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Blockchain-based food supply chain traceability: a case study in the dairy sector

Fran Casino[a], Venetis Kanakaris[b], Thomas K. Dasaklis[a], Socrates Moschuris[c], Spiros Stachtiaris[c], Maria Pagoni[d] and Nikolaos P. Rachaniotis[c]

[a]Department of Informatics, University of Piraeus, Piraeus, Greece; [b]Department of Computer and Informatics Engineering, TEI of Eastern Macedonia & Thrace, Kavala, Greece; [c]Department of Industrial Management and Technology, University of Piraeus, Piraeus, Greece; [d]Pagonis Sisters and Co., Erythres, Greece

ABSTRACT
Traceability has become a critical element in supply chain management, particularly in safety-sensitive sectors like food, pharmaceuticals, etc. Upstream (manufacturers, producers, etc.) and downstream (distributors, wholesalers, etc.) supply chain members need to store and handle traceability-related information for providing proof of regulatory compliance to both state authorities and more demanding customers. Consumers also place high expectations on food supply chains (FSC) with specific emphasis on facets related to safety. However, the complexity of modern FSC networks and their fragmentation act as barriers for the development of sound traceability mechanisms. In this paper a distributed trustless and secure architecture for FSC traceability is developed and tested. For assessing the feasibility of the proposed approach, a food traceability case study from a dairy company is presented. The applicability of the model is further illustrated by the development of fully functional smart contracts and a local private blockchain. Moreover, the various links between the proposed blockchain-based model and its managerial implications are presented. The overall benefits of the proposed model are discussed along with fruitful areas for future research. The results are of significant value to both practitioners and researchers.

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Supply chains and networks; supply chain management; Industry 4.0; blockchain; smart contract

1. Introduction

Food traceability captures, stores and transmits adequate information about a food, feed, food-producing animal or substance at all stages in the Food Supply Chain (FSC) so that the product can be checked for safety and quality control, traced upward and tracked downward at any time, as claimed by Aung and Seok Chang (2014). It includes product, process, genetic, inputs, disease and pest and measurement traceability, as suggested by Zhu et al. (2018). There are three essential characteristics for traceability systems: (i) identification of units/batches of all ingredients and products, (ii) information on when and where they are moved and transformed and (iii) a system linking these data, as stated by Aung and Seok Chang (2014).

Traceability is considered as a new quality index in the food industry, according to Bosona and Gebresenbet (2013). Storing and handling sensitive case information for tracing in FSC becomes mandatory worldwide. Regulations are imposed in order to enable tracking and identification of all raw materials used in food products as claimed by Dabbene, Gay, and Tortia (2014). These requirements tangle many FSC participants, some of them still depending on non-automated information managing methods, as mentioned by Rabah (2018) and Gromovs and Lammi (2017). The food industry uses traceability systems for the improvement of FSC and the facilitation of the traceback for food safety and quality. Traceability is viewed as a strategic tool to improve food safety systems, the quality of raw materials, inventory management and as a source of competitive advantages, according to Aung and Seok Chang (2014), Dasaklis, Casino, and Patsakis (2019), Dasaklis and Casino (2019). Traceability systems help firms identify the cause and extent and resolve safety or quality control problems.

Traceability-driven FSC management is based on novel technologies like the Internet of Things (IoT). IoT-related applications provide real-time information about products as well as contamination information throughout production and distribution. IoT applications address practical problems/monetary constraints and (re)design/optimise food supply networks, as stated by Zhu et al. (2018). IoT-enabled applications and relevant technologies such as Radio Frequency Identification (RFID) could revolutionise the industry by digitising information to be queried and controlled in real

CONTACT Nikolaos P. Rachaniotis nraxan@unipi.gr

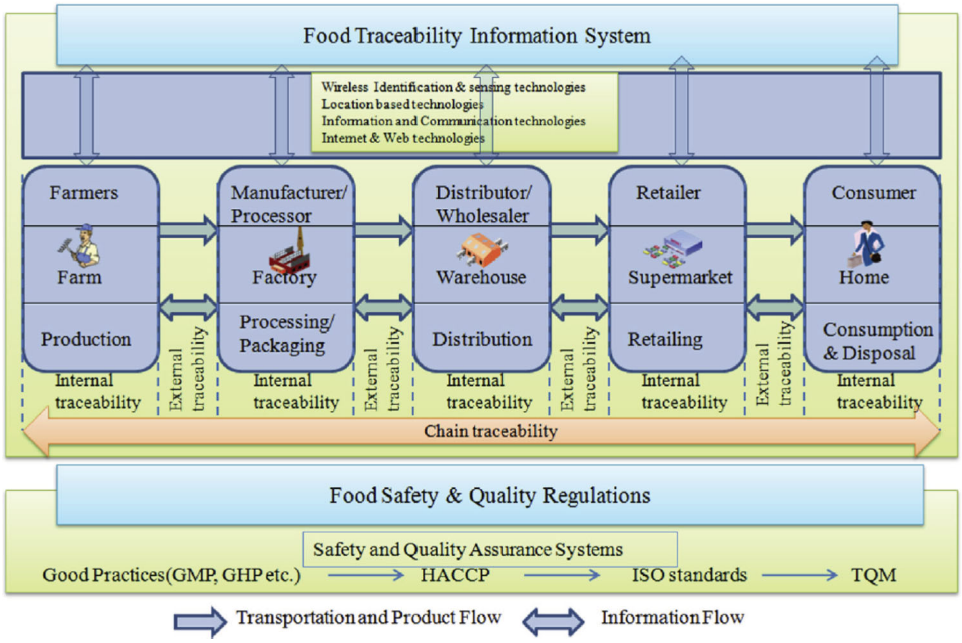

Figure 1. Conceptual framework of food traceability system (Aung and Seok Chang 2014).

time. These digital technologies are creating significant opportunities for the food industry, reshaping the FSC in terms of business and operational processes and requiring revisions of existing analytic models in this domain to accommodate the changes (Figure 1).

