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RESEARCH ARTICLE

Application of Blockchain Technology in Aquaculture Management

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Abstract

In recent years, food safety has become a growing concern in Taiwanese society. To ensure efficient management of the supply chain within the L Aquatic Products company, it is imperative to employ reliable technical support in establishing an effective traceability management system. The traceability of products can provide managers with valuable insight into the intricacies of the supply chain. By establishing a dependable food traceability system, brand trust can be strengthened, and consumers can inquire about the movement of aquatic products within the supply chain. Blockchain technology offers features such as traceability, accountability, transparency, reliability, trust, privacy, and security, making it a viable solution for the aquatic industry. Although some researchers propose comprehensive solutions for application in aquatic companies, it is important to note that many aquatic firms are traditional companies with unique supply chain requirements. A one-size-fits-all solution may not be suitable and could lead to increased operational costs. In this research, we begin by conducting interviews with the company to gain insight into their actual production processes. Based on these findings, we design and implement a blockchain traceability process tailored specifically to the aquatic firm's supply chain. Additionally, we survey the opinions of the company's staff to ensure that the system aligns with their needs. The results indicate that the blockchain traceability system benefits the company's development.

Keywords: Blockchain, Food safety, Aquaculture management

1. Introduction

Aquatic food production refers to the process of raising aquatic organisms for food consumption. The supply chain for aquaculture products involves a complex network of stakeholders overseeing various operations to transport these products to their final destinations. Aquaculture operations typically encompass the cultivation and harvesting of aquatic organisms such as fish, algae, aquatic plants, and crustaceans within controlled environments like ponds, tanks, or cages. These activities take place in diverse water environments, including salty, brackish, and fresh waters, sourced from in-land wetlands, coastal areas like estuaries, or open seas and oceans. Given this diversity, meticulous monitoring of the product flow within these fishery supply chains is essential to ensure food safety and prevent fraudulent activity.

Food traceability encompasses the capability to track food and its constituents across all stages of the supply chain, encompassing both upstream and downstream traceability. It involves the production, processing, and distribution of food and ingredients. Effective food traceability helps government agencies or food producers quickly identify the source of a product and identify potential links that may have led to safety issues. Conversely, affected products can be swiftly removed from the market, reducing the harm caused by food safety hazards [1−4]. In recent years, due to the increasing frequency of food safety issues, there has been a significant demand from businesses, governments, and consumers for food traceability information [5,6].

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Food traceability data can be effectively monitored and recorded through various means, including commercial transactions and Internet of Things (IoT) devices [7,8], wireless sensor networks [9], QR codes [10], and NFC [11]. However, despite the real-time recording of food-related information, the current practice of information sharing remains centralized, which poses challenges to ensuring the transparency and security of the information.

The World Economic Forum (2016) has pointed out that blockchain, as the underlying technology of Bitcoin, will play a central role in the future global financial system. This technology can help improve mainstream transactions such as international payments and stock trading, and benefit lesser-known areas such as trade financing and convertible bonds. In a statement accompanying their report, Giancarlo Bruno, the Director of Financial Services at the World Economic Forum, stated, "Blockchain technology will no longer be on the fringes of the financial industry but will occupy a central position." Today, countries are assigning a high level of importance to blockchain, and the atmosphere for its development and application is favorable. Currently, the most mature large-scale application of blockchain technology in is the financial field, and some governments have even passed legislation to regulate blockchain. Furthermore, the healthcare industry is actively investigating the utilization of blockchain technology for storing electronic medical records, medication records, and other pertinent data, facilitating seamless tracking and authentication [12]. In the field of education, some schools are recording graduation certificates, certification licenses, and more using blockchain [13]. Shipping companies are also investigating the critical factors that influence the application of blockchain technology in their operations, laying the groundwork for potential future implementations [14]. Blockchain technology facilitates the verification and maintenance of authority. Over the past few years, there has been extensive experimentation in and application of blockchain technology across diverse domains, with a particular emphasis on digital finance. Governments of various countries in Europe and North America have invested significant amounts of money in research and development, on related hardware equipment, and in investment opportunities. Blockchain technology is currently a technological trend, ushering in a new wave of trust mechanisms across various sectors worldwide. Applying characteristics such as decentralization and immutability from blockchain to product supply chains integrates information onto a single platform, not only ensuring the accuracy of product information but also streamlining administration tasks. It amplifies the precision and security of enterprise data, augments transparency, and enhances the operational efficiency of the complete supply chain.

