A Note on Enactment of Blockchain for HACCP-based Cooperative Model

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Received: December 10, 2021; Accepted: February 5, 2022; Published: February 28, 2022

Abstract

Food safety has lately attracted an upsurge of academic and industrial concerns. Blockchain technology with several platforms available combined with the internet-of-things system has grown significantly in improving traceability in the supply chain area, providing openness, transparency, neutrality, reliability, and security to all members. The food traceability system is addressed through Hazard Analysis and Critical Control Points (HACCP) testing that meets the standard criteria for physical, microbiological, chemical, and visual observations. These approaches are argued capable of covering the drawbacks of a centralized system that is vulnerable to collapse since a single point of failure (SPoF) can lead the whole design to collapse. However, adopting blockchain technology instantly without considering specific parameters can negatively affect the system. Therefore, in this paper, we elaborate on the critical points to be considered in adopting blockchain into a food safety environment which refers to the HACCP-based cooperative model. This paper also notes and explores an empirical investigation of the decentralized HACCP model with several techniques, including the pros and cons. Finally, we recapitulate the essential details to consider in developing blockchain technology in food safety systems.

Keywords: Blockchain, decentralized technology, food safety, HACCP, traceability

1 Introduction

During the last couple of decades, food safety management has been a serious concern by consumers and related institutions. Consumer confidence and satisfaction are decreasing over time due to the many food safety incidents and scandals that occur in many aspects [1], such as genetically modified food, mad meat disease, toxic milk, deadly E.coli bacteria in lettuce, to name a few. The food quality management process from raw production to distribution is essential in maintaining the human body's immune system, especially during the coronavirus disease of the 2019 (COVID-19) pandemic. The research in [2] states that among 50 US states, 36 (72.0%) responded to the Centers for Disease Control and Prevention (CDC) inquiry; where 33 (91.7%) noted $\geq$1 laboratory-confirmed COVID-19 case among the food processing, food manufacturing, or agriculture workers throughout March up to May 2020. Therefore, the food control institutions require a system that can overcome these issues, which refer to the general standards that have been established in every country. There are multiple standards organizations to ensure the food quality management systems, such as Good Hygienic Practice (GHP), Good Manufacturing

Journal of Internet Services and Information Security (JISIS), volume: 12, number: 1 (February), pp. 44-56
DOI:*10.22667/JISIS.2022.02.28.044*

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Practice (GMP), Global Food Safety Initiative (GFSI), and Hazard Analysis and Critical Control Points System (HACCP). In this research, we emphasize the application guidelines of HACCP since it is an internationally recognized system with a systematic preventive approach for reducing the risk of safety hazards in food (biological, chemical, and physical hazards).

The application guidelines HACCP integrated into the supply chain system still have drawbacks, namely single point of failure (SPoF) inherent to the centralized system. The SPoF is practically a flaw in the design, configuration, and supply chain implementation that poses a potential risk that can lead to a malfunction or fault in access to the information. Accordingly, academia and industry have developed a new approach to eliminate the SPoF issue, such as adopting blockchain technology that transforms the centralized supply chain to a decentralized manner. By nature, blockchain removes the dependency on a single node in deploying a transaction while preserving an immutable data record (permanent and unable to be changed). Blockchain also provides anonymity and privacy with a decent security mechanism. In short, it would be inconceivable to attack every simultaneously. Blockchain in the supply chain environment can also increase access for diverse populations and locations, improving the transaction's scalability. Conclusively, blockchain brings uncountable benefits at first glance. However, the decentralized approach is still in its infancy, whereby several challenges must be well-addressed.

Embracing blockchain technology for supply chain management concerning the HACCP-based cooperative model faces numerous critical deliberations. Many factors are considered in integrating decentralized technology into the HACCP system that can affect security, transparency, legitimate entities, regulations and management, awareness and adoption, latency, complexity, and so forth. Not to mention that several countries do not fully accept the practical system where blockchain is the core technology. Despite the varying regulations of different countries, we elaborate on the critical aspects of implementing blockchain technology in HACCP-based cooperative models. We also emphasize the empirical investigation and evaluation of the existing techniques with several blockchain platforms. Typical hazard control for HACCP food safety plan and digital valuation assets with International Financial Reporting Standards are also presented.

The roadmap of this paper is organized as follows. Section 2 presents the background of blockchain technology and the HACCP-based cooperative model as the core components. These technologies synergize in forming a decentralized food safety traceability system. The motivation of the paper is outlined in Section 3. Whilst Section 4 details the existing concept of blockchain for HACCP-based cooperative model derived from multiple resources. We also describe the outcome of a mapping study in this Section. Eventually, we conclude our paper in Section 5.

