Using Blockchain to Trace PDO/PGI/TSG Products

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Abstract: For helping preserve the cultural traditions of populations and their social and economic sustainability, the European Union created a set of denominations such as "Protected Designation of Origin" (PDO), "Protected Geographical Indication" (PGI) and "Traditional Specialty Guaranteed" (TSG), for certifying and guaranteeing a set of characteristics of the region in the product and/or manufacturing process. In this paper, a blockchain-based traceability platform is proposed, to trace PDO/PGI/TSG products from their source to the final consumers, using Hyperledger Fabric. This platform enables the transparent registration of activities throughout the value chain and provides the traceability information demanded by informed consumers while, at the same time, helps in avoiding forgeries.

1 INTRODUCTION

Traditional products help to preserve traditions and local culture, as they protect the ancestral knowledge that has passed from older generations to current ones.

The European Union, as a way of defining and guaranteeing the quality of traditional products and protecting them from forgeries, has created a set of denominations such as "Protected Designation of Origin" (PDO), "Protected Geographical Indication" (PGI) and "Traditional Specialty Guaranteed" (TSG). These designations guarantee a set of characteristics of the region, product or manufacturing process. Products registered under one of the three schemes may be marked with the logo for that scheme to help identify those products. The schemes are based on the legal framework provided by the EU Regulation No 1151/2012 of the European Parliament and of the Council of 21 November 2012 on quality schemes for agricultural products and foodstuffs.

A PDO is a geographical designation that identifies a product originating from that region, whose quality or characteristics are essentially or exclusively due to the specific geographical environment, including natural and human factors, whose production phases take place in that defined geographical area. To receive the PDO status, the entire product must be traditionally and entirely manufactured (prepared, processed and produced) within the specific region and thus acquire unique properties.

The PGI is linked to the name of an area, a specific place or even a country, used as a description of an agricultural product or a foodstuff that comes from such a region, which has a specific quality, goodwill or other characteristic property, attributable to its geographical origin, whose production, processing or preparation takes place within the determined geographical area. A PGI product must be traditionally and at least partially manufactured (prepared, processed or produced) within the specific region and thus acquire unique properties.

The TSG certification provides a protection regime for traditional food products of specific character. Differing from PDO and PGI, this quality scheme does not certify that the protected product is linked to a specific geographical area, instead it must be of a "specific character", and either its raw materials, production method or processing must be "traditional". All of these products are usually more expensive than similar ones, and so they are often subject to forgery.

In this paper we are proposing a traceability platform, using blockchain, to trace PDO/PGI/TSG products from their origin to the final consumer. The proposed platform helps assuring the source of the products and avoiding forgeries. Providing means for traceability is essential to provide transparency and

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create trust in the consumers about the product quality and sustainability (da Cruz and Cruz, 2020; Jeppsson and Olsson, 2017; Tian, 2017). For this platform, we are using the Hyperledger Fabric blockchain. The blockchain technology, seen as one of the technologies that better fits the needs of traceability in supply chains, is a distributed technology, owned by none of the peers that enables transparent and immutable information. It allows registering all chain activities in a distributed, transparent, secure and trustful manner (da Cruz and Cruz, 2020).

The structure of the presentation is as follows: In the next section, related work is presented, namely applied research on food traceability platforms and on using blockchains for traceability. Section 3 addresses the development of the proposed Blockchain-based platform, focusing on the smart contract. Section 4 presents the platform architecture and identifies the needed front-end applications to use those services. A *proof-of-concept* application, which has been built to test our approach, is also addressed. In section 5, some conclusions are drawn and some ideas for future work are disclosed.

2 RELATED WORK

In 2015, as part of the 2030 Agenda for Sustainable Development, the United Nations created a set of goals for sustainability (UN, 2019). One of these goals is waste less food and support local farmers. For this, some platforms have been created to ensure and certify the origin of certain products for "supporting local farmers" and to prevent forgeries, as is the case of (Regattieri et al., 2007; Bachev, 2016; Bevilacqua et al., 2009). Additionally, some authorities are requiring the registration and control of the origin of certain food products (Regulation no 178/2002 of the European parliament and of the council, 2002), improving products traceability. So, several proposals for the implementation of traceability have been carried out within food value chains. Some of these proposals are presented below.