We perform a comprehensive literature review using targeted keywords, including "blockchain", "supply chain", "food", and "aquatic food" within the Web of Science database spanning the last four years (2019–2022). The results of this review are shown in Table 1. Note that Fig. 1 demonstrates the increasing interest in blockchain research, particularly its application to supply chains and the food industry. Researchers clearly recognize the potential benefits of utilizing this innovative technology in the food domain. However, we emphasize that there is a lack of comprehensive studies that thoroughly explore the wide-ranging application of blockchain technology in the context of aquatic food or fishery supply chains.

To accommodate the specific characteristics of the aquatic company's supply chain processes, we conducted interviews with the company to understand its current state. Subsequently, we designed and implemented a customized blockchain traceability system tailored to the unique requirements of the aquatic company's supply chain. Furthermore, a questionnaire was administered to collect employees' viewpoints regarding the implementation of blockchain technology and workflow. The structure of the paper is outlined as follows: Section 2 provides a brief overview of previous research on applications of blockchain technology in supply chains. Section 3 describes in detail the framework of the proposed system, which incorporates the valuable input and feedback obtained from the aquatic company. Section 4 provides a case study that demonstrates the operational procedures of the blockchain traceability system. Section 5 concludes with an overview of the research findings from our study.

Table 1. Total number of recent publications focusing on blockchain and its relevant applications.

Key	2019	2020	2021	2022
Blockchain	1560	3018	4193	4674
Blockchain + supply chain	157	405	632	724
Blockchain + supply chain + food	28	78	116	147
Blockchain + supply chain + aquatic food (or fishery)	1	2	3	6

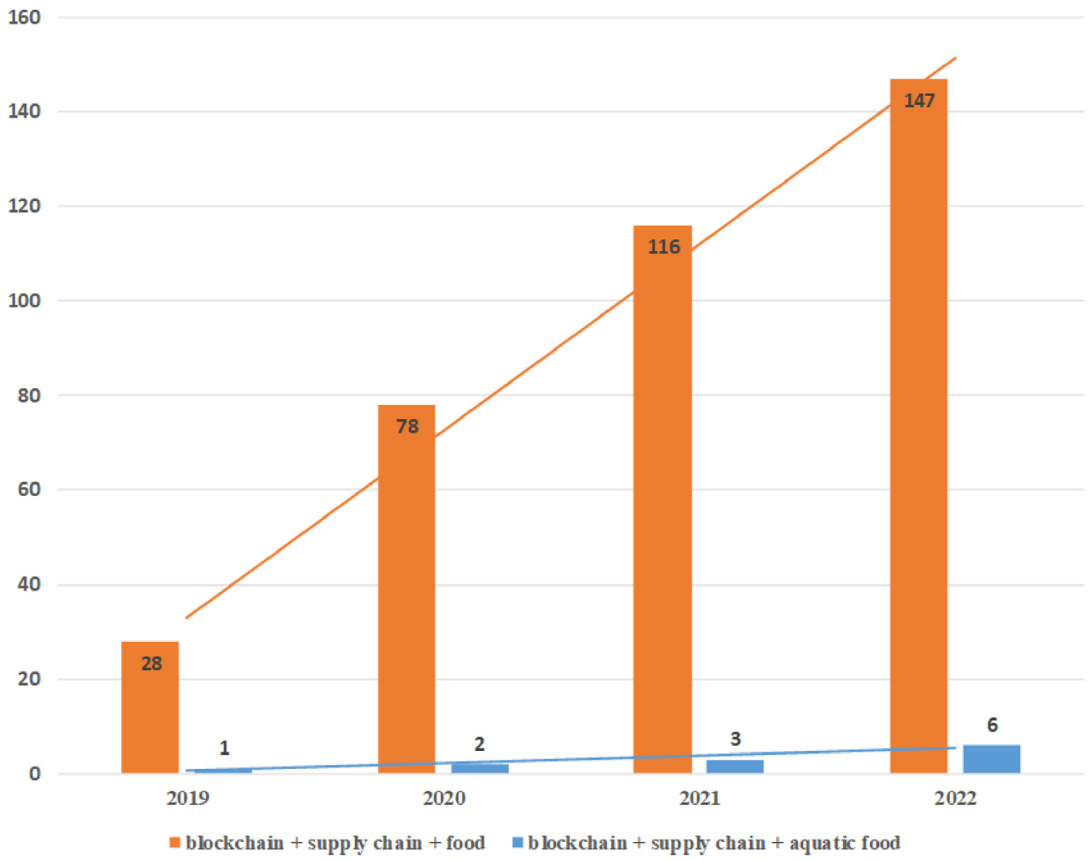

Fig. 1. Publishing trends related to blockchain technology and its application in the field of supply chains, along with statistical analysis results.

