of properties, specific transactions to stakeholders that do not need to be shared with other nodes, functionalities to improve the usability of applications, and many others, will be considered as integral parts of the applications. This work will not detail these features as they can be quite different from case to case. We will focus on what is seen as a common part of any traceability system for a supply chain. In the proposed architecture, the application nodes can communicate with the T&T kernel through four primary operations:

- **Node setup**: All the participating entities require the node setup to invoke transactions. This step is only required if the participating entity is not already enrolled in the T&T kernel.
- **Notification**: In notification, the entity gives information about the current state of the product.
- **Registration**: In registration, the raw product or the product is registered on the transaction. It is described details such as the ID of the product/s, the temperature where the material is stored, the date and time of the product creation, and other details. These details are different depending on the supply chain and depending on the supply chain stage.

- **Consultance**: This is a generic and a customised event, where the nodes can retrieve specific information from the T&T kernel through an API in the node application.

The four mentioned operations were proposed based on the European Commission Business Innovation Observatory case study [24], and also on what we think a T&T system must have to assure a level three traceability system. The number of operations proposed on this work is not limited to these four. There is the possibility to add more operations based on the business needs.

Figure 5 illustrates all the operations between the application node and the T&T kernel in the architecture.

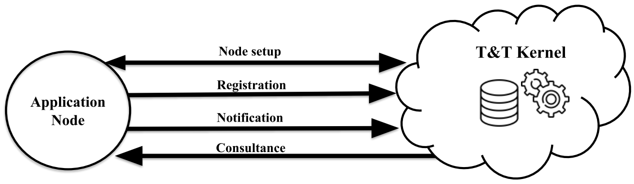

Figure 5 - Operations between the application node and T&T kernel in the proposed T&T architecture

Besides the operations between the application node and the T&T kernel, the proposed T&T architecture will have four main components. These four components are part of the T&T kernel: business model rules, database, network and user authentication system.

Business Rules Model is an essential component of the T&T kernel. The business rules model is responsible for shaping a business's behaviour and guide the behaviour of the business's employees. The business rules explain what is and not allowed, and it explains the consequences of violation. With this model, it is possible to achieve communication, training and learning, managing compliance, software requirements, direct execution and knowledge management [25].

Another component of the T&T kernel is the database. A database is an organised collection of information that a user can access through an API in a computer system.

The network is another component in the architecture that allows the communication between the application node and the T&T kernel. Also, it contains a gateway, which has a set of policies related to the user's authentication and management.

For last, we have the user authentication system, responsible for the verification and confirmation of the user's authenticity.

B. Application nodes: A use case

After explaining the different operations of node applications with the T&T kernel, it is important to give some examples of each entity operations with the T&T kernel. Figure 6 illustrates an example of the proposed T&T architecture. It contains different node applications connected to the T&T kernel.

The supplier application has a node setup, registration, and notification interaction with the T&T kernel. In terms of traceability, the supplier should register the raw material source, where each raw material has a unique code. It should also notify when the raw material departs to the producer, explaining the quantity of raw material dispatched, the distributor responsible for the transportation, and other details.

The registration and notification details should be followed according to the business rules model.

The distributor application has a node setup and notification interaction with the T&T kernel. The role of the distributor is to update the direction of the product flow continuously. In notification, the transaction will contain different types of information related to product transportation, such as the location of the product at different dates and times tracked by a GPS, for example, the temperature where the products are stored and other types of information.

The producer application has a node setup, notification, registration, and consultance interaction with the T&T kernel. The producer is responsible for encapsulating the product information and register it into the system. Each product should have a unique code according to the chosen international coding standard. The producer can notify when the raw material is received or when the product is dispatched to the retail. Also, the producer can consult any details about the current transaction or from previous transactions.

The retailer application has the same interactions as the producer application, but different responsibilities. It is important to refer that the retailer in consultance may have different privileges than the producer. For example, the retailer could only access the details about the transaction made with the producer, which means that the retailer cannot access the details between the producer and the supplier.

The consumer application has only one interaction with the T&T kernel, which is consultance. The consumer can choose to participate in the network, which allows the consultance of the bought product, more precisely, the consumer would get details of the product from the supplier to the retail.

Besides explaining the operations between the application nodes and the T&T kernel, it is also essential to explain how the different T&T architecture components can be implemented in a centralised and decentralised system.