Despite the significant benefits of the adoption of IoT-related applications, various impediments still exist in the FSC. For example, FSC networks are getting increasingly more complex and fragmented nowadays. This complexity makes the identification and tracking of products and processes along globalised FSC networks extremely difficult. In this context, traceability has become a requirement for ensuring not only safety in FSC but also regulatory compliance, better understanding of the products' life cycle and conscientious consumption. Missing or unreachable information can induce food insecurity and consumer health issues. In fact, food contamination is still a significant health problem in several countries (according to the World Health Organization, every year around 600 million people worldwide endure illnesses from eating contaminated food, out of which 420,000 die) and results to public suspicion and a substantial reduction in demand, as stated in Trebar et al. (2013). In addition, traceability-related information is not shared between participants, since they have their own traceability mechanisms and inevitably store their unique traceability records. This information sharing impediment poses significant risks for the core participants in terms of food safety and quality and also hinders external stakeholders from checking for regulatory compliance. The reliability of traceability-related information is also a key challenge in nowadays. This is particularly true for globalised FSC networks with numerous suppliers, different regulators and millions of clients, in which traceability data needs to be in digital format and accessible by the various stakeholders and its processing to be automated to comply with different regulations. Nevertheless, some of the key players still depend on non-automated information managing methods, as observed by Saikouk and Spalanzani (2016).

1.1. Motivation and contribution

Blockchain technology is evolving to be the most significant technology revolution since the invention of the Internet and its adoption is a reality in many fields, as claimed by Rabah (2018), Gromovs and Lammi (2017), Garay, Kiayias, and Leonardos. (2015), Saha et al. (2018), Casino, Dasaklis, and Patsakis (2018). A relatively recent aspect of the blockchain technology is the notion of smart contracts, introduced by Szabo (1997) (with a full Turing complete Language), which provide the ability to perform computations within the blockchain, thus operating as a decentralised virtual machine. Generally, a smart contract pertains to the computer protocols or programmes that permit an agreement to be automatically executed/enforced taking into account a set of predefined conditions. Today smart contracts have been included in the majority of existing blockchain applications (Dolgui et al. 2019).

The above mentioned features of blockchain and smart contracts could be extensively used for solving several problems in current FSC traceability approaches. The blockchain is a technological advance that has the potential to change services by providing trust in distributed environments such as FSC. It can provide backward control from the end consumer to the factory or farm, bypass traditional authorities and ensure faster and secure transactions. For instance, blockchain-enabled applications enhance the sharing of information among disparate partners across FSC networks without compromising privacy and security. Significant benefits from the adoption of blockchain-enabled applications in FSC traceability may relate to data interoperability, cost reduction, transparency, auditability, integrity and authenticity. It is worth noting that blockchain-enabled FSC approaches coupled with IoT will improve communication and selective export of data, offering several additional benefits to the logistics sector regarding data management and data analytics, according to Banafa (2017), Huh, Cho, and Kim (2017).

Various blockchain-enabled FSC traceability mechanisms have been proposed in the literature. However, most of the studies are limited to theoretical implementations and unstructured experimentation of the blockchain technology within the FSC domain. In addition, despite the hype, blockchain is an emerging technology with several technical functionalities that haven't been evaluated regarding their potential to create real business value in FCS traceability systems. Therefore, this paper addresses this gap in the literature by providing and testing a distributed trustless and secure architecture for the establishment of a sound FSC traceability mechanism. The aim is to develop an interoperable, autonomous, functional and back-end data sharing model, which provides decentralised and automated FSC traceability. A definition of a real-world use case scenario, its integration with the proposed model and a blockchain-based implementation is provided, using not only transaction information but a set of smart contracts as well. Moreover, the various links between the proposed blockchain-based model and its managerial implications are presented, along with the significant benefits for all FSC participants. Finally, some limitations of the developed architecture are discussed and several fruitful areas for future research are proposed.

The remainder of the paper is organised as follows: In Section 2 an overview of food traceability is provided, along with an introduction to blockchain technology and its main characteristics. In Section 3 a brief review of the available relevant literature is presented. In Section 4 the proposed model is described in detail, along with its integration with the use case scenario for a real-world dairy products company. Section 5 analyses the model performance according to a set of key performance indicators and discusses the benefits and limitations of the proposed framework. Finally, the paper ends with some concluding remarks.

2. Literature review

Traceability applications in FSC management have been extensively covered in the literature (Bosona and Gebresenbet 2013; Dabbene, Gay, and Tortia 2014; Badia-Melis, Mishra, and Ruiz-García 2015; Yan et al. 2018). During the last couple of years various authors have also proposed blockchain-enabled FSC traceability mechanisms (Galvez, Mejuto, and Simal-Gandara 2018; Behnke and Janssen 2019; Bordel et al. 2019; Creydt and Fischer 2019; George et al. 2019; Kamble, Gunasekaran, and Sharma 2019; Pal and Kant 2019; Chen et al. 2020; Duan et al. 2020; Feng et al. 2020). For example, several authors have proposed blockchain-enabled traceability mechanisms for tracking agricultural products (Casado-Vara et al. 2018; Li and Wang 2018; Lin et al. 2018; Borrero 2019; Hong et al. 2019; Salah et al. 2019; Surasak et al. 2019; Wang and Liu 2019; Xie and He 2019; Kamble, Gunasekaran, and Sharma 2020). Within the FSC domain, various authors have developed blockchain-based traceability mechanisms for meat (Meidayanti and Arkeman 2019), animal product supply chain (Marinello et al. 2017) and eggs supply (Bumblauskas et al. 2020). In Behnke and Janssen (2020), the authors define various boundary conditions (such as regulatory prerequisites, standardisation and governance to name a few) for actually implementing blockchain-enabled applications in FSC.