2. Related work

The decentralized nature of blockchain technology has sparked significant interest among researchers, particularly in its potential applications in supply chain management [15−18]. The utilization of smart contracts is a characteristic feature of blockchain, particularly suited for enhancing supply chain operations [19−21]. Drawing from these previous investigations, notable achievements have been made in the development of traceability systems for food supply chains. An exemplary study carried out by Kamilaris et al. in 2019 delved into the implications of blockchain technology on agriculture and food supply chains, providing valuable insights [22]. Their research indicates that blockchain has the potential to establish transparent food supply chains, with several ongoing initiatives covering various food items and related issues. Gao et al. develop a blockchain-based traceability system called FSCTS, which integrates various entities and establishments involved in the food supply chain. This system facilitates streamlined transactions and interactions among the stakeholders [23]. Pelé et al., in turn, focus on the logistics aspect of the food supply chain and develop a holistic framework that combines blockchain technology with the IoT [24].

Numerous scholars have examined the benefits associated with integrating blockchain technology into food supply chain management. Liu and Guo propose that blockchain technology has the capacity to serve as a catalyst for improving the overall management of the fresh food e-commerce supply chain [25]. Kshetri and DeFranco highlight the advantages of incorporating blockchain technology into food and beverage supply chains, such as the improvement of food safety, enhancement of supplier reputation, increased visibility for small farmers, efficient tracing of food contamination sources, greater transparency, and strengthened accountability [26]. Enhancing the sustainability performance of the supply chain is paramount, and blockchain technology has the potential to contribute to sustainability improvement in this aspect [27]. Katsikouli et al. conduct an extensive examination of obstacles encountered in traditional food management systems, including ethical issues such as safety and fraud [28]. Implementing a supply chain management system based on blockchain

provides notable benefits, including expedited and dependable traceability. In the context of India, Patidar et al. use the Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify the primary barriers in food supply chain management [29]. In their survey, the two foremost significant obstacles identified were "insufficient government policy and regulatory support" (B8) and "challenging and varied climate conditions in India" (B15). Nevertheless, the latest developments in blockchain technology present opportunities to alleviate the influence of these obstacles on the performance of food supply chains.

However, the literature has given limited attention to the application of blockchain technology, particularly in the context of seafood or fisheries, as indicated by our research findings. Nevertheless, some researchers believe that blockchain technology will have far-reaching implications for policy, administration, economy, trade, society, and science. By leveraging emerging data technologies, the fisheries sector can enhance trust among stakeholders through increased transparency and improved availability of information throughout the entire supply chain, spanning from net to plate [30,31]. Howson suggests utilizing blockchain technology to address trust issues in marine conservation and global seafood production networks [32]. The inherent security, resistance to hackers, and lack of single-point authorization that can lead to errors or system failures make blockchain an attractive solution. Furthermore, the implementation of blockchain technology contributes to achieving sustainable development goals in the fisheries industry, designing more sustainable supply chains. Digital technologies like blockchain can support the achievement of specific sustainable development goals, facilitating sustainable management of aquaculture and fisheries [33,34]. In 2022, a report proposed an efficient and decentralized approach to managing the operations of the fisheries supply chain using blockchain technology. The proposed solution strives to automate processes within the fisheries supply chain, with the key objectives of achieving decentralization, transparency, traceability, security, privacy, and trustworthiness [35]. Note however that many seafood companies are traditional firms with diverse supply chain requirements. One-size-fits-all solutions may not be suitable as they can potentially increase overall operational costs.