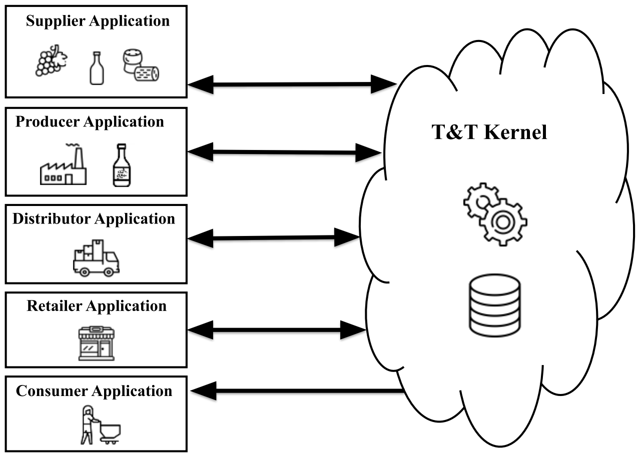

Figure 6 - Example of proposed T&T system architecture

C. Centralised and Decentralised Architectures

On a centralised architecture, there is a central entity that obtain and store all the data in a single location, and make all the decisions individually (Figure 7).

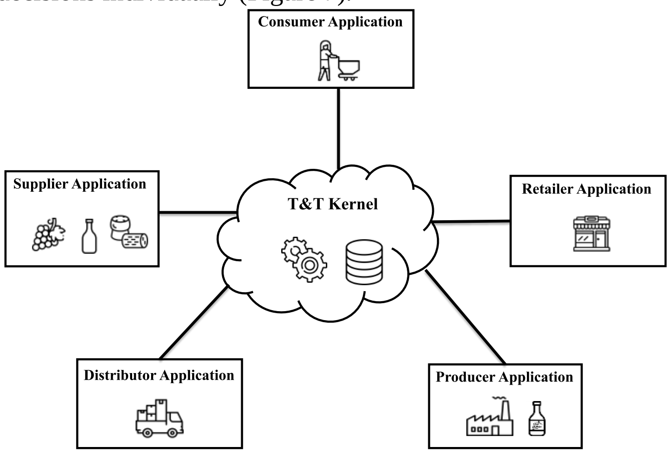

Figure 7 - Centralised T&T architecture

On a decentralised architecture, there is no central database, instead, the data is distributed through a set of nodes and stored in a ledger as shown in Figure 8. Each node is capable of interacting with other nodes through a gateway. Also, the nodes can interact with the kernel (that is distributed over the applications), either by receiving a transaction to store in the ledger or to submit a transaction to the kernel.

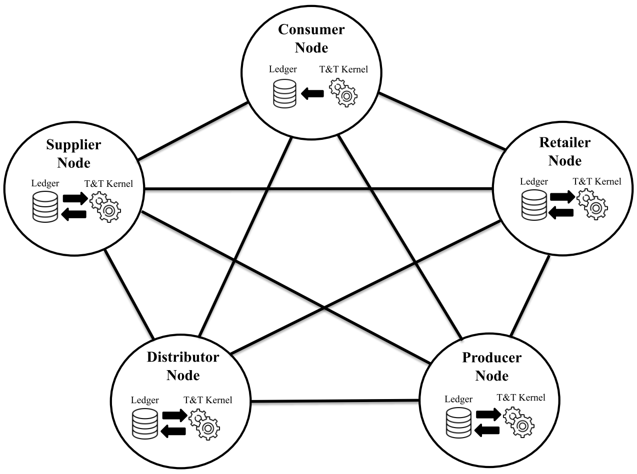

Figure 8 - Decentralised T&T architecture

D. Comparing Centralised and Decentralised Systems

Both centralised and decentralised system have been used in business processes for the last century. From a business perspective, in a decentralised system, the business can make the decisions locally by using the local resources with the condition that the decision is reported to the management in a specified way. The centralised system is the opposite of decentralised system, where all the business processes and decisions are controlled only by a central authority [26].

It is essential to know each system's advantages and disadvantages to understand that centralisation and decentralisation can be useful in different situations. We will compare in both systems the databases, and the application in a supply chain environment.

In a centralised system, there is a centralised database in it. In terms of advantages, the storage cost is small and there is a low redundancy. Also, there is a high-level security and it is cost-effective solution. As for disadvantages, the communication costs are high, it can have bottlenecks, and there is a lack of transparency [27]. When implementing a centralised system in a supply chain, in terms of benefits, there is a better alignment with the overall supply chain objectives, the overall supply chain efficacy is improved, and there is a lower network. Also, there are more transparent patterns along the supply chain, and an increased delivery performance However, in terms of disadvantages, there is a low degree of knowledge sharing, there is a lack of adaptability, and the latency of a centralised system is higher when comparing to decentralised systems [28].