The development of blockchain-based traceability mechanisms for defining different granularity levels when tracking products across complex SC networks (Dasaklis, Casino, and Patsakis. 2019) and the use of blockchain tokens (Dasaklis et al. 2019; Kim et al. 2019) is another interesting topic. Other authors have proposed traceability systems based on blockchain and the Electronic Product Code standard (Huang, Zhou, and Liu 2019; Lin et al. 2019). Various authors have also developed blockchain-enabled traceability schemes which are coupled with IoT applications. For instance, Tian (2018) developed a FSC traceability system by using IoT and blockchain technologies and it is compared with the linear centralised system widely used in FSC. The new system uses blockchain for guaranteeing that the information shared and published in this traceability system is reliable and authentic. Bettín-Díaz, Rojas, and Mejía-Moncayo (2018) integrate blockchain in the food industry supply chain to allow traceability along the process and provide end customer with adequate information about the origin of the product to make an informed purchase decision, thus enhancing supply chain provenance. Finally, Caro et al. (2018) presented a fully decentralised, blockchain-based traceability solution for agri-food supply chain management, which integrates IoT and blockchain in a "from-farm-to-fork" approach. In Casino et al. (2019), a distributed functional model that provided decentralised and automated FSC traceability based on blockchain technology and smart contracts was introduced. In this paper in order to assess the feasibility of the proposed approach, a food traceability case study from a dairy company is presented. The applicability of the model is further illustrated by the development of fully functional smart contracts and a local private blockchain. Moreover, the various links between the proposed blockchain-based model and its managerial implications are presented.

It should be noted that most of the studies above, although significant, are limited to theoretical implementations and unstructured experimentation of the blockchain technology within the FSC domain. As a direct consequence, most of the studies fail to evaluate the objective or the feasibility of blockchain technology to create real business value in FSC traceability. In addition, most of the studies present high-level or even abstract implementations, and the development of smart contracts is minimal. Finally, this paper is the first attempt to the best of the authors' knowledge to deal with the application of blockchain technology in the dairy SC and the translation of the various operational requirements within the dairy FSC into a sound distributed architecture.

3. Proposed framework

In this section, a real use case scenario is described and the corresponding requirements and features are mapped into a functional blockchain-based architecture. Next, the implementation and the interactions between the smart contracts are described in detail. For developing the proposed architecture a multi-disciplinary research methodological framework (both SC and Information technology-oriented) was applied, which is based on hybridisation of various approaches, both of qualitative and quantitative nature. The overall methodological framework consists of the following steps: (a) Determining ecosystem's requirements: Based on the theoretical findings from the relevant literature and the current state-of-practice (as described by the participating company) the technical and management processes requirements are defined. (b) Development of ecosystem's architecture: The requirements defined in the previous step are carefully translated into a distributed trust architecture with specific infrastructure characteristics. In particular, the system's components and sub-systems are developed and their interfaces are defined. (c) System implementation, testing and validation: Appropriate technologies are employed for building the system while ensuring its operability. Simulation techniques along with feedback from key personnel of the participating company are used for further fine-tuning the overall system in an iterative process.

3.1. Case scenario description

Pagonis Sisters and Co. is a Hellenic family-owned medium-sized company established in the town of Erythres of Attica that is active in the field of dairy and milky products for more than half a century. These products are distributed in more than 360 points of sales in Greece, while during the last years the company has expanded its sales in 12 countries in Europe, Asia and Africa[1].

The major concern of Pagonis family is the respect of the traditional practices in dairy goods production in order to guarantee the end-customer safety and high quality. This leads the company to keep stable and long life collaborations with local and regional breeders and to aim at securing the overall control and traceability of its products throughout its entire supply chain. Towards this direction, the company on one hand offers breeders continuous technical support in terms of good practices and on the other hand performs daily quality controls of the raw materials either in the company's certified laboratory or certified external laboratories. Milk, which is the basic raw material, is collected on a daily basis from approximately 100 breeders and is controlled for its composition (fat, protein, SNF, addition of other kind of milk, addition of water), presence of inhibitory substances / antibiotics, as well as for its microbiological state (TCC), but also for the number of somatic cells (cow milk). Additionally, microbiological and physicochemical analysis are carried out for the company's products, either in the company's laboratory or/and in the laboratories of external partners.

The quality control system of the company is certified according to ISO 22000:2005 and implements a HACCP approach. Therefore, its traceability procedure is designed to comply with regulations, to support products' safety and quality, to improve the effectiveness, productivity and profitability of the company and to meet customers' expectations according to the standards' basic requirements. The person responsible for applying the process is the company's Quality Assurance Manager. If there are any changes required in the process, the company's CEO and the Quality Assurance Manager are responsible.

According to the company's HACCP procedures/records and flow charts (see Figure 2), the process begins with the