3. Material and methods

3.1. Case analysis

The focus of this research is L Aquatic Products Co., Ltd., a prominent Taiwanese aquaculture and fishery company that possesses a comprehensive supply chain encompassing various stages, as depicted in Fig. 2. This includes the supply of raw materials such as fish food and medicine, fry cultivation carried out in their own hatchery and outsourced fry farms, fish farming, transportation, and sales. The company's products are not only distributed domestically but also exported to foreign markets. In the future, the company aims to establish its own sales brand to enhance product recognition and strengthen the brand image. The objective of this study is to assist L Aquatic Products Co., Ltd. in developing a database for their aquatic supply chain and leveraging blockchain technology to establish a traceability process within the supply chain.

Although L Aquatic Products Company has a complete supply chain, all information systems are separate. These record and manage cultivation, breeding and transportation, and sales. The sales data are even still recorded traditionally. Some sales pieces of information are recorded as a single transaction and then stored chronologically, whereas other descriptions are recorded on paper. The company director believes that introducing blockchain immediately into the complete supply

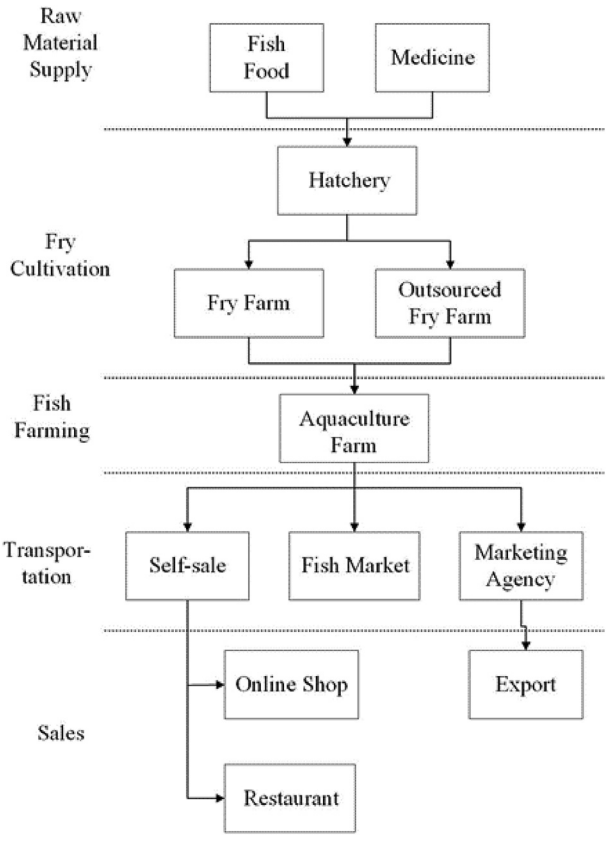

Fig. 2. L Company supply chain progress.

chain would lead to high operating costs, which would increase the product price and cause the company's products to be uncompetitive in the market. However, the company director agrees that providing a credible product traceability service could attract consumers. He feels that blockchain should be introduced in stages according to the company's current situation.

This research is mainly from the perspective of L company's supply side, as shown in Fig. 2, in the downstream transportation and sales part of the supply chain. We utilize blockchain technology to track products, which will help L company to improve their work process efficiency and promote service quality to attract consumers.

3.2. System architecture

Fig. 3 illustrates the system architecture, which employs a MySQL database to digitize the supply chain data of L company. The company's primary products were confirmed through interviews, categorized accordingly, and used to establish a comprehensive database. To create a private blockchain, we used the Ethereum platform, which features smart contracts. In our architecture, producers and consumers both use application programs connected to the blockchain platform. We used the React framework to build interactive front-end interfaces and set up multiple pages to distinguish permissions by account number. Producers use their account authority to record the product process, master the supply chain situation, and establish a complete product history with a timeline through the blockchain system.

Based on the Ethereum environment, we used the Remix IDE development environment to compile smart contracts written in Solidity syntax and implement the functions of the supply chain system. For interaction, we used the Visual Studio code editor and React.js as the framework to connect the front-end interface, which is composed of CSS3 and HTML5. The interactive function makes use of the Web3 library provided by Ethereum, linking smart contracts to form a supply chain system. Additionally, JavaScript was used to build consumer client and supply chain system inquiries.