As for the databases in decentralised systems, in terms of advantages, it has an increased reliability and availability. In distributed databases, there is more local control, fast response, transparency and an improved performance and parallelism when executing processes. In terms of disadvantages, the practical and design implementation are complex and costly, and the data shared between the participants are vulnerable to attacks [27]. As for a decentralised system in a supply chain, there is a speeding up in lead times, more proximity between the parties involved, improved flexibility and responsiveness and a decrease in inventory levels due to a production based on predictions [29].

V. BLOCKCHAIN SUPPLY CHAIN

In this section, we will discuss the implementation of blockchain in the proposed T&T architecture.

We have chosen permissioned blockchain since it has the same traceability of digital assets, the same distributed, resilient, and redundant data storage system as a public blockchain. Also, this type of blockchain is more used in organisations to control and protect the blockchain or when organisations do not fully trust each other. Besides the type of blockchain, it was chosen as a blockchain framework the Hyperledger Fabric since it has some functionalities and features useful for a supply chain scenario. For example, the transactions applied to the architecture should be confidential only between the exchanging parties using a private channel.

A. Blockchain Architecture Components

As for the blockchain components in the proposed architecture, the T&T Kernel has three identical components: Business Rules Model, Database and User Authentication System. The only different component is the blockchain network.

The Business Rules Model is composed of smart contract and consensus protocol. These two components are responsible for ensuring the correct behaviour of the blockchain. They also have implemented behaviours for the traceability system. The smart contracts contain the logic of the transaction, where assets are created and update and are responsible for carrying out transactions between two entities. It is important to mention that the smart contract must have ownership. Smart contracts without ownership can lead to security issues in enterprise blockchains. For the proposed blockchain architecture the smart contracts will have shared custody ownership where the two entities involved in the agreement are responsible for the administrative actions over the contract. The consensus protocol plays a significant role in validating the transactions inside a block, allowing a block to be or not published on the blockchain [30].

The blockchain network has multiple components such as ledger, peer nodes, ordering service, channel and gateway [31]. The ledger contains the transaction data from a specific set of blocks or all the blocks published on the blockchain. The peer hosts instances of ledgers and smart contracts and interacts with the node application to access those resources. The ordering service is formed by a set of orderer nodes and is responsible for validating transactions within the block. The channel is where private communications occur between two or more network members to ensure that the information exchanged is private and confidential. For last, the gateway manages the network interaction on behalf of the node application. It has a set of policies related to the user's authentication and management in the system.

In terms of database, blockchain has distributed ledgers, which means that all the information is stored and located in different network nodes. Besides the distributed ledgers, blockchain also has a database called state database. The state database contains the ledger's current state data, which means that it is available the latest key values known to the channel. When a smart contract is invoked, it executed the transaction against the current state data, making the smart contract interactions efficient during the transaction process [32].

The User Authentication System comprises a membership service provider (MSP) and a certificate authority (CA), where both components are responsible for the user's authenticity in the blockchain. The MSP is responsible for verifying a blockchain participant's identity to allow the participant to transact on the network and contains the peer's public key transmitted by a CA to verify that the transaction's signature is valid, thus validating the member's identity. The CA plays a significant role in the user authentication system since it issues X.509 digital certificates for the participating organisations. Organisations can use digital certificates to sign transactions, indicating that the organisation is endorsing the transaction. CA works together with the MSP, where the MSP is responsible for mapping the certificates to member organisations.

Besides those components, there is also outside of the blockchain the application node, which is responsible for interacting with the blockchain network and can invoke smart contracts to submit a transaction to a ledger or querying ledger content.

After explaining all the components in the blockchain architecture, it is still important to demonstrate how these components interact with each other and how they are disposed in the architecture. Figure 9 shows an example of the interactions that the different blockchain components can have.

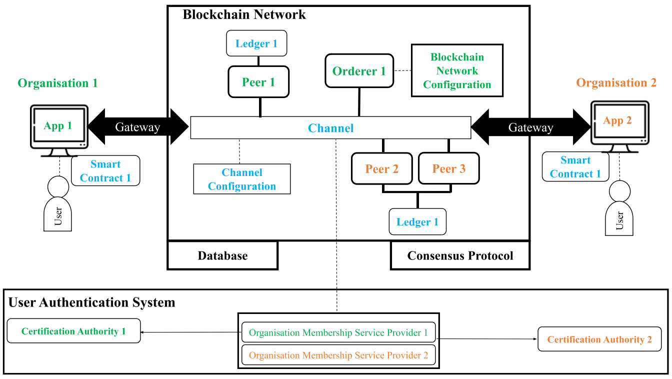

Figure 9 - Example of interactions between the different blockchain architecture components

It is important to refer that the architecture can be very different in each supply chain. Each organisation must have at least one peer with the option to include more peers. Peers from different organisations may have the same or different smart contracts and ledgers. For example, imagine that we have three organisations: a supplier, producer and retail.