2 Blockchain-based Traceability in Agri-Food Sector - An Overview

This section briefly defines the core components of the decentralized HACCP-based cooperative model approach. Firstly, we start the background by presenting the decentralized ledger technology technique with no intermediaries involved in conducting a transaction. Secondly, this section describes the HACCP-based cooperative model for food safety plans by referring to the existing system. Lastly, the blockchain technology for the HACCP system is delivered with rigorously selected supporting theories.

The applications based on decentralized approaches have grown in prominence in recent years. Many researchers/clinical practitioners cite blockchain benefits regarding different aspects of any enterprise, market, agency, or governmental institution. Since blockchain appeared in 2009 through Bitcoin cryptocurrency, numerous achievements have been assembled regarding how decentralized ledger can be utilized in various fields of sciences and industries. Blockchain technology can be understood as a system of recording information that makes it complex or impossible to modify, hack, or cheat the system. Every block in the network consists a number of transactions, and each new transaction is added to every

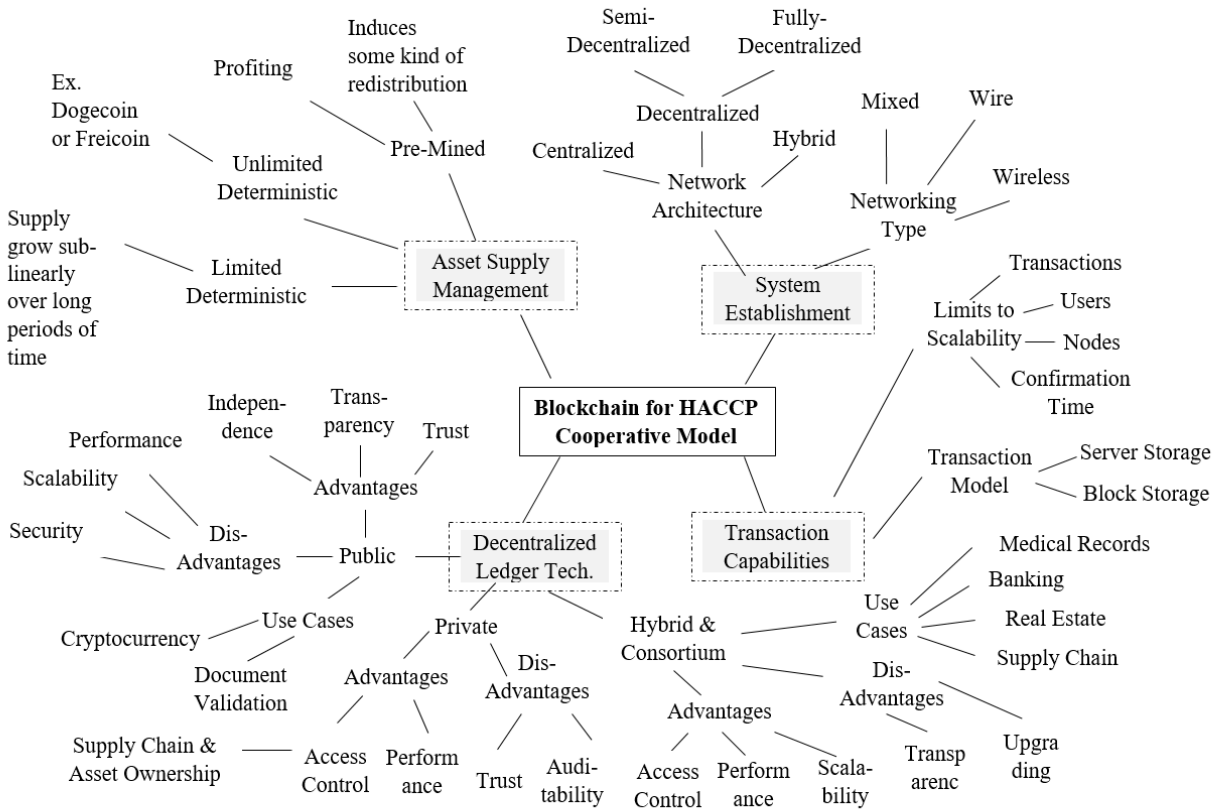

Figure 1: Topology of blockchain for HACCP cooperative model.

member's ledger. A cryptographic fingerprint unique to each transaction block and a consensus protocol to guarantee the stable function during the operation makes blockchain becomes immutable.