2.1 Food Traceability Platforms

Traditional products try, most of the times, to preserve the origin of production and the manufacturing process, in order to preserve traditional characteristics such as quality, flavor, texture, etc. The processes can, however, be slightly altered to improve hygiene and health safety, working conditions or animal welfare. These products are generally more expensive and are therefore more subject to forgery.

Hrabrin Bachev studies and assesses the sustainability of farming enterprises in Bulgaria. His study includes evaluating economic, ecological and social aspects of farming enterprises' sustainability (Bachev, 2016).

In (Regattieri et al., 2007) the authors propose a platform to support the traceability of the Italian "Parmigiano Reggiano" PDO cheese, from the bovine farm to the final consumer. The developed system collects data in all identified steps of the food chain and stores it in a centralized database.

Bevilacqua *et al.* re-engineered the business processes of vegetables supply chain and created a system for managing those products' traceability (Bevilacqua et al., 2009).

In (da Cruz et al., 2019; Cruz et al., 2019) the authors propose a traceability platform for the fish and fishery value chain. The platform registers, in a centralized database, all the activities of the value chain from sea to fork, namely from the capture of fish or aquaculture production, to the purchasing activity of the final consumer, going through all other activities of the value chain, such as transport, storage, intermediate sale or industrial transformation.

2.2 Traceability using Blockchain Technology

Nowadays blockchain is seen as one of the technologies that better fits the needs of traceability in a supply chain (da Cruz and Cruz, 2020; Jeppsson and Olsson, 2017). In fact, the blockchain technology is being used as a distributed database in many areas including traceability in agriculture and food supply chains (Saberi et al., 2019; Tian, 2017; Biswas et al., 2017; Tan et al., 2019).

In recent years, many authors have used blockchain technology to implement traceability in value chains. According to Ruoti *et al.*, blockchain has strong points, such as shared governance and operations, resilience to data loss, provenance tracking and auditability (Ruoti et al., 2019).

Kamilaris *et al.* discuss the impact of blockchain in agriculture and food supply chains. Blockchain is seen as a technology that helps in adding transparency in the food supply chain (Kamilaris et al., 2019).

Biswas *et al.* propose a blockchain-based platform to trace the wine value chain, from its production to the purchase history (Biswas et al., 2017).

Abderahman Rejeb implements traceability in the Tilapia supply chain, from farmers to the final consumers in Ghana (Rejeb, 2018). Tilapia is one of the most consumed fish species in Ghana. The Blockchain technology has been used to implement

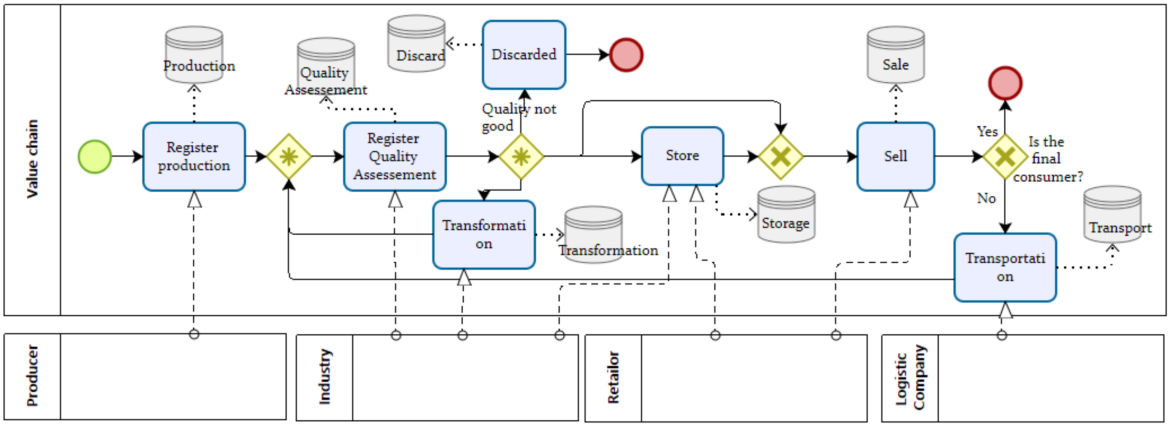

Figure 1: Inter-organizational Generic value chain business process model.

traceability of aquaculture fish (Rejeb, 2018).