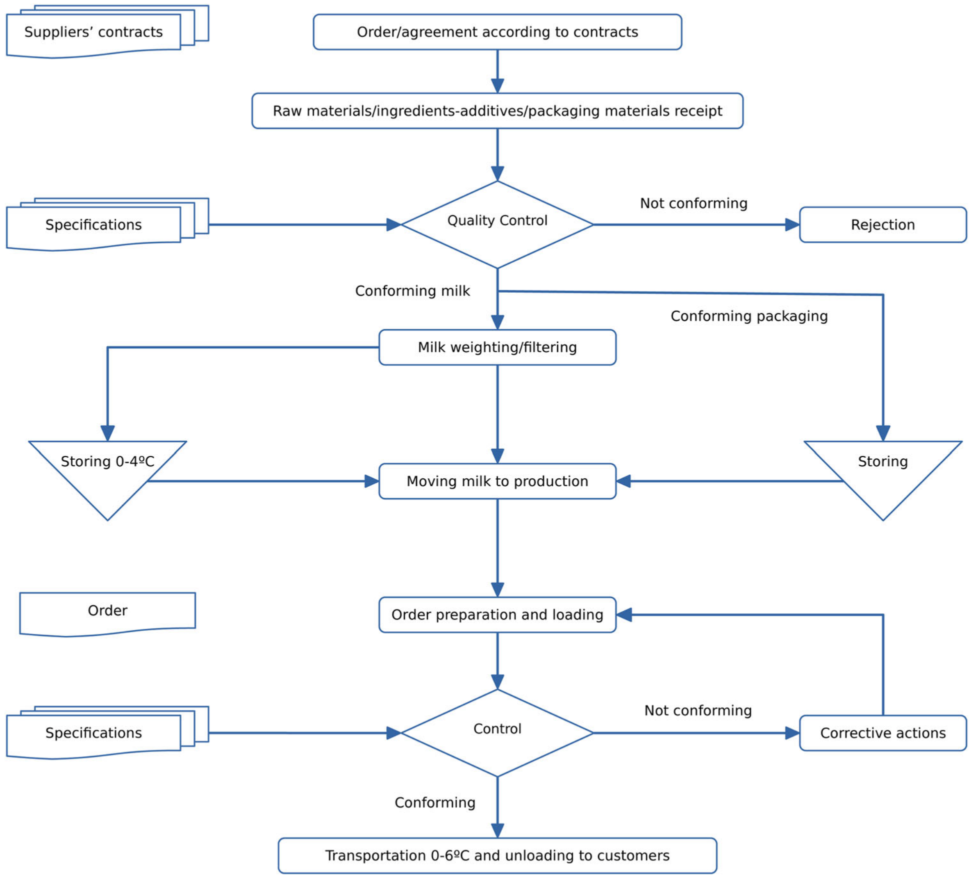

Figure 2. Pagonis Daily HACCP flow chart.

incoming materials' receiving. As verified from the company's ISO22000:2005 internal documentation ('Products' Identification and Traceability Process"), the information to be compulsorily recorded by the Quality Control Manager and Production Manager in every product's process control sheet comprises of the incoming materials' supplier's name, denomination, quantity, arrival date and transporter. All incoming raw materials, other ingredients/additives and packaging materials are identified by a code number or their arrival date (a six digits unique code dd/mm/yy). Especially for each type of milk (cow, goat, sheep), the identified/coded incoming is the total quantity received from a single day vehicle routeing that has collected milk from a single or multiple breeders. Then the product's process control sheet identifies its type and production date (an 1 to 3 letters code for the product type and a six digits code dd/mm/yy for the production date), which is monitored during its stay in company's premises. The BOM (Bill of Materials) is recorded, along with the control parameters, the place where the control is conducted, the person responsible and the results (data, conforming/non-conforming checks) in all production phases. Finally, for the transportation and delivery to the end-customer (wholesaler or retailer), this code is recorded on the order receipt and delivery invoice. In general, data to be recorded in the invoices include: weight and number of SKUs (Stock Keeping Units) delivered, name and code number of the final product, customer's name and date and time of delivery.

3.2. Experiments and integration details

The required interactions between stakeholders, products and processes have been implemented by means of smart contracts and different tests have been performed in a local private blockchain to showcase the feasibility and performance of the proposed method. More specifically, an Ethereum-based blockchain using `node`[2] and `ganache-cli`[3] was created, and `truffle`[4] was used to code and deploy a set of fully functional smart contracts. Moreover, a graphical interface was developed in order to query the information stored in the blockchain by using node package manager `npm`[5], which also retrieves the corresponding pedigree hash of a product's information and its link to the Inter-Planetary File System (IPFS) (Benet 2014), as seen in Figure 3. Ethereum was selected due to its robust consensus mechanism as well as its smart contract framework (i.e.

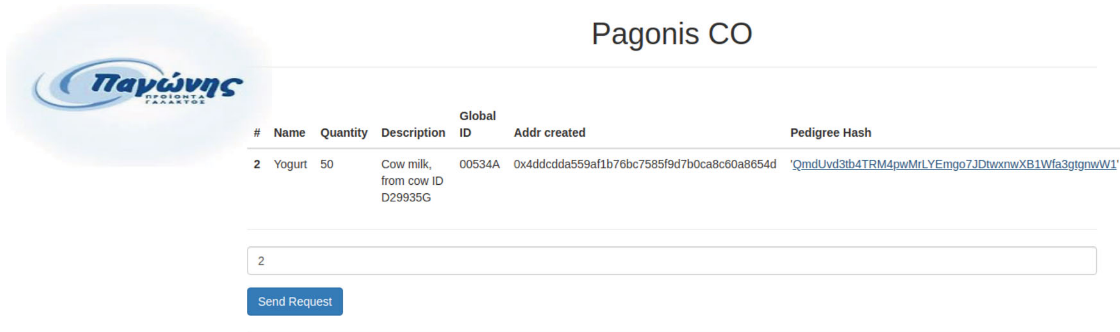

Figure 3. Pagonis blockchain query interface.

we use solidity 0.5.0, which prevents vulnerabilities such as *unitialised storage pointer* and *erroneous visibility*). For more information about the security of Ethereum and its smart contract framework, the interested reader may refer to Xiao et al. (2020) and Chen et al. (2019), respectively.

The proposed framework consists of three smart contracts (see Figure 4). The first one includes the main relationships between raw materials, products and their interactions with stakeholders and processes, as well as tracking internal characteristics such as temperatures and location. The second smart contract manages the stakeholders list and their interactions with products. Finally, the third enables the managerial tasks related to processes. Note that the implementation of different smart contracts to manage each set of interactions enables more fine grained and transparent resources' management. For the sake of completeness, a detailed description of the functions implemented in the Products, Stakeholders and Processes smart contracts in Tables 1, 2 and 3, respectively, is provided. As an additional feature, every time the information of the smart contract is updated, a *trigger()* function is called, which can be used as an alert. Therefore, the stakeholders will be able to check in real time the information about the contents of the order using the *get/retrieve* functions implemented in the smart contracts for verification or managerial purposes.