Food safety is essential to humankind; therefore, FAO (Food and Agriculture Organization of the United Nations) adopted HACCP systems and guidelines for its application in 1997. Nowadays, HACCP is a standard in the food industry used worldwide. Manufacturing industries, including the food industry, are evolving to be more and more automated through stunning developed ICT for effectiveness [19]. For the HACCP process, checking and controlling the CCP factors through the sensors can automatically keep monitoring stable and prevent manual alteration of the actual data. Even if the HACCP-based cooperative model is established, there are often cases in which food companies intentionally tamper with CCP-related data to forge HACCP authentication. More and more attempts have recently been made to prevent the forgery of data and track and manage problems in the event of food safety accidents using blockchain technology. The research in [19] shows an example of implementing the HACCP-based cooperative model by applying blockchain technology.

In this research, blockchain for the HACCP cooperative model can be understood as integration between a decentralized approach for HACCP, critical control points factors, and equipment status monitoring (hardware and software) in the agri-food sector. The scope of decentralized HACCP might be broadened covers many aspects, such as transaction capabilities, asset supply management, system establishment, as shown in Figure 1. The type of blockchain selection in decentralized HACCP is essential since various platforms and approaches exist. In general, there are four types of blockchain structures; namely, permission, permissionless, and hybrid blockchain networks. Every type of blockchain structure has distinct characteristics that may not be suitable for every use case, including the HACCP system. The

Table 1: Summary of previous researches in chronological order.

Author	Year	Source Type	Application Area	Maturity
Kamble et al. [3]	2022	Conference	Agriculture domain (decentralized)	Concept and theory
Tan et al. [4]	2022	Book series	Supply chain	Theory
Rana et al. [5]	2021	Journal	Agri-food management	Literature review
Casino et al. [6]	2021	Journal	Dairy sector	Design and architecture
Al-Amin et al. [7]	2021	Conference	E-agro business	Model and architecture
Saurabh et al. [8]	2021	Journal	Agri-food	Concept and Theory
Niknejad et al. [8]	2021	Journal	Food and agriculture industry	Bibliometric analysis
Cocco et al. [9]	2021	Journal	Traditional bakery use cases	Implementation
Sudha et al. [10]	2021	Conference	Traditional bakery	Implementation
Biscotti et al. [11]	2020	Conference	Food safety system	Concept and theory
Danish et al. [12]	2020	Journal	Food supply chain	Model and adoption
Qian et al. [13]	2020	Journal	Agriculture	Concept and theory
Xu et al. [14]	2020	Journal	Food safety management	Theory and evaluation
Jie et al. [15]	2020	Journal	Agri-food	Criticial thinking and Literature review
Liu et al. [16]	2020	Journal	Food traceability management	Traceability framework and implementation
Bumblauskas et al. [17]	2020	Journal	Supply chain	Implementation
Sunny et al. [18]	2020	Journal	Supply chain	Implementation
Kho et al. [19]	2020	Journal	Smart Factory (co-operative model)	Architecture
Astill et al. [20]	2019	Journal	Supply chain	Proposal
Creydt et al. [21]	2019	Journal	Supply chain	Proposal
Ejaz et al. [22]	2019	Book series	Food traceability and smart home	Implementation
Casino et al. [23]	2019	Journal	Food supply chain management	Model and architecture
Rahmadika et al. [24]	2018	Conference	Supply chain	Concept and theory
Kim et al. [25]	2018	Journal	Supply chain	Architecture
Tian et al. [26]	2018	Degree thesis	Supply chain based on HACCP	Evaluation
Moran et al. [27]	2017	Journal	HACCP	Proposal
Tien et al. [1]	2017	Conference	Supply chain	Proposal

industries and developers must also consider the network architecture type (semi or fully decentralized) in terms of system establishment. Therefore, several factors must be thoroughly considered.

3 Motivation

Most previous studies have focused on implementing blockchain technology for the HACCP-based collaborative model (supply chain environment). Several mapping studies have either focused on blockchain throughput, scalability, or security and privacy as highlighted in Table 1 (detail in Section 4). Moreover, the vast majority of research is not derived from a systematic mapping study, resulting in the research's comprehensiveness and meaningfulness staying insignificant. In a nutshell, blockchain technology can improve the conventional HACCP-based cooperative model in terms of process integrity, traceability, security, unparalleled transparency (instant transparency), and faster processing. By nature, decentralized permanent transaction records can provide accurate tracking while also preserving an absolute user's anonymity. However, in the long run, blockchain can also be very expensive regarding the cost of mining (proof-of-work consensus), power consumption with many environmental consequences, market manipulation, scalability and cybersecurity concerns, competing platforms, and the concerns about the absence of physical form or intrinsic value as described in [28]. Therefore, an in-depth analysis of the blockchain technology and several benchmarks in Figure 1 and the HACCP system is required regarding the benefits and risks of developing the decentralized HACCP system.