In (da Cruz et al., 2020) the authors are using blockchain technology to trace and calculate the carbon footprint of products and organizations. The authors use a solidity smart contract to implement a platform in Ethereum blockchain. The paper also presents a distributed application for providing consumers with information about the carbon footprint of a product or organization stored in the blockchain.

In (Cruz and Cruz, 2020) the authors used the Ethereum blockchain to implement traceability in fish and fishery value chains from harvest to final consumers.

Gao *et al.* created a system based on Hyperledger Fabric to implement traceability in food value chain in order to "solve food safety problems". The system stores and aggregates data from each participant involved in the food supply chain (Gao et al., 2020).

3 THE PDO/PGI/TSG TRACEABILITY PLATFORM

In the PDO/PGI/TSG products value chain, consumers want to be informed, not only about the parts that make up the product they are buying, but also about how and where these parts and the final product have been created or manufactured. This way, consumers can know if the certified product they are buying has met all the certification requirements, and which organizations were involved in the process.

3.1 Analysis

The Platform proposed in this paper is prepared to be used by any organization in the PDO/PGI/TSG products' value chain. Figure 1 shows the BPMN model that represents the generic business process model of the integrated PDO/PGI/TSG products' value chain. As we may see in the figure, several participants, like producers, industries, retailers and logistics, are involved. Each participant provides data about their participation in the value chain (production, breeding, transportation, manufacturing, storage, etc.), and must indicate when, how and where their activity/task has been performed. The activities performed by each participant in the value chain are represented in Figure 1 by a message flow between the participant and the activity. Since we are working on the blockchain, the data entered can not be changed, making it more difficult to tamper, or falsify the data. This way, the value chain provides more transparent and reliable information to the end consumer.

As a specific example, Figure 2 shows a BPMN model that represents the inter-organizational business process for the "Serra da Estrela" PDO cheese value chain. It depicts the activities that each organization in the value chain needs to register on the traceability platform. Serra da Estrela PDO cheese is manufactured from sheeps' milk. The sheeps, from "Bordaleira da Serra da Estrela" or "Churra Mondegueira" breeds, graze in spontaneous pastures of the largest and highest mountain in mainland Portugal, with the same name as the cheese.

There are few producers of sheep's milk and they are properly identified and cataloged. These, and only these producers, deliver the milk to the cheese factories on a daily basis. After checking the quality of the milk, the thistle flower previously grounded with salt is added to it and the milk is heated up to 30 ºC for about 1 hour. Then the mix goes through a set of steps like curd cut, serum removal, molding and pressing and maturation. In the end, a new batch of cheeses is ready, and it is numbered and registered in the platform. After registration, the new batch may be stored or sold. After a sale there is always a trans-

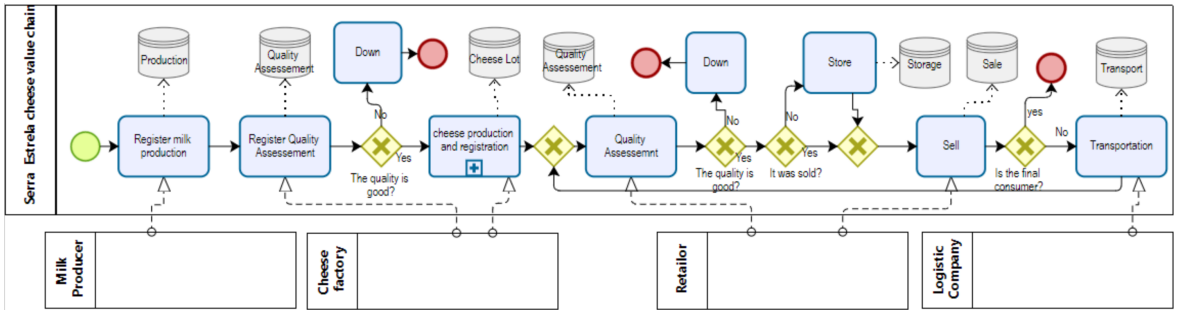

Figure 2: Inter-organizational business process for the "Serra da Estrela" PDO Cheese value chain.

Figure 3: The use case model for the platform.

portation and, after that, the quality is verified again.

The previous example is for a PDO product, where every products and activities need to be produced in a designated region. Other types of products, such as PGI and TSG, have less restrict requirements.