The supplier and the producer have one peer with a ledger one, which are both related to the transactions between the supplier and producer. However, the producer can have a peer that is connected to a different channel with smart contract two and ledger two, which are related to the transactions between the producer and the retail. This example should give an idea that one organisation may have multiple peers with different functions connected to different channels. There is also the orderer in the blockchain network, which may be one (usually controlled by the organisation that deployed the blockchain) or more. Each organisation has one application node capable of connecting to one or more peers in the network. As for the user authentication system, it is possible to have also different scenarios.

In the entire architecture, it is possible to have only one CA responsible for the digital certificates of all the participating entities or each entity can have their own CA. For each CA, there will be one membership service provider for that organisation.

B. *Integration of T&T Technologies in Blockchain Smart Contracts*

A combination of T&T technologies (auto-ID technologies) can be used in supply chains. For example, the usage of RFID with GPS tracker, where both can cover different parts of the supply chain network with a QR Code attached to the product [11], [33]. The combination of different auto-ID technologies is essential for a level three traceability system since those technologies are responsible for the trace of the whole supply chain system.

Blockchain can have multiple smart contracts for different purposes. For example, different node applications can use different IoT devices to trigger different smart contracts. As an example of the integration of T&T technologies in blockchain smart contracts, when the seller is sending the goods to the buyer, a distributor entity is responsible for the goods transportation. In this transportation phase, it is activated a smart contract that records a set of values related to the temperature and the goods location during transportation. A temperature sensor technology can measure the temperature alongside a particular smart contract called Oracle that receives and relay information about the outside world. An oracle is used in this case because the smart contracts cannot interact with any application programming interface (API) outside of the blockchain network for security reasons [34]. In the same contract, it can be used a GPS responsible for giving the coordinates of the goods. It is essential to mention that the smart contract can end at any time if any rule is violated in the state of the contract. The contract state can be bad if the distributed goods location is wrong or if the temperature of the stored goods was much higher or lower than the defined in the contract. If the contract is in a bad state, the transaction is cancelled.

There are other types of smart contracts that can be activated during the proposed architecture operations. For example, in the registration operation, a product registration smart contract is either activated by the supplier for the raw material registration or by the producer for the product registration.

C. *Integration of T&T Technologies in the Blockchain Supply Chain*

Figure 10 demonstrates how the blockchain and T&T technologies are integrated into the proposed Blockchain Supply Chain architecture and their interaction with the other architecture components. It shows the supply chain from the supplier to the consumer.

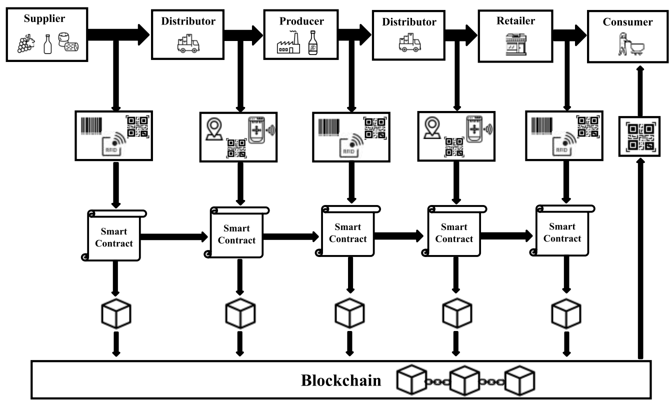

Figure 10 - Proposed T&T architecture with the implementation of blockchain and T&T technologies

There is an interaction of the T&T technologies between each participant, where different T&T technologies are used depending on the supply chain stage. These T&T technologies collect information about the raw products or the product, where this information is posteriorly stored in a smart contract. As for the supplier, producer, and retailer, the T&T technologies used are either a barcode or an RFID with a QR Code. For example, barcode and RFID can be used mainly to track and trace the inventory of raw materials or products. On the QR Code, it can be inserted information about the raw product or product conditions. The distributor, for example, can use T&T technologies such as GPS, temperature sensors, and QR Code. Only the essential data about GPS coordinates and the temperature which the raw material or product was transported will be inserted on the QR Code. For last, the consumer can use its smartphone with a QR Code reader application to see all the product details. The QR Code contains a link for the correspondent block, where that block should contain the same information as written in the QR Code. If the information is different, the sold product is counterfeit, or there was an error during the insertion of data in the QR Code.