In addition to the benefits enabled by the smart contracts, it is essential to guarantee the privacy of the transactions and the involved actors. Therefore, the contents can be modified only by participants with specific roles (each function is implemented with concrete permissions, e.g. using the *require* clause of solidity and variables such as *msg:sender* to check account authenticity), thus enabling secure access control. For example, stakeholders will be able to create new processes, or to add new product traces or temperatures (i.e. this information can be retrieved directly from IoT devices interacting with the blockchain). Read-only functions and variables can be checked by public users, in order to enhance the trust of the consumers (e.g. basic qualitative information of final products). On the other hand, if it is desired to apply

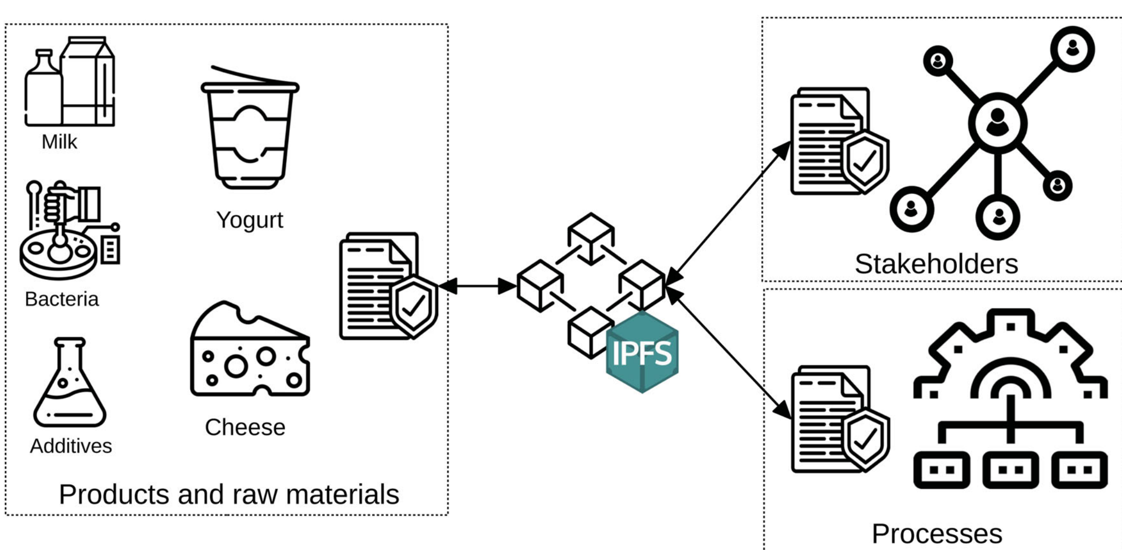

Figure 4. Interaction flow between the different smart contracts.

Table 1. Main characteristics and permissions of the functions implemented in the Products smart contract.

Code	Function	Input	Output	Permissions	Description
*pr*1	constructor	void	na	na	creates the smart contract
*pr*2	addProduct	String name, uint quantity, String description, String globalID, hash	void	A,S	adds a new product to the system
*pr*3	UpdateProductDescription	uint productID, String description	void	A,S	updates the description of a product
*pr*4	addTestProduct	uint productID, String test_number	void	A,S	updates chemical tests of product
*pr*5	getNumberOfProducts	void	uint	P	global number of products
*pr*6	getProduct	uint productID	Product struct	A,S	global information of a product
*pr*7	getProductGlobalID	uint productID	uint	P	the global product ID
*pr*8	getProductTest	uint productID	hash	P	the id of the test
*pr*9	getProductHistoric	uint productID	hash	P	product pedigree information
*pr*10	addTrace	uint productID, string location, string temp_owner, timestamp	void	A,S	adds a new location to a product
*pr*11	addTemperature	uint productID, uint celsius, string temp_owner, timestamp	void	A,S	adds a new temperature to a product
*pr*12	getNumberOfTraces	void	uint	P	global number of traces
*pr*13	getNumberOfTemperatures	void	uint	P	global number of temperatures
*pr*14	getTrace	uint traceID	Trace struct	A,S	trace information
*pr*15	getTemperature	uint temperatureID	Temperature struct	A,S	temperature information
*pr*16	getNumberOfTracesProduct	uint productID	uint	A,S	number of traces of a product
*pr*17	getNumberOfTemperaturesProduct	uint productID	uint	A,S	number of temperatures of a prodcut
*pr*18	getTracesProduct	uint productID	List of traces	A,S	traces information of a product
*pr*19	getTemperaturesProduct	uint productID	List of temperatures	A,S	temperatures information of a product
*pr*20	retrieveHashProduct	uint productID	hash	P	hash of product information
*pr*21	triggers	void	void	na	trigger events for updates
*pr*22	updateNumberOfProcesses	address ext	void	P	updates number of processes (external call)
*pr*23	checkStakeholder	address ext, address stakeholder	boolean	P	returns true if a stakeholder exists (external call)

Note: In the permissions column, A states for Admin(s), S for Stakeholder(s) and P for Public.

Table 2. Main characteristics and permissions of the functions implemented in the Stakeholders smart contract.

Code	Function	Input	Output	Permissions	Description
*s*1	constructor	void	na	na	creates the smart contract
*s*2	addStakeholder	String name, timestamp, string description, address stakeholder	void	A	adds new stakeholder to system
*s*3	addStakeholderProduct	uint id, address stakeholder	void	A,S	relates a product with a stakeholder
*s*4	changeStatus	boolean active, address stakeholder	void	A	changes status of stakeholder
*s*5	getStakeholdersProduct	uint id	List of products	A,S	list of stakeholder's products
*s*6	getStakeholder	uint id	Stakeholder struct	P	stakeholder global information
*s*7	getNumberOfStakeholders	void	uint	P	total number of stakeholders
*s*8	exists	address stakeholder	boolean	P	returns true if a stakeholder exists
*s*9	updateNumberofProducts	address ext	void	P	updates number of products (external call)
*s*10	updateNumberOfProcesses	address ext	void	P	updates number of processes (external call)

Note: In the permissions column, A states for Admin(s), S for Stakeholder(s) and P for Public.

more restricted policies, although not mandatory in private blockchain contexts, functions *s*8, *p*9 and *pr*23 could be used to provide another layer of security (i.e. only registered and active stakeholders will be able to commit changes when enforced with the *require* clause).