The proposed platform allows the registration of activities in the three previously mentioned types of certified products. The use case model, modeling the functionalities that each user in the traceability platform must be able to access, is shown in Figure 3.

There are five types of user: A SysAdmin maintains organizations (value chain operators), and has other administrative tasks; an Organizational Admin maintains the worker/users of a given organization; an Organizational Worker is an organization's user that may register activities for their organization; a Certification Entity creates or updates certified organizations for a given product and certification type; and, a Final consumer may consult the traceability information in the platform.

The identified platform functionalities act on data that will be put into the Hyperledger Fabric blockchain. Figure 4 shows the domain entities' model of the PDO/PGI/TSG traceability problem. These entities are implemented in the blockchain contract through Participants, Assets and Transactions resource types, using the Hyperledger Composer tools. The next subsection explains the implementation of the platform depicted in these models, using the Hyperledger Fabric blockchain and the Composer tools.

3.2 The Platform Design

For developing the platform, Hyperledger Composer has been used. This, comprises a set of tools for creating smart contracts on Hyperledger Fabric blockchain. In Hyperledger Composer, a business network (BN) is a model of all the data in the

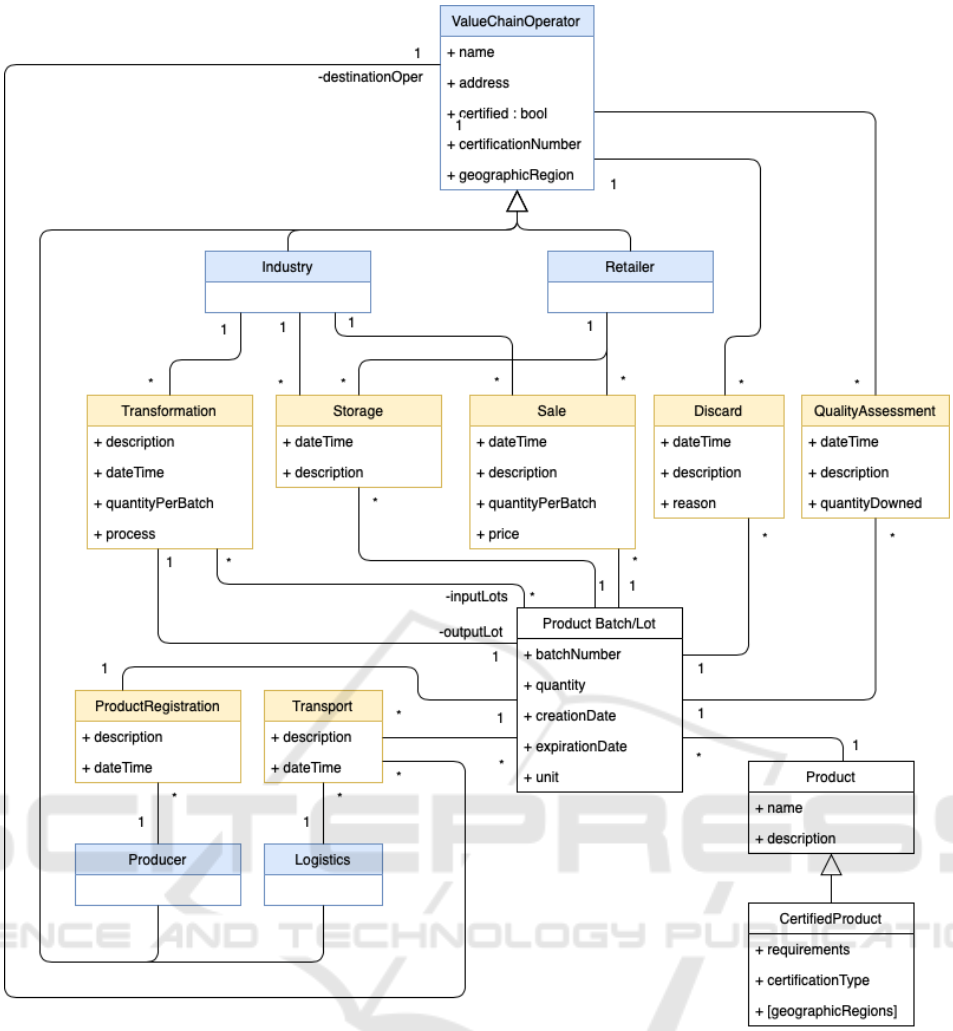

Figure 4: PDO/PGI/TSG domain model.

blockchain which includes all the objects, functions, transactions and identities that will connect to each other and be saved on the ledger. It is basically an abstraction of the chaincode that will be installed onto Fabric.