The information collected by the T&T technologies is inserted into the smart contract. The smart contract executes a transaction containing all the information collected to publish a block in the blockchain. It is essential to mention that the smart contract information is carried over to the next smart contract along the supply chain cycle, where only the essential information will be put in a block.

D. *Off-Chain Supply Chain: An alternative solution for the Application Nodes*

It is necessary to make several different systems to communicate with each other to implement a level three T&T system. For example, a food supply chain could demand different applications for the farmers, drivers of distributors, distribution warehouses, producer warehouses, production line, package suppliers, retailer, and the final consumer. For several reasons (costs, limitation of knowledge, legacy systems, etc.) can be a management challenge to implement some of these applications using blockchain technology. Even though the proposed architecture can be used in this scenario, but with an adjustment. In this section, we will propose an extension of application nodes to be part of the blockchain supply chain. For this extension, we call it off-chain supply chain because the transactions can occur either inside and outside of the blockchain. The application nodes will centralise the communication of a group of applications. It receives all the generated data and processes them through smart contracts. Figure 11 shows how this alternative solution is implemented in the proposed T&T architecture.

The applications of farmers and truck drive act like a child application (child of application node). They produce the data independently from the blockchain (can be a legacy system) and send it to the application node (responsible for main storage). The main database is managed by the application node (e.g. Raw Supplies Entity or Distributor Entity). Posteriorly, during a transaction, the application node must provide the information stored in the database to store it in the blockchain ledger.

It is essential to highlight that the components outside of blockchain lose some important features such as integrity and immutability of data described for the kernel. It loses both features because the children application writes the data first in a database before its commitment to the ledger. There are no guarantees that the data stored in the database is tampered or modified during this process.

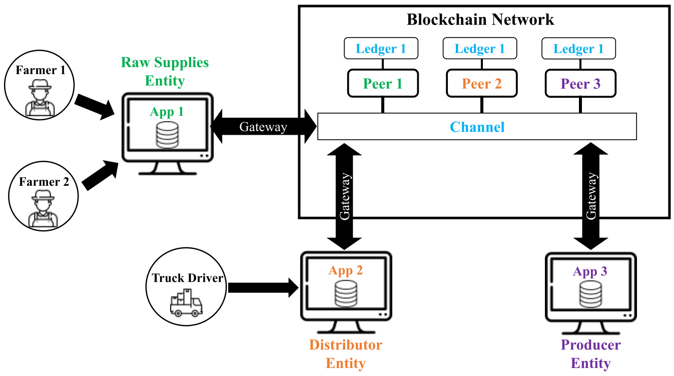

Figure 11 – Off-Chain T&T architecture

VI. SECURITY IN T&T SYSTEMS FOR SUPPLY CHAIN

Security is a fundamental key that every digital system must have and is natively approached by blockchains. Over the years, the blockchain has been widely used for different purposes (cryptocurrency, healthcare, insurance, asset management), and with this increased usage, various types of attacks have emerged. The reality is that blockchain technology is still a new topic, and the tendency is that more organisations will use blockchain to solve or improve some of the organisation's needs.

A. *Cryptography and Digital Certificates*

There are two elements that can be implemented in a centralised system and that are natively implemented in blockchain, which are: asymmetric-key cryptography and digital certificates.

Cryptography can be described as a set of principles and techniques used to secure the information and communications. It is possible to achieve the most important components in security with cryptography such as confidentiality, integrity, authenticity, and non-repudiation. To achieve those, we can use cryptography in different flavours, such as symmetric-key cryptography, asymmetric-key cryptography, and hash functions [35].

A digital certificate, also called a public-key certificate, is an electronic document that identifies an entity (an individual, a server, a company, or another entity) and associates that identity to a public key. Digital certificates are issued by certificate authorities (CA), and it contains a unique feature called digital signature. This digital signature addresses the problem of impersonation [36]. The digital certificate will enhance the communication's security by assuring the authentication of the entities on the network, assuring the confidentiality and integrity of any message transmitted.

B. *Security Concerns Towards Quantum Computing*

Some authors are worried about the impacts of quantum computing on blockchain security. Multiple reports are stating and measuring the real impacts of quantum computers in the current blockchains. The real concerns are focused on the cryptographic features, where the practical quantum computer systems could weaken or even break some of the existing cryptographic algorithms. Based on a NIST report [37], quantum computing could impact seven types of cryptographic algorithms: AES, SHA-2, SHA-3, RSA, ECDSA, ECDH, and DSA. As for the Elliptic Curve Cryptography (ECDSA and ECDH) and Finite Field Cryptography (DSA), these algorithms are no longer secure.