In order to provide a practical link between the smart contracts and the traditional tasks enabled by them, the relation between the implemented functions and high-level managerial requirements is described in Table 4.

The transactions tested in the developed private blockchain (e.g. deployment of the smart contracts, adding a product, adding a process and adding a stakeholder) are performed in the order of milliseconds, and thus, the approach enables real-time interactions. The

Table 3. Main characteristics and permissions of the functions implemented in the Processes smart contract.

Code	Function	Input	Output	Permissions	Description
*p*1	constructor	void	na	na	creates the smart contract
*p*2	addProcess	String name, timestamp, string description	void	A,S	adds a new process
*p*3	addProcessProduct	uint id	void	A,S	relates a product with a process
*p*4	changeStatus	uint id, boolean active	void	A,S	changes status of a process
*p*5	getProcessProduct	uint id	List of products	A,S	list of products related with a process
*p*6	getNumberofProductsProcess	uint id	uint	A,S	number of products related with a process
*p*7	getProcess	uint id	Process struct	A,S	process global information
*p*8	getNumberOfProcesses	void	uint	P	total number of processes
*p*9	checkStakeholder	address ext, address stakeholder	boolean	P	returns true if a stakeholder exists (external call)
*p*10	updateNumberofProducts	address ext	void	P	updates number of products (external call)

Note: In the permissions column, A states for Admin(s), S for Stakeholder(s) and P for Public.

Table 4. Relationship between managerial requirements and the implemented smart contract functions.

Managerial Requirement	Code Function		
stakeholders operations and participation	*pr*10–11, *pr*18–19, *pr*23	*p*2, *p*3, *p*7–9	*s*2–*s*8
product lifecycle and quality assurance	*pr*2–20	*p*3, *p*5–6	*s*3, *s*5
processes data, interrelations with products and stakeholders	*pr*6, *pr*22	*p*2–*p*8, *p*10	*s*6, *s*9–10
products pedigree, quality tests and storage	*pr*4–*pr*9, *pr*14–*pr*20	*p*3, *p*5–6	*s*3, *s*5
product distribution operations	*pr*3, *pr*5–20	*p*3, *p*5	*s*3, *s*5–6
global statistics	*pr*5, *pr*8–10, *pr*12–13, *pr*16–20, *pr*22	*p*5–6, *p*8	*s*5, *s*7, *s*9–10

implementations as well as the graphical web service are available on GitHub[6].

4. Discussion

The proposed blockchain-enabled model provides significant advantages and has various benefits in terms of improved trust, efficiency, quality and resilience (see Figure 5). Specifically in terms of efficiency (a) it minimises the overall handling of traceability processes and, therefore, the relevant traceability-related operating costs and (b) removes hidden costs and paper load from the FSC traceability process. The automation provided by the deployment of smart contracts (forcing the execution of almost all traceability-related functions through smart contracts) also serves as a cost-reduction mechanism. Moreover, the self-executing capabilities of smart contracts guarantee redundancy with real-time synchronisation of the corresponding information.

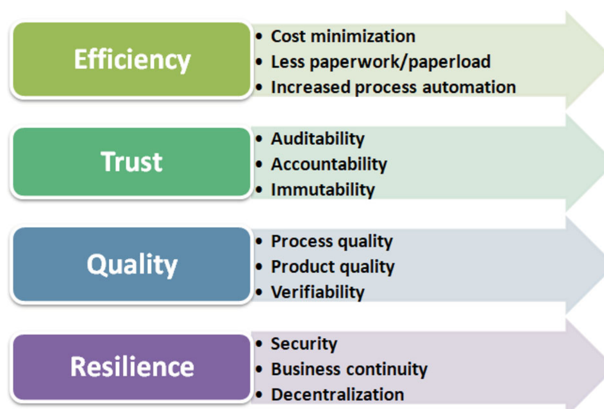

Figure 5. Performance characteristics of the proposed blockchain-enabled FSC traceability model.

Apart from the inherent security of the blockchain architecture, the proposed model also offers excellent benefits in terms of auditability and trust (auditable records that can be inspected and used by key participants or by external stakeholders like regulators, policymakers, etc.). It takes into account the importance of regulatory compliance, particularly in safety-sensitive industries like food, in which traceability becomes an ongoing concern for various SC stakeholders (consumers, SC managers, public policymakers and special interest groups). It provides significant benefits to the overall regulatory framework related to SC traceability by (a) mobilising state structures responsible for traceability regulations and bodies in charge of reporting cases of harmful/dangerous products, (b) simplifying and automating the record-keeping and information exchange and (c) granting easiest access to traceability data for regulatory authorities and policymakers. In particular, its free, decentralised and trustless nature provides regulators with an easiest access to traceability processes/data on time, paving the way for continuous traceability supervision. Moreover, the proposed architecture will enable not only the tracking of products but also the tracking of processes and therefore, will grant access to the full link between the goods provided to the consumers and the operations executed in the various SC processes.

The proposed model also increases the overall quality and safety of the products/services offered to consumers. Food safety is an increasingly important public health issue, and the implemented architecture will enhance several aspects of business operations like, for instance, improved process control for managing product recalls and/or product quality. Besides, the immutable and distributed nature of the proposed mechanism safeguards quality since any tampering with food data can be immediately identified and prevented. As a direct consequence, the high quality of food products offered to end-customers reinforces the business continuity of the FSC participants. Moreover, blockchain's inherent features enhance the accuracy, trustworthiness, timeliness and usability of the exchanged traceability records.