A BN, defined as a network model, can be deployed into an instance that runs on a certain number of nodes. Composer features a modeling language that makes it easy to define a business network. It is divided into four main components: Model, Script, Access Control and Query.

The BN definition is then packaged and exported into a Business Network Archive (.bna file) that can be deployed into an instance of Hyperledger Fabric or a Web Browser using ID Cards that contain connection profiles and credentials[1] (see Figure 5).

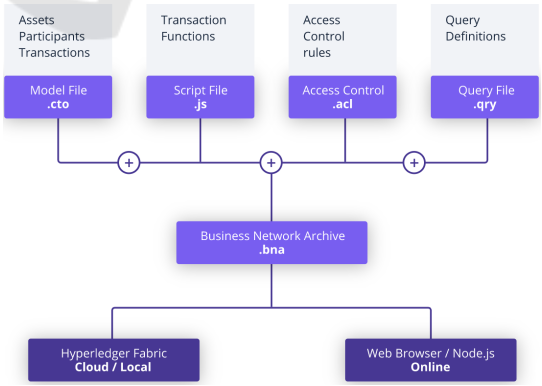

Figure 5: Hyperledger Composer Diagram.

3.2.1 Model

This is where all the main data components are defined. Assets correspond to the main objects, which

[1] https://hyperledger.github.io/composer

are handled in transactions, and they can represent a variety of things. Participants are the types of users that will be participating in the network. An instance of a participant can be linked to a real identity of a person/user or type of entity using the blockchain. Transactions are data objects that model what information must be registered about interactions between participants and involving assets.

These three types of components (Assets, Participants and Transactions) have their own registry. While the Assets and Participants registries are mutable, the Transactions registry is not. The business network model for Hyperledger Composer includes the specifications for the model file (.cto), with the definitions of all class types participants, assets, transactions and events, as well as the enumerated types and concepts.

Participants. For the PDO/PGI/TSG traceability platform, the main participants are the value chain operators, represented in Figure 1 as external participants, such as:

- Producer: Raw material harvesting Operator;
- Industry: Entity responsible for Industry activities (Quality Assessment, Transformation, Storage, Sale and Discard)
- Retailer: Entity responsible for Retailer activities (Storage and Sale and or Discard);
- Logistics: Operator for transportation purposes between any two entities;

Besides these, there are two more participants in the value chain. One is a Certification Entity Authority, which is a EU organization that creates certified products and certifies industries and producers for PDO/PGI/TSG products. Only certified organizations may create and register certified products' batches. The other is the End Consumer, that is any person who wants to check the product batch traceability.

Hyperledger Composer Participants are defined as presented next for the Producer:

```
abstract participant ValueChainOperator
identified by operatorId{ ... }
participant Producer extends
        ValueChainOperator{
  --> Certification certification optional
}
```

Assets. Another integral component of the system are the Assets. These correspond to data entities that, along with Participants, will be persisted in the blockchain, and that will be manipulated in the transactions. To register products' batches traceability, these products and batches need to be modeled as assets:

- Certification: A certified designation of type PDO, PGI or TSG (e.g.: "Serra da Estrela" Cheese PDO);
- Batch: A product batch, on which different operators will act upon;
- Product: The product that a batch refers to;
- Certified Product: A specific type of PDO/PGI/TSG product that may only be created by certified operators.

These assets are defined as:

```
asset Certification
identified by certificationNumber{
  o String certificationNumber
  o String name
  o CertificationType certificationType
  o String[] regions optional
  o String[] requirements
  --> CertifyingEntity creatorEntity
}
asset Product identified by GTIN {
    o String GTIN // Global Trade Item Number
    o String name
    o String description
    --> ValueChainOperator creator
}
asset CertifiedProduct extends Product {
    --> Certification certification
}
asset Batch identified by batchId {
    o String batchId
    ...
    o DateTime creationDate
    o DateTime expirationDate
    --> Product product
    --> ValueChainOperator currentOwner
}
```

Transactions. Transactions, in Hyperledger Fabric, correspond to information that is to be persisted inside blocks and protected through a chained structure (the ledger). Thus, while participants and assets model users and data entities in the system, transactions model the business information that relates and implies participants and assets.