3.3. System implementation

Remix IDE is an online version of the integrated development environment (IDE) officially provided

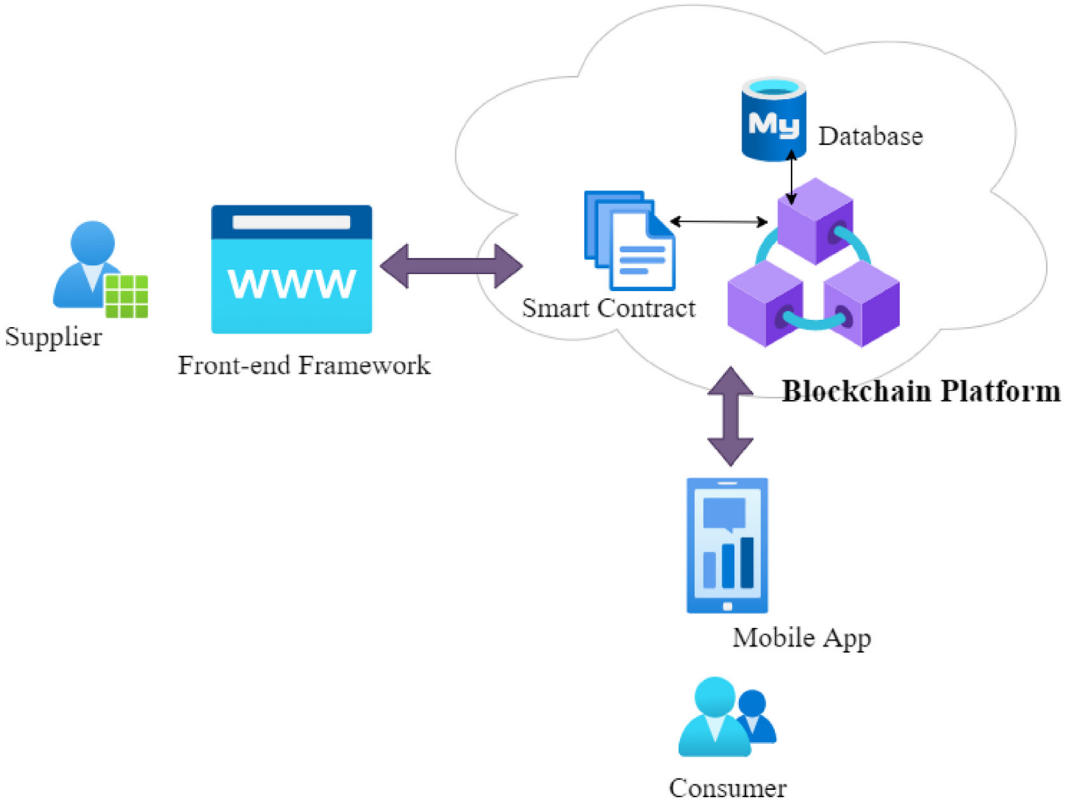

Fig. 3. System architecture.

by Ethereum. It has functions that help developers develop smart contracts, including a complete compiler, contract execution, environment construction, and contract publishing. Prior to the official execution of the smart contract, it is possible to conduct function tests, and the local node can be connected using the Web3 Provider. Go Ethereum is an Ethereum client platform developed based on the Go language. Its functions include the functional modules mentioned in the Ethereum public agreement, including blockchain state management, mining, P2P network, cryptographic encryption, database, and EVM functions. The system development environment uses the Go Ethereum platform (Geth) to establish an Ethereum development environment on the Windows system, establish an initialized blockchain through instructions, create accounts and nodes, and use the Web3 library to issue instructions in the development environment, connect accounts, nodes, and repositories in the blockchain.

The functions necessary for the supply chain system are implemented through smart contracts written in the Solidity programming language and serving as the backend component of the system. We used the Remix IDE to compile and deploy the smart contract, as shown in Fig. 4. Local nodes connect to the Web3 Provider environment, build the front-end web page with the React framework connection, and use Web3 to access data on the blockchain and create it on the front-end web page. The master account serves as the primary interactive interface for the entire supply chain system. The main interface functions include inputting, querying, confirming, changing data status, and recording product data. We use smart contracts to connect with the organized enterprise electronic database, and created an interface to the primary management interface for managers to view product information and new data at any time. The blockchain records the added data, and the data recorder has a unique private key. These messages are encrypted and recorded with a timestamp during the recording process to facilitate later data confirmation. If necessary, when determining the attribution of product liability, the blockchain system has records. Furthermore, during the construction phase, other supply chain processes have the ability to input data into the system, label the products, indicate the current status of the products within the supply chain, or add supplementary notes. The records of data modification are recorded by the blockchain system by forming blocks through cryptographic encryption. Managers understand the status of the supply chain from the central management interface; we have added a label confirmation function for managers to confirm orders.