It should also be noted that the proposed modelling approach offers significant benefits in terms of SC resilience by (a) eliminating both system boundaries and geographic limitations and (b) allowing the integration of heterogeneous traceability-related data across the entire SC. For instance, the decentralised nature of blockchain prevents denial of service attacks, contrary to centralised systems. The latter prevents possible loss of information, which could entail monetary losses as well as health risks for the customers. Blockchain is also suitable when transactions and operations need to be traced (sequential chain of events) or when operations require strong security and privacy (centralised data structures are more vulnerable to malicious attacks than decentralised structures). The use of decentralised storage such as IPFS guarantees the integrity of the information, since the access to objects is content-oriented (i.e. each hash is unique, and so is the information of a specific file). Therefore, the use of timestamps and hashes guarantees the proof-of-existence as well as the immutability of the contents in the proposed framework. Note that contents are stored with their corresponding timestamps and hash variables point to external information in each case.

Currently, Pagonis Sisters and Co. products' tracking process is conducted only by phone. If the product's delivery was made to retailers, then they are directly called from the company, but if the delivery was made to wholesalers, then the company does not know the retailers that the product has been delivered, therefore the wholesalers must call them. Moreover, if there is a potential hazard for public health due to a product's safety/quality issue, then public authorities must also be notified by phone. The process' duration may vary significantly (typically it takes several hours for the described phone quest), depending on the product's sales network, especially in the case of exporting abroad, which leads to cost ineffectiveness and valuable time loss.

Concluding, according to the national legislation (law 4235/14), which incorporates EU legislation requirements, there is an obligation of administrative measures, procedures and penalties in the fields of food, feed, animal health/welfare and other provisions of responsibility of the Ministry of Rural Development and Food. Article 5 of the above law declares that in the context of the implementation of official control, if the competent authorities find noncompliance with the requirements or procedures laid down by Union and national legislation, they shall impose immediately the measure of restricting or prohibiting the placing on the market of food or feed by the procedures of seizure. Moreover, according to article 8, in order to effectively remove or withdraw unsafe food or feed from its supply chain, the business unit must maintain an adequate (not exhaustively described) traceability system. As part of a measure to withdraw food or feed, the following obligations are described: (a) to remove unsafe food or feed directly from the distribution network on business' own responsibility, (b) to store in a special, separate place with appropriate labelling of the food or feed concerned and keep appropriate documentation, (c) to inform the local competent authority immediately and in writing, (d) to cooperate with any other distribution network operator to ensure effective withdrawal or recall and e) to inform the consumers immediately providing clear information on the type, characteristics and the reasons for the recall. Table 4 highlights the compliance of the implemented smart contract functions with the above mentioned national regulations. It supports products' safety and quality, it improves the effectiveness and productivity and thus company's profitability and meets customers' requirements.

5. Conclusions

In this paper, a blockchain-based framework for FSC traceability is presented. The various traceability functionalities provided along with the various stakeholders/processes/products involved as well as their interrelationships are detailed. More concretely, blockchain is used as a distributed tamper-proof chain-of-custody mechanism and Smart Contracts as an automation mechanism for managing SC stakeholders and processes as well as for product definition and creation. A real-world case scenario is presented for defining the context and the managerial requirements of a local food provider (dairy company). Implementation details are provided by using a local private blockchain and the details of three smart contracts, which implement a set of functions to provide an end-to-end traceability flow, from raw materials acquisition to end customers product delivery. Several benefits of the proposed blockchain-enabled SC traceability model such as improved SC process management, security and resilience are discussed.

Although the proposed blockchain-enabled SC traceability approach presents significant SC functionalities, some limitations should be taken into consideration. Blockchain technology is not suitable for storage of vast amounts of data and it is recognised that scalability is one of the main challenges to solve, stemming from the time required to confirm/verify transactions. For example, a multi-tier FSC network would require the processing of a large number of transactions in a relatively short period; therefore, scalability issues could arise. In this regard, the use of private permissioned blockchain guarantees the necessary performance in food supply scenarios. Nevertheless, a hybrid approach (i.e. use a private blockchain to store all the details and store only the hashes of the blocks in a public blockchain), could be used to enable trust and verifiability of the system without compromising its performance. Future research could also focus on the enhancement of the illustrated implementation to provide interoperable features and standardised information structures. To this end, the use of tokens and different granularity levels are promising areas in conjunction with supply chain optimisation techniques.

Notes

1. http://www.pagonis-dairy.gr/en/.
2. https://nodejs.org/.
3. https://github.com/trufflesuite/ganache-cli.
4. http://truffleframework.com.
5. https://nodejs.org/en/knowledge/getting-started/npm/what-is-npm/.
6. https://github.com/francasino/food_supply_case_scenario.

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Disclosure statement

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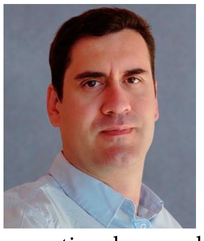
Notes on contributors

Fran Casino Cembellín (Tarragona, 1986) is a postdoctoral researcher in the Department of Informatics at Piraeus University (Piraeus, Greece). He obtained his B.Sc. degree in Computer Science in 2010 and his M.Sc. degree in Computer Security and Intelligent Systems in 2013, both from Rovira i Virgili University in Tarragona, Catalonia, Spain. He received a Ph.D. in Computer Science from the Rovira i Virgili University in 2017 with honours (*A cum laude*) as well as the best dissertation award. He was visiting researcher in ISCTE-IUL (Lisbon-2016). He has participated in several European-, Spanish- and Catalan-funded research projects and he has authored more than 40 publications in peer-reviewed international conferences and journals. His research focuses on pattern recognition, and data management applied to different fields such as privacy and security protection, recommender systems, smart health and blockchain.