In the context of the traceability platform being proposed, transactions are information registered by the value chain operators (participants). These transactions are presented in Figure 1 as data stores and correspond to information stored during the execution of the following value chain activities:

- Production Registration: The Producer registers the information about the batch of the harvested raw material.

- Register Quality Assessment: The industry/retailer checks a batch's quality and whether it meets the PDO/PGI/TSG requirements and records the information about it.
- Transformation: The Industry stores information about one or more input batches to create a new product batch.
- Storage: The Industry/Retailer stores information about a batch storage condition.
- Sale: Industry/Retailer register a sale. It involves a different Industry/Retailer (seller and buyer).
- Transport: Logistics transaction of transporting the batches from one operator to another.
- Discard: The information about a batch (or part of it) that is not in condition of being used.

The transactions are declared on the Hyperledger Composer model file. Below, the Task abstract transaction, that is a super "class" of every other transaction in our platform, and BatchTask, another abstract transaction, are defined:

```
abstract transaction Task {
    o String taskId
    o String description
    o String message optional
    o Address address
}
abstract transaction BatchTask extends Task{
   --> Batch[] batches
}
```

Concrete transactions extend one of the above abstractions. Below, *ProductTransaction* is defined. This is created when a new product batch is registered:

```
transaction ProductRegistration extends Task{
// Register a single batch on the network
   // Task parameters
   o String name default = 'Product Regist.'
   o String[] processes optional
   --> ValueChainOperator currentOperator
   // New batch parameters
   o String batchId
   o Double amount range = [0.001,]
   o Units unit
   o DateTime expirationDate
   --> Product product
}
```

Other transactions are *Transformation*, *QualityAssessement*, *Storage*, *Sale*, *Transport* and *Discard*, as identified in the domain model in Figure 4.

Enums, Concepts and Events. Other needed data types, also present in the model file, are enumerations (enum) and concepts (a kind of C-like struct data type). These are non-instantiatable data-types.

Events can be emitted by the contract functions (in the script file) and subscribed by applications, which can handle them, for instance, to generate notifications.

3.2.2 Script

Composer uses a javascript (.js) file to implement the contract's functions. This is where the business rules and logic of the network reside. This script file can be found in *https://github.com/lcvalves/DOP-Trace*, together with the rest of the *proof-of-concept* project developed.

3.2.3 Access Rules

Composer features the concept of Participant, a network instance of the class that represents a user, but it also features identity cards, which are files that function as the private key and identification card for a user. An identity card and an instance of a participant can be linked to each other. Control rules may be defined to reflect what actions are allowed to certain participant class types, to specific participant instances, and even to specific identity cards.

An example rule, that prevent value chain operators to create and delete other operators, is shown next:

```
rule deny_ValueChainOper_CREATE_DELETE_VCO {
 description: "Operator can't delete Opers"
 participant: "org.gitseu.ValueChainOperator"
 operation: CREATE, DELETE
 resource: "org.gitseu.ValueChainOperator"
 action: DENY
}
```

3.2.4 Queries

The smart contract's functions, in the script file, are used for executing actions on the Assets and other model structures, but are not able to fetch or query data from the contract data structures. Hyperledger Composer allows to automatically retrieve all the data of each asset, participant and transaction structures, defined in the model file, but any result producing query must be defined in the queries' file. With that in mind, we decided not to implement queries in the contract, since they were not able to implement traceability features. Instead, we work the automatically retrieved data in functions in the script file.