Due to the aforementioned concerns, we present critical points to be appraised in embracing blockchain into a food safety management which refers to the HACCP-based cooperative model. We derive several essential points from many literature reviews that have been chosen through rigorous screening, such as the quality and correctness of the information, suitability of data, type of publication, and to name a few. To support this, we also note and investigate an empirical analysis of the decentralized HACCP model with different existing techniques, including the advantages and drawbacks in real-world applications. The final objective of this paper is to bridge the research gap by elaborating a systematic mapping analysis. Eventually, this paper cultivates current bibliographies on implementing blockchain technology in supply chain management with the HACCP-based cooperative model. Even though this paper does not cover many aspects of security, scalability, and so on; however, it would provide valuable insights in developing proper advancement techniques for a decentralized HACCP environment.

4 Decentralized HACCP Cooperative Model

Firstly, this section presents the outcome of the mapping study in adopting blockchain for several application areas. We selected numerous related research from different sources, such as journals and conferences. Secondly, we elaborate on the existing works as well as our perspective about hazard control for the HACCP food safety plan and blockchain consideration, including the protocols and algorithms to secure blockchain transactions.

4.1 The Outcome of a Mapping Study

The implementation of blockchain technology in the agriculture domain has been extensively increasing over the years. The food supply chain has become more complex. It has a lot of ability to make foodborne illness outbreaks during processing. When the problems happen, tracking which part caused the situations is needed, where HACCP regulations back the environment. Hence, decentralized traceability and transparency supply chain management can be a plausible solution where a single node does not fully control the transaction; instead, every entity possesses the same database status. Figure 3 can be understood as a practical example of Critical Control Points (CCP) used by the HACCP-based cooperative model in general. Monitoring the CCP is the key point of the HACCP system for the supply chain. The workers manually recorded and checked the CCP data in the conventional HACCP system. In this sense, the system relies on a single node to process the data, while it causes several issues such as forgery, alteration, data modification, human errors, and so forth. Accordingly, CCPs in the HACCP environment is expected to improve the monitoring system, accuracy, security, and food safety. The asset supply management and system establishment are also varied, supported by their affiliated platforms and techniques. Therefore, we specify some research questions to be dealt with and the requirements for the selection and exclusion. The followings are the research questions:

(i) RQ1: What is the current trend in deploying blockchain technology for the HACCP-based cooperative model and the platform mechanism selection?

(ii) RQ2: What types of network architecture and asset supply management techniques have been commonly implemented to cope with the issues that arise in a centralized HACCP system?