4. Result

This section presents a case demonstrating the operation of L Aquatic Products Company. This

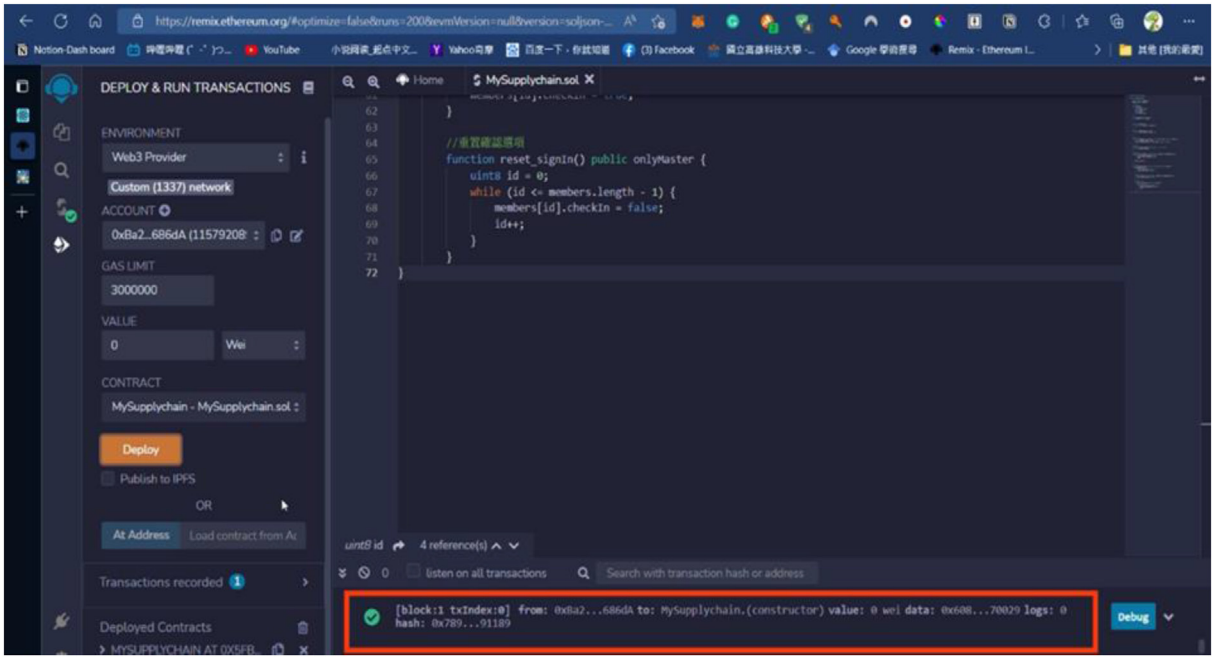

Fig. 4. Remix IDE compiles and deploys smart contracts.