Venetis Kanakaris was born in Komotini, Greece. He received the B.Eng. degree in Electronic Engineering from Lamia Technical University, Greece, the B.Eng. degree in Electrical Engineering from Kavala Technical University, Greece, in 2004, and the M.Sc. degree in Telecommunications and Technologies from Technical University of Gabrovo, Bulgaria, in 2006. Also, received his PhD from University of Portsmouth in 2012, U.K. as well as the M.Ed. from Open University of Greece in 2013. Since October of 2016, is adjunct Lecturer at International Hellenic University, Dept. of Computer Science, Kavala, Greece. His current research interests lie in energy ad hoc routing protocols and low-power underwater wireless sensor protocol architecture OSINT techniques, LORA infrastructures, Blockchain technologies in farming and agriculture. Besides the engineering research interests, he focusses on lifelong learning sector as well as the adult education. At the present he is postdoctoral student at School of Early Childhood Education, Aristotle University of Thessaloniki in Greece.

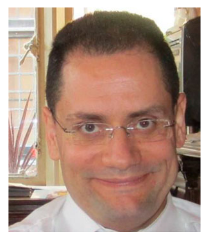


Thomas K. Dasaklis graduated from the University of Piraeus, Department of Industrial Management and Technology. He holds a M.Sc. degree in supply chain management and a Ph.D. degree in emergency supply chain management and disaster response. His research interests lie in the area of supply chain management, operational research, humanitarian logistics/disaster response, data analysis, and blockchain technology. He has participated in National and European Research projects and has published papers in several international journals and conference proceedings. He has worked for the European Commission (DG Humanitarian Aid and Civil Protection) and the University of Piraeus Research Centre. He has also worked in the private sector for three years as supply chain director. He is Adjunct Academic Staff at the Hellenic Open University. He is also seasonal lecturer at the Department of Informatics, University of Piraeus.

Socrates J. Moschuris is an Associate Professor of Logistics and Supply Management at the Department of Industrial Management and Technology, School of Maritime and Industrial Studies, University of Piraeus, Greece. He has a Bachelor degree from the Department of Business Administration, Piraeus Graduate School of Industrial Studies, Greece. He has also a Ph.D. degree from the Department of Industrial Management and Technology, University of Piraeus, Greece. He has extensive teaching and research experience in the field of supply management, procurement, supply chain management and logistics. Under his supervision, three Ph.D. dissertations have been completed. His work has been published in scientific journals such as *Omega, European Journal of Marketing, Production and Inventory Management Journal, International Journal of Operations and Production Management, Industrial Marketing Management, Journal of Supply Chain Management, Journal of Health Organization and Management, Journal of Public Procurement, EuroMed Journal of Business, and Sustainability*. He has also published papers in conference proceedings and volumes. He has a large number of citations. He is a reviewer in a number of scientific journals. He is a member of the Economic Chamber of Greece, Hellenic Purchasing Institute, IPSERA, and Institute for Supply Management.

Spyridon Stachtiaris is a graduate of the Department of Food Science and Technology of the Agricultural University of Athens (1997), graduated from the Postgraduate Program in Decision Sciences (International MBA) at the Athens University of Economics and Business (2000). He holds a Master's Degree in "Integrated Rural Development and Management" from the Agricultural Economics Department of the Agricultural University of Athens (2006). Moreover, he holds a PhD from the Department of Agricultural Economics and Development of the Agricultural University of Athens on the topic of consumers' willingness to pay (WTP) to participate in the market for quality products – a methodological approach (2013). He holds an ISO 9000: 2000 Quality Assurance Systems Inspector Certification from the International Inspection Certification Authority (IRCA / IATCA and RAB (USA)). He currently works at ELGO DIMITRA as a Strategic Planning and Policy Officer, where he has served for many years as Head of Services such as the Certification and Specifications Directorate as well as the General Directorate of Agricultural Education & Training. He has taught the course "Marketing Management" and "Total Quality Management" at the University of Patras and University of Piraeus. He has participated in research projects in the "Innovation and Entrepreneurship Unit" at the Agricultural University of Athens and in Horizon 2020 research projects. His scientific interests are in the fields of Marketing Management, Rural Entrepreneurship and Quality Assurance management.

Maria Pagoni graduated from the University of Bari, Italy, specializing in Molecular Biology and Biochemistry. She completed her master's degree in Molecular Medicine at the University of Essex in England. She won a scholarship from Cardiff University in Wales where she studied the genetics of prostate cancer and the role of environmental epigenetic activity in the development of the disease. During her stay, she taught General Biochemistry, Protein Biochemistry, Spectrophotometry, Enzymology, Microscopy and Histology to undergraduate students of the School of Medicine and Life Sciences. Her work on cancer was sponsored at the China-UK Cancer Conference 2015 in Cardiff, UK. She is trained in clinical trials by MTA, Medical Trials Analysis CRO, Italy. She was a collaborator of the Urological University Clinic of Patras, of the Bioinformatics laboratory at the BRFAA, but also of the Bioinformatic team of the department of Biochemistry of Bari in Italy. Today she is a collaborator of the proteomics at BRFAA and the pharmacology department of National and Kapodistrian University of Athens. As a freelancer, is licensed to practice her profession in Research and Development and she is registered at the ONB (National Order of Biologist in Italy). She is professionally based in Italy and Greece. She is a co-owner of Pagonis Sisters and Co., dealing with quality control procedures and product design for people with medical records.



Nikolaos P. Rachaniotis is Assistant Professor in Supply Chain Management in University of Piraeus, Department of Industrial Management and Technology. His research interests lie in the area of Decision Support Systems, Humanitarian Logistics and Epidemics control. He has published in several peer-reviewed international academic journals such as *International Journal of Production Research, European Journal of Operational Research, International Journal of Production Economics, Journal of Heuristics, Transportation Research Part E, Computers and Mathematics with Applications and International Journal of Logistics*.

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