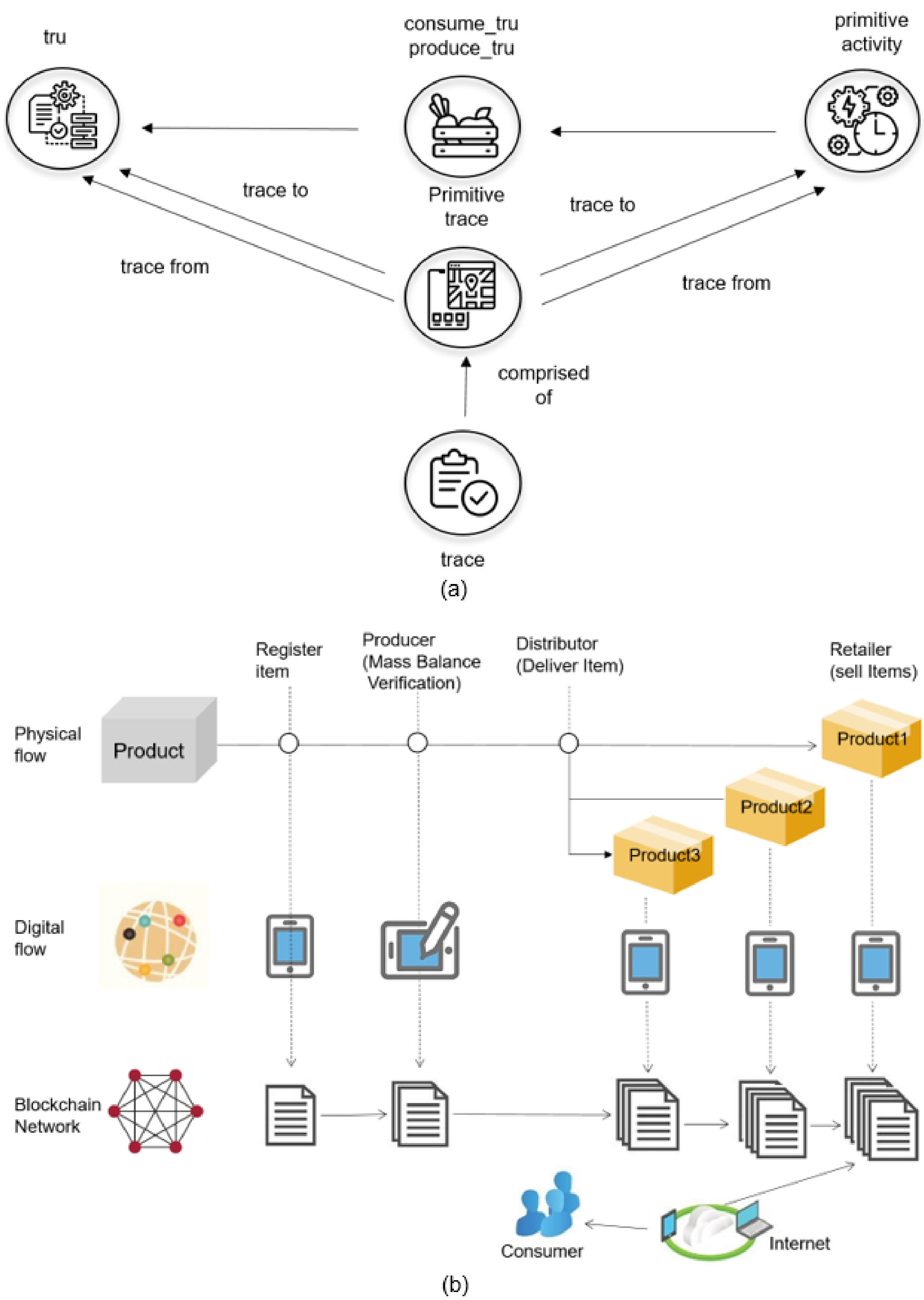

Figure 2: A preliminary concept of blockchain technology in supply chain and HACCP system [24]. (a) Traceability ontology data model [25]; (b) Traceability for supply chains.

(iii) RQ3: What types of typical hazard control is heavily developed for the HACCP food safety plan, and what are the standard parameters used to measure different type of control?

(iv) RQ4: What are the current research challenges in applying blockchain technology for critical control points in the agriculture environment?

To address the research questions RQ1 - RQ4, we summarize the prior research in chronological order, as shown in Table 1. We select several journals, conferences, and book series as the main references. We categorize our selected references into multiple application areas and maturity, distinct between one technique and others. As an illustration, the research in [24] have explored and proposed a preliminary concept of blockchain technology in supply chain management systems by relying on HACCP guidelines as shown in Figure 2. The authors also suggested a traceability technique called TOVE, which stands for traceability ontology data model to be adopted in order to achieve proper traceability in the supply chain area. This approach can improve traceability for the material supply chain while also ensuring all processes meet the minimum requirements for food safety management (improving visibility).

4.2 Critical Control Points (CCP) and Blockchain Remarks

The HACCP-based cooperative model integrated with physical equipment must be designed properly to support these goals. As shown in Figure 3, the cooperative model of the food industry can be divided into CCP and non-CCP factors. Several parameters can be categorized into standard equipment, CCP factors, sensors, and equipment status monitoring subjects. In general form, the CCP factors in the HACCP-based cooperative model represent the industry's environment, such as the temperature, heating equipment, humidity, cleaning water, foreign substance, and to name a few. The CCP factors information is derived from physical sensors or equipment installed in advance. In the meantime, the status of equipment and monitoring subjects are supervised by legitimate entities. For instance, the information of temperature/humidity is frequently recorded into a decentralized ledger, likewise the condition of the compressor for the separator in metal detection equipment.