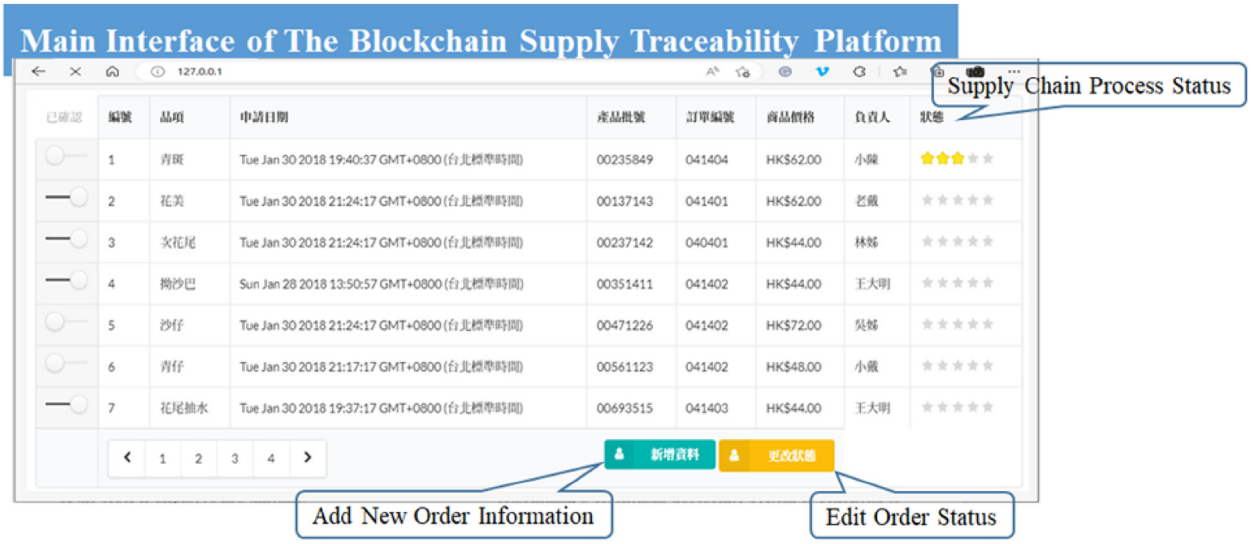

Fig. 5. Supplier application interface.

study divides the supply chain process into five stages: fry output, entering processing, entering the warehouse, entering logistics, and successful harvesting, represented by an asterisk. The company-end manager enters the blockchain traceability platform through the primary system account. Other supply chain-related personnel create new accounts to interact with the system through the Geth blockchain platform. Fig. 5 shows the manager and supply chain-related personnel entering the main interface of the blockchain traceability platform, where the latest commodity order is displayed. The managers enter new order information through the **Add New Order Information** function. The smart contracts encrypt and record the newly added data on the blockchain traceability platform. Supply chain-related personnel can change the supply chain status of the order through the **Edit Order Status** function.

The blockchain traceability platform includes five stages: output from the cultivation farm, processing, warehousing, shipping, and

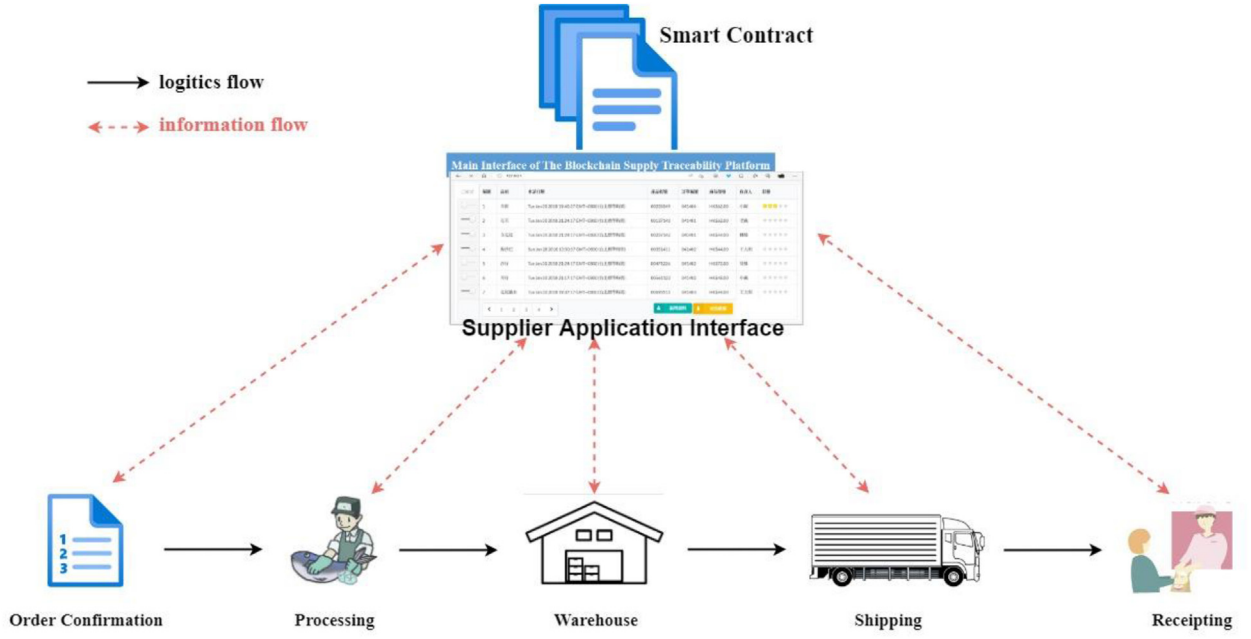

Fig. 6. Workflow of communication between front-end interface and smart contract.