Most blockchains use Elliptic Curve Cryptography for signatures and key exchange in the network. So, the authenticity of each blockchain node can no longer be assured. Since this type of cryptographic algorithm is no longer secure with quantum computing, there is a need to replace such an algorithm if quantum computing becomes a reality.

VII. THEORETICAL ANALYSIS OF BLOCKCHAIN SUPPLY CHAIN

This chapter discusses the Blockchain Supply Chain architecture properties, such as privacy, data consistency, auditability, transparency, scalability, and performance. Each one of these properties is analysed in a theoretical way, and we will discuss some trade-offs that exist between these properties.

A. Privacy, Transparency and Data Consistency

Privacy is a desired property since it is responsible for assuring that sensitive information is exchanged only between the authorised entities.

There is a trade-off between privacy and data consistency. Data consistency is achieved by sharing the data between all nodes. Since the data is exposed to all nodes, privacy can be an issue for blockchain. However, privacy was not neglected by blockchain technological solutions. For example, Hyperledger Fabric framework has addressed this subject.

There is another trade-off between privacy and transparency. The higher the transparency, the lower the privacy, and vice-versa [38]. This trade-off can be seen as a challenge for current T&T systems and in some blockchain systems. There is a dilemma around this topic since, in blockchain, it can either be assured full or partial transparency. It depends whether the information is disclosed publicly or if it is disclosed only to all the participant entities in the network.

B. Auditability

In the proposed architecture, the blockchain has natively implemented an audit capability. In the blockchain, the data about the transactions are available to audit at any time. This transaction data is immutable, which means that no one can modify the data. Also, the transaction data is private only for the peers of a specific channel.

This audit capability on the proposed architecture can be achieved in different ways. The first one is that the organisations could share the certificates with the auditor, allowing him to access their peer nodes and posteriorly query the ledger history on that peer channel. The second option is an auditor that maintains a peer node on each channel or a peer node with access to all channels with the condition that the auditor peer(s) cannot act as an endorser for smart contract transactions. The third and last option would be in the audit time, the auditor could join as a peer in the channel to receive all the transaction data, and once the audit is done, the auditor is removed from the channel. From the three options, the one that gives more privacy is the third one since the auditor can only access the transactions data during the audit. In contrast, in the other options, the auditor can have access at any time, leading to privacy issues.

C. Scalability and Performance

It is essential to discuss scalability and performance because they are correlated. Poor scalability can result in poor system performance [39]. The analysis of scalability and performance is based on the Hyperledger Fabric framework since this is the framework used in the proposed blockchain architecture.

The Fabric framework was designed to increase scalability in the blockchain. For example, the blockchain transactions are executed in parallel by the endorsers, which increases the performance. This framework uses channels responsible for splitting the blockchain into many private blockchains, thus increasing the system's scalability. Considering the different blockchain types and their scalability, Hyperledger Fabric sacrifices some decentralisation to improve the scalability and performance compared to other blockchains. However, there are scalability and performance constraints in Fabric related to the block size and endorser scaling.

VIII. CONCLUSION

In this work, we have discussed a traceability system for a supply chain, with an emphasis on a possible specific implementation using blockchain. We have built a traceability concept (at three levels) and discussed some concrete examples that exist for each level. We also have demonstrated a general architecture for implementing a traceability system for a supply chain of level three (the most complete) to maximise the confidence of the stakeholders involved in the process. This confidence can be improved thanks to the attention in the aspects of data quality (wide traceability), security, auditability, privacy, transparency, scalability, and performance.

The choice to further analyse the use of blockchain in a decentralised implementation of the T&T architecture is because this technology presents excellent results in topics such as security, auditability, privacy, without having signs of seriously compromising issues such as transparency, scalability and performance. Also, blockchain features such as immutability, data integrity, persistency, and consistency makes it a good candidate for areas besides supply chain.

Also, broad traceability (level three) can be achieved by adding auto-ID and IoT technologies to application nodes (in applications linked to application nodes). These technologies can help gather information about the product along the entire supply chain, from the raw products to the end consumer.

A level three traceability system for a supply chain network brings numerous benefits to everyone involved. It expands access to data, bringing more engagement and confidence from the end consumers. It allows improvements in management since processes can be better understood, and predictions can be made in certain cases. It reduces the costs thanks to better flow control, and for last, it ensures a safer system, with less fraud and counterfeiting, due to the traceability of parts in this chain.

In this direction, we have proposed a conceptual system, which means that it was not implemented throughout this paper. Currently, we do not know any system as complete as this one in use, and therefore, implementing it would be a challenge beyond the scope of this paper. However, we still believe that the analysis conceptualises well the components of a level three traceability system for a supply chain, as well as discusses the trade-offs of the theoretical aspects.