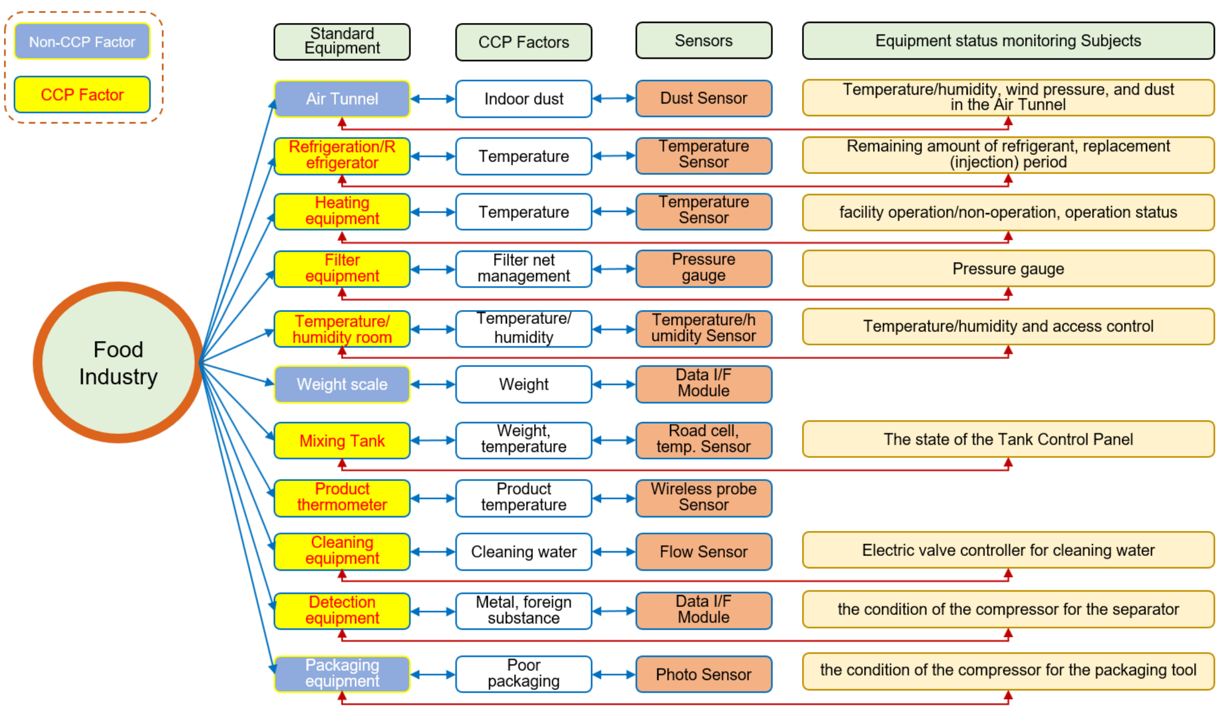

Figure 3: Critical Control Points (CCP) factors and equipment status monitoring of HACCP system.

Intuitively, a typical flow diagram for the food supply chain system backboned by HACCP standardization is highlighted in Table 2. The diagram is separated by several parameters such as control symbol

Table 2: Typical hazard control for HACCP food safety plan.

Control	Hazard	Control Measures	Supervising	Correctional Actions
CA1	Humanising safety (embracing safety risk)	Gathering accurate and complete site data such as water quality, sunlight, soil, etc.	Approvement from the regulator (frequent monitoring)	Examination site category; Reassess site marker; document action taken
CA2	Field practices perspective of safety risk	Every field practice with recording details (e.g., type, variety, number, producing area, etc.) are included	Field documentation	Inspection methods; study workforce activity;
CA3	Excess residues from any material of natural or synthetic origin	Fertilizers and pesticides bought from trusted suppliers; documenting the current status	Approvement from the regulator, and supplier documentation	Inspection methods; study workforce activity from supplier, producer, etc.
CB1	Facility-related environmental	Site examination as a piece of assured schemes such as temperature setting and the types of equipment	Approvement from the regulator and the documentation	Inspection site classification redesigned the scheme, flexible documentation
CB2	Safety risk related procedural	All integrated components must be fit for many purposes	Supplier documentation and approvement from regulator	Inspection procedural, examine the workforce training, and the status
CC1	Safety risk from protective equipment	Assure every equipment is properly maintained	Maintenance records management	Check maintenance steps, the workforce training and documentation
CC2	Warehouse safety risks	Every warehouse management procedures according to adequate operational procedures	Proper documentation	Inspection procedural, examine the workforce training, and the status
CD	Retail management - Health and safety	All retail management concepts according to adequate operational procedures	Proper documentation	Review procedures, examine the workforce training, and the status