Fig. 7. Client-end application program interface.

completion of shipping. The asterisk indicates the current state of the supply chain process for the ordered product.

This study offers a comprehensive depiction of the essential tasks undertaken at each stage of the aquatic food supply chain. Fig. 6 visually presents the distinct responsibilities allocated to each stage throughout the supply chain process.

(1) Order Confirmation: In this stage, the staff prepares fresh fish from the aquaculture farm based on each order.
(2) Processing: The processing division receives a variety of fish species and separates them according to the order and established working methods.
(3) Warehouse: The warehouse is responsible for receiving fish packages from the processing division and storing them at low temperature.
(4) Shipping: Shipping is responsible for delivering the goods to consumers based on the order.
(5) Receipting: Consumers are the ultimate participants in the business supply chain. They receive seafood products and consume food.

The client-end consumer uses the mobile device application program to enter the order number to check the progress. The application program connects to the blockchain traceability platform and captures order information. Fig. 7 shows the status of the order. The supply chain flow process of the order is displayed in a timeline.

The survey results from the staff of L Aquatic Products Company are presented in Table 2, utilizing a five-point scale (5: strongly agree; 4: agree; 3: neutral; 2: disagree; 1: strongly disagree). About 55% believe the blockchain traceability systems interface to be easy to use. About 78% of staff offer feedback on user experience. This is a positive result, because about 77% of staff think establishing a blockchain traceability system is beneficial to the company's development. The company director views this

Table 2. Questionnaire survey results from company staff.

No.	Content	5	4	3	2	1
a.	I think the blockchain traceability platform interface is easy to use.	11%	44%	22%	22%	0%
b.	I like to use the blockchain traceability platform in my work.	22%	33%	44%	0%	0%
c.	The blockchain traceability platform provides great help for my work.	11%	44%	33%	11%	0%
d.	I would like to give feedback on my experience.	22%	56%	22%	0%	0%
e.	I think establishing a blockchain traceability process is beneficial to the company's development.	33%	44%	22%	0%	0%

The rating scale used in this study is as follows: 5: strongly agree; 4: agree; 3: neutral; 2: disagree; 1: strongly disagree.

questionnaire's results positively: he has more confidence in importing the blockchain technique to improve the company's entire supply chain process.

5. Conclusions

Our visits to aquaculture enterprises yielded insight into their main operational models. Aquaculture is a traditional family industry with limited digitization, and some order information is still manually recorded. While the company attempted to establish a breeding data database to enhance fish species development, the participation of fishermen in data recording remained limited. Consequently, immediate implementation of blockchain technology across the entire supply chain would have led to substantial operational expenses. As advised by the company's management, our study focuses on constructing traceability processes downstream of the supply chain, specifically in the sales and transportation sectors.

The objective of this study is to design and implement traceability processes for aquatic food suppliers utilizing blockchain technology. The core component of this system is the adoption of distributed ledger technology, providing three key features: decentralization, traceability, and immutability. Our traceability system is developed on the Ethereum platform, on which all ledgers are stored. We designed a front-end framework capable of recording the processing status of each workflow. This framework also incorporates a user-friendly interface, enabling easy access to the complete line of aquatic food products. Furthermore, we developed a mobile application for end-consumer clients, facilitating access to comprehensive product information, including order details and shipment status.

The application provides comprehensive information on each supply chain, as verified by the participating company. The primary contribution of this research lies in the development and implementation of traceability processes for aquatic food supply chains using blockchain technology. Our main focus is leveraging blockchain smart contracts to record the movement of aquatic food products in the supply chain logistics. By harnessing the power of blockchain, seafood supply chains can achieve higher transparency and traceability. The company employees also acknowledge the benefits of establishing a blockchain traceability system for the company's development. Moving forward, we intend to continue collaborating with aquatic food companies to optimize the blockchain-based traceability system. Additionally, our current primary focus is on digitizing the upstream supply chain processes of aquatic food companies.

Conflict of interest

The authors declare no conflict of interest.

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