We believe that the absence of a system like this is due to the difficulty of convincing the diverse stakeholders in a supply chain network to adopt such a system due to costs (for implementation or adaptation of existing systems, training of operator, and eventual changes in operation) and lack of confidence of the participants (in the system or other stakeholders in the chain). In other words, the greatest difficulty for the existence of such a system is, in our view, is more a question of management rather than a technological one.

Future research should focus on the practical implementation of the proposed architecture and, posteriorly, an analysis of the practical implementation in a real-world context.

IX. REFERENCES

[1] P. Costa, “Supply Chain Management with Blockchain Technologies,” University of Porto, 2018.

[2] GS1, “GS1’s framework for the design of interoperable traceability systems for supply chains,” *GS1 Global Traceability Standard*, 2017. [Online]. Available: https://www.gs1.org/sites/default/files/docs/traceability/GS1_Global_Traceability_Standard_i2.pdf. [Accessed: 20-Jul-2020].

[3] E. Kok *et al.*, “Traceability,” in *Chemical Analysis of Food: Techniques and Applications*, Elsevier Inc., 2012, pp. 465–498.

[4] J. Duan, C. Zhang, Y. Gong, S. Brown, and Z. Li, “A content-analysis based literature review in blockchain adoption within food supply chain,” *Int. J. Environ. Res. Public Health*, vol. 17, no. 5, pp. 1–17, 2020.

[5] K. M. Karlsen and P. Olsen, “Problems and Implementation Hurdles in Food Traceability,” in *Advances in Food Traceability Techniques and Technologies*, Elsevier Ltd, 2016, pp. 35–46.

[6] GS1, “The need for global standards and solutions to combat counterfeiting,” *White Paper*, 2013. [Online]. Available: https://www.gs1.org/docs/GS1_Anti-Counterfeiting_White_Paper.pdf. [Accessed: 28-Jul-2020].

[7] B. Singhal, G. Dhameja, and P. S. Panda, *Beginning Blockchain : A Beginner’s Guide to Building Blockchain Solutions*. Apress, 2018.

[8] F. Tian, “An agri-food supply chain traceability system for China based on RFID & blockchain technology,” in *13th International Conference on Service Systems and Service Management*, 2016.

[9] V. G. Venkatesh, K. Kang, B. Wang, R. Y. Zhong, and A. Zhang, “System architecture for blockchain based transparency of supply chain social sustainability,” *Robot. Comput. Integr. Manuf.*, vol. 63, pp. 1–9, 2020.

[10] R. Casado-Vara, J. Prieto, F. De La Prieta, and J. M. Corchado, “How blockchain improves the supply chain: Case study alimentary supply chain,” *Procedia Comput. Sci.*, vol. 134, pp. 393–398, 2018.

[11] A. Shamsuzzoha, M. Ehrs, R. Addo-Tengkorang, and P. Helo, “Tracking and Tracing of Global Supply Chain Network: Case Study from a Finnish Company,” in *17th International Conference on Enterprise Information Systems*, 2015, pp. 46–53.

[12] S. Aich, S. Chakraborty, M. Sain, H. I. Lee, and H. C. Kim, “A Review on Benefits of IoT Integrated Blockchain based Supply Chain Management Implementations across Different Sectors with Case Study,” in *International Conference on Advanced Communication Technology (ICACT)*, 2019, pp. 138–141.

[13] A. Shamsuzzoha and P. Helo, “Real-time tracking and tracing system: Potentials for the logistics network,” in *International Conference on Industrial Engineering and Operations Management*, 2011, pp. 242–250.

[14] A. H. M. Shamsuzzoha, M. Ehrs, R. Addo-Tenkorang, D. Nguyen, and P. T. Helo, “Performance evaluation of tracking and tracing for logistics operations,” *Int. J. Shipp. Transp. Logist.*, vol. 5, no. 1, pp. 31–54, 2013.

[15] B. Ahmed, T. Sriram, K. V. Rao, and S. Biswas, “Applications of barcode technology in automated storage and retrieval systems,” in *22nd International Conference on Industrial Electronics, Control, and Instrumentation*, 1996, pp. 641–646.

[16] S. Tiwari, “An introduction to QR code technology,” in *15th International Conference on Information Technology, ICIT*, 2016, pp. 39–44.

[17] J. Slovak, P. Vasek, M. Simovec, M. Melicher, and D. Sismisova, “RTLS tracking of material flow in order to reveal weak spots in production process,” in *22nd International Conference on Process Control, PC*, 2019, pp. 234–238.