(CA1 - CD), hazard type, control measures, supervising, and correctional actions [1]. For instance, the basic humanizing safety risk in CA1 ensures the site assessment and quality of certain components such as water quality, soil, sunlight, and a few. Legitimate regulators provide regular assessments for each input received. In the meantime, in the parameters of the corrective action, the documentation is made by certain parties after reviewing site classification. In line with CA1, the safety risk from field practices is underlined in CA2, whereby every field practices process must be recorded, such as producing area, type of products, variety, and so forth. Field practices also require adequate site documentation with proper review procedures. The rest of the typical hazards are identified as follows: excess residues of fertilizers and pesticides (CA3), safety risk on processing environment (CB1), safety risk related procedural (CB2), site equipment (CC1), warehouse safety risk (CC2), and retail management-health and safety (CD). Meanwhile, the valuation of digital assets (cryptocurrencies) with the International Financial Reporting Standards (IFRS) report can be seen in Table 3.

A number of protocols and algorithms can be extensively deployed within the decentralized HACCP environment regarding the user's anonymity, privacy, and security. However, many studies show that straightforwardly adopting blockchain technology can affect several other parameters while also having security and performance trade-offs, as remarked in [29], [30], and [31]. Especially when blockchain is associated with the type of consensus mechanism used. Moreover, PoW is becoming more expensive to be implemented in a decentralized HACCP system. The mining pools in this consensus are almost all controlled by big companies (as shown in Figure 4 and 5) such as F2Pool, AntPool, PoolIn, ViaBTC, SlashPool, SBICrypto, and to name a few. For example, the consensus used in Bitcoin is proof-of-

Table 3: Valuation of digital assets (cryptocurrencies) to International Financial Reporting Standards.

Code	Standard	Assessment	IFRS Acceptance
MRS 7	Currency flow statement	Currency and currency equivalents	Not acceptable
MSFI 9	Financial instruments (assets that can be traded)	Digital assets at appropriate value (profit or loss)	Not acceptable
MRS 40	Real estate investments (with its natural resources)	Land and building investments	Not acceptable
MRS 16	Property, plant, and equipment (PP&E)	PP&E physical or tangible long-term assets	Not acceptable
MRS 38	Intangible assets	identifiable non-monetary asset	Acceptable
MRS 2	Supply	Supply	In certain circumstances (conditionally)

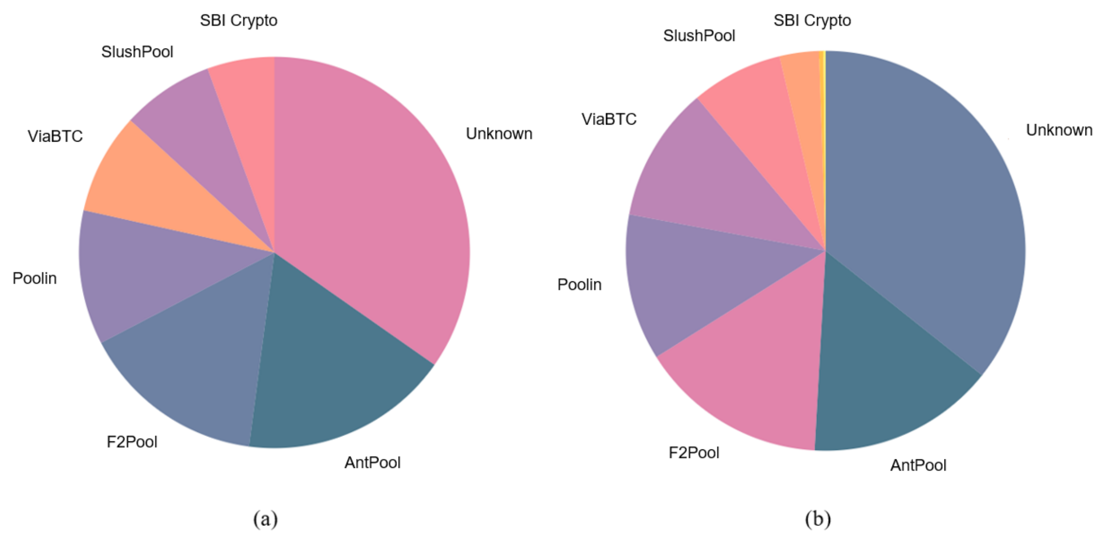

Figure 4: Summary of mined blocks for consecutive hours (24 and 48 hours).

work which consumes massive energy. Therefore, the consensus mechanism selection is vital in the decentralized HACCP sector. The additional protocols to make the transactions even more secure can be a research challenge also for the agrifood sector. The followings are the prominent techniques in disguising user's information and data transactions:

(i) Confidential transactions - Pedersen Commitments [32]. This protocol is based on a cryptographic primitive computation that enables one to deploy to the desired value while maintaining it hidden to other parties, revealing the committed value later.