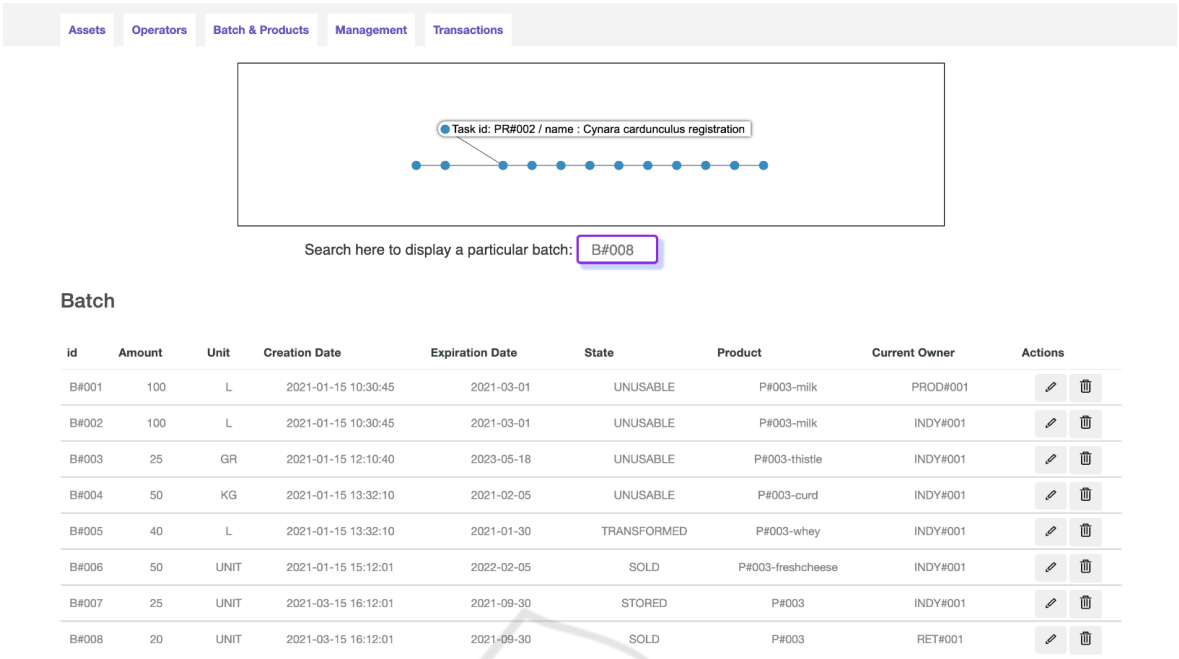

Figure 6: Traceability graph visualization in the proof-of-concept web app.

4 PLATFORM ARCHITECTURE AND FRONT-END APPLICATIONS

Hyperledger Composer enables the quickly creation of "full-stack" blockchain solutions, comprising the blockchain-based business logic and REST APIs that expose that logic to web or mobile applications or for integrating with existing enterprise systems. The proposed platform uses the following frameworks:

- Hyperledger Fabric: blockchain framework that acts as a foundation for developing blockchain-based products, solutions and applications using plug-and-play components that are aimed for being used within organizations.
- Hyperledger Composer: framework that runs on a layer above the Hyperledger Fabric. The Composers' Web Playground is a premade web application for quickly testing the .bna file components (model.cto, script.js, permissions.acl and query.qry). Hyperledger Composer includes a standalone Node.js process that exposes a business network as a REST API;

A proof-of-concept application has been built for testing the Hyperledger Composer smart contract, running on top of the Hyperledger Fabric blockchain. For this application, the following components have been used: Passport - authentication middleware for Node.js; Angular - open-source web application framework; Sigma - JavaScript library for graph drawing; Yeoman - scaffolding tool for generating a skeleton webapp for starting development.

A set of activities' registrations have been made, by using the smart contract through the application. Figure 6 shows the result of a query made in the application about the batches created and the types of activities registered.

Applications to be built on top of the deployed REST API, exposing the blockchain functions, are needed. Future work will address applications for:

- End consumers, to be able to consult the traceability of any batch number. There may be a personal mobile app for the consumers, and a Kiosk-like app to be available at retail points;
- Value chain operators, to be able to integrate with the traceability platform even if they do not have their ERP system integrated with the platform.

Of course, integrating some ERP systems with the traceability platform will ease the process of feeding traceability information to the platform.

5 CONCLUSION

This paper proposes a blockchain-based platform, that allows tracking products with a PDO/PGI/TSG

certification, from their creation to the final consumer, by implementing traceability in the value chains of these products. The proposed platform uses a smart contract on the Hyperledger Fabric blockchain.