[18] M. Z. Hoque, “Basic Concept of GPS and Its Applications,” *IOSR J. Humanit. Soc. Sci.*, vol. 21, no. 3, pp. 31–37, 2016.

[19] J. Eriksson, “Towards a more efficient Supply Chain: A study at Bombardier Rail Control Solutions with a focus on centralizing their Supply Chain,” KTH Royal Institute of Technology in Stockholm, 2017.

[20] K. V. Singh and R. K. G. V. V, “Improving Manufacturing Enterprise Efficiencies Through Track and Trace Technologies,” *White Paper*, 2018. [Online]. Available: https://www.infosys.com/engineering-services/white-papers/documents/improving-efficiency-manufacturing.pdf. [Accessed: 28-Apr-2020].

[21] T. Lotlikar, R. Kankapurkar, A. Parekar, and A. Mohite, “Comparative study of Barcode, QR-code and RFID System,” *Int. J. Comput. Technol. Appl.*, vol. 4, no. 5, pp. 817–821, 2013.

[22] L. Bi, Z. Feng, M. Liu, and W. Wang, “Design and implementation of the airline luggage inspection system base on link structure of QR code,” in *International Symposium on Electronic Commerce and Security*, 2008, pp. 527–530.

[23] S. Qiao, Z. Wei, and Y. Yang, “Research on vegetable supply chain traceability model based on two-dimensional barcode,” in *6th International Symposium on Computational Intelligence and Design*, 2013, vol. 1, pp. 317–320.

[24] L. Probst, L. Frideres, and B. Pedersen, “Traceability across the Value Chain - Advanced tracking systems,” Luxembourg, 2015.

[25] D. M. Bridgeland and R. Zahavi, “Business Rule Models,” in *Business Modeling: A Practical Guide to Realizing Business Value*, 2009, pp. 139–181.

[26] M.-Å. Hugoson, “Centralized versus Decentralized Information Systems,” *Int. Fed. Inf. Process.*, pp. 106–115, 2009.

[27] N. M. Iacob and M. L. Moise, “Centralized vs. Distributed Databases Case Study,” *Acad. J. Econ. Stud.*, vol. 1, no. 4, pp. 119–130, 2015.

[28] B. de R. M. S. Brito, “Centralization of supply chain management operations : the case of Unilever Ultralogistik,” Faculdade de Economia da Universidade do Porto, 2016.

[29] K. R. Petersen, A. Bilberg, and R. Hadar, “Responsiveness and flexibility in a Decentralized Supply Chain,” in *4th World Conference on Production & Operations Management*, 2012, pp. 1–10.

[30] Hyperledger, “Introduction to Hyperledger Business Blockchain Design Philosophy and Consensus,” in *Hyperledger Architecture*, vol. 1, 2017, pp. 1–15.

[31] Hyperledger, “Identity.” [Online]. Available: https://hyperledger-fabric.readthedocs.io/en/release-2.0/identity/identity.html. [Accessed: 30-Jun-2020].

[32] Hyperledger, “CouchDB as the State Database.” [Online]. Available: https://hyperledger-fabric.readthedocs.io/en/release-2.0/couchdb_as_state_database.html. [Accessed: 30-Jun-2020].

[33] D. M. Tavares, S. J. Bachega, and G. A. de P. Caurin, “Architecture Proposal For The Use Of QR Code In Supply Chain Management,” *Rev. Científica Eletrónica Eng. Produção*, vol. 12, no. 1, pp. 73–90, 2012.

[34] A. Knecht, “Securing Goods Distribution with Smart Contracts and Sensors,” University of Zurich, 2016.

[35] S. Y. Yan, *Cybercryptography: Applicable cryptography for cyberspace security*. Springer, 2018.

[36] IBM, “What is a digital certificate.” [Online]. Available: https://www.ibm.com/support/knowledgecenter/SSB23S_1.1.0.2020/gtps7/s7what.html. [Accessed: 23-Apr-2020].

[37] D. Yaga, P. Mell, N. Roby, and K. Scarfone, “Blockchain Technology Overview,” *National Institute of Standards and Technology Internal Report 8202*, 2018. [Online]. Available: https://doi.org/10.6028/NIST.IR.8202. [Accessed: 09-Jun-2020].

[38] A. Akram and P. Bross, “Trust, Privacy and Transparency with Blockchain Technology in Logistics,” in *12th Mediterranean Conference on Information Systems(MCIS)*, 2018.

[39] A. B. Bondi, “Characteristics of scalability and their impact on performance,” in *2nd international workshop on Software and performance*, 2000, pp. 195–203.