(ii) Zero-Knowledge Succinct Non-Interactive Argument of Knowledge (zk-Snark) and its variant (Pinocchio zk-Snark) [33]. This protocol can be understood as a zero-knowledge proof protocol used in encryption, where it first developed in the late 1980s. However, zk-Snark has been employed by the cryptocurrency Zcash to preserve the user's anonymity.

(iii) Ring Confidential Transactions (RingCT) [34]. This technique is based on the ring signatures algorithm, allowing users to hide amounts, origins, and destinations of transactions. RingCT can

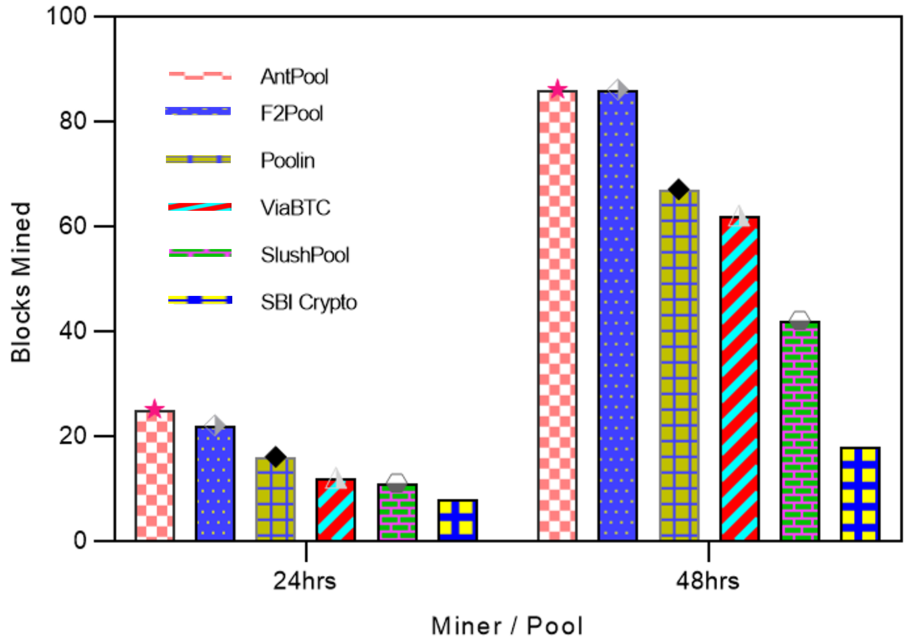

Figure 5: A detailed breakdown of the most recent blocks mined.

be modified accordingly to fit the HACCP environment.

(iv) CryptoNote Monero (XMR). CryptoNote protocol is applied on the Monero cryptocurrencies, the foremost cryptocurrency concentrated on confidential and censorship-resistant transactions.

(v) Stealth Addresses [35]. This protocol is extensively used to obscure public access to the entities involved in the blockchain network. In short, the senders possess a one-time address for every transaction, even though multiple transactions are conducted with the same senders.

5 Conclusion

A note on the enactment of blockchain technology for the HACCP-based cooperative model was explored in this paper. This study elaborated a thorough benchmark of critical control points (CCP) factors integrated with blockchain in the HACCP environment and several protocols to secure decentralized HACCP transactions embedded into peer-to-peer networks. We have highlighted typical hazard control for the HACCP food safety plan with a valuation of digital assets referred to the International Financial Reporting Standards report. Among the conceivable approaches and techniques to extend this research, we believe that including more security protocols to disguise the HACCP transactions would be the most intriguing since this might help researchers/clinical practitioners in adopting suitable blockchain platforms in the decentralized HACCP system. For future work, it would be interesting to deal with the limitation of this research about the performance, latency, scalability, and comparison of different blockchain platforms with several security protocols embedded into the design. To this end, while a large number of techniques of cryptography protocols and different types of blockchain platforms are taken into consideration, sustainability and efficiency might be improved. It is worth noting that not every blockchain platforms and security protocols are suitable for the HACCP environment. It is worth noting that not every blockchain platforms and security protocols are ideal for the decentralized HACCP environment. Hence, it would be meaningful to precisely understand the benefit and drawbacks of HACCP characteristics, blockchain attributes, and security protocols standards.

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