Blockchain is a technology suitable for traceability, where each operator has their copy of the data, allowing all operators to work together even without having to trust each other completely. The value chain operators can share blockchain governance and operations. The consensus mechanism allows an agreement between those operators (peers) about the information that is to be persisted in the system. And, as the data is stored and replicated in each peer node, resilience to data loss and data tampering is assured.

PDO/PGI/TSG products bear a seal with a code sequence that identifies the certification entity, the registered company, certification mark, etc. However, the consumer is often unaware of the real origin of the product. Besides that, the seal can be forged. By accessing the proposed traceability platform, the final consumer (or any business partner) may know in which value chain operator the product was created and the entire route taken by it so far. The platform also allows to improve communication and the coordination between the involved parties, and the integration and sharing of information in the value chain.

In order for the final consumer, the authorities, or any business partner, to easily access the information stored on the blockchain, a proof-of-concept web application has been created to provide the traceability information in an easy and user-friendly environment.

As future work, we intend to further develop the proposed system, by developing the previously identified front-end applications, and to implement the smart contract using other blockchain frameworks, in order to study and compare them.

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REFERENCES

Bachev, H. (2016). A framework for assessing sustainability of farming enterprises. *Journal of Applied Economic Sciences (JAES)*.

Bevilacqua, M., Ciarapica, F., and Giacchetta, G. (2009). Business process reengineering of a supply chain and a traceability system: A case study. *Journal of Food Engineering*, 93(1):13 – 22.

Biswas, K., Muthukkumarasamy, V., and Tan, W. L. (2017). Blockchain based wine supply chain traceability system. In *Future Technologies Conference (FTC)*

Cruz, E. F. and Cruz, A. M. (2020). Using blockchain to implement traceability on fishery value chain. In *15th International Conference on Software Technologies (ICSoft2020)*. SciTePress.

Cruz, E. F., Cruz, A. M., and Gomes, R. (2019). Analysis of a traceability and quality monitoring platform for the fishery and aquaculture value chain. In *14th Iberian Conference on Information Systems and Technologies (CISTI 2019)*.

da Cruz, A. M., Cruz, E. F., Moreira, P. M., Carreira, R., ao Gomes, J., Oliveira, J., and Gomes, R. (2019). On the design of a platform for traceability in the fishery and aquaculture value chain. In *14th Iberian Conf. I.S. and Tech. (CISTI 2019)*.

da Cruz, A. M. R. and Cruz, E. F. (2020). Blockchain-based traceability platforms as a tool for sustainability. In *22st Int. Conf. on Enterprise Information Systems (ICEIS)*, volume 2, pages 330–337. SciTePress.

da Cruz, A. M. R., Santos, F., Mendes, P., and Cruz, E. F. (2020). Blockchain-based traceability of carbon footprint: A solidity smart contract for ethereum. In *22st Int Conf on Enterprise Information Systems (ICEIS)*, volume 2, pages 258–268. SciTePress.

Gao, K., Liu, Y., Xu, H., and Han, T. (2020). Design and implementation of food supply chain traceability system based on hyperledger fabric. *Int'l Journal of Computational Computational Science and Engineering.*

Jeppsson, A. and Olsson, O. (2017). Blockchains as a solution for traceability and transparency. Master's thesis, LUND UNIVERSITY.

Kamilaris, A., Fonts, A., and Prenafeta-Boldu, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science & Technology*, 91:640–652.

Regattieri, A., Gamberi, M., and Manzini, R. (2007). Traceability of food products: General framework and experimental evidence. *Journal of Food Engineering*, 81(2):347 – 356.

Rejeb, A. (2018). Blockchain potential in tilapia supply chain in ghana. In *Acta Technica Jaurinensis*, volume 11.

Ruoti, S., Kaiser, B., Yerukhimovich, A., Clark, J., and Cunningham, R. (2019). Blockchain technology: What is it good for? *Commun. ACM*, 63(1):46–53.

Saberi, S., Kouhizadeh, M., Sarkis, J., and Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7):2117–2135.

Tan, B., Yan, J., Chen, S., and Liu, X. (2019). The impact of blockchain on food supply chain: The case of walmart. In *International Conference on Smart Blockchain*.

Tian, F. (2017). A supply chain traceability system for food safety based on haccp, blockchain amp; internet of things. In *International Conference on Service Systems and Service Management*.

UN (2019). The sustainable development goals report. Technical report, United Nations.