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Traceability System in Hydroponic Vegetables Supply Chain Using Blockchain Technology

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Keywords

Blockchain
Decision Support System
Hydroponic Vegetables
QR Code
Traceability System

Abstract.

Hydroponics is a soilless plant cultivation technology using nutrient solutions in water. The development of hydroponic agriculture globally and in Indonesia is increasing, which correlates with hydroponic vegetable production. There is a safety issue for hydroponic vegetables in diseases and poisoning cases due to contamination related to the product supply chain's security issue amid the coronavirus pandemic or COVID-19. The laws and regulations about hydroponic vegetables' traceability encourage companies to adapt and implementing the rules to give consumers trusted information. One of the tools to ensure food supply chain information and transparency is a traceability system. The study aims to design a traceability system using a rapid structured prototyping approach that combines the System Development Life Cycle (SDLC) and Prototyping methods. This study examined the traceability system in the hydroponic vegetable business process and reviews its authenticity by developing a traceability system prototype using blockchain technology.

1. Introduction

Food poisoning continues to grow in some consumers, making them less dependent on food. In 2019 data on poisoning cases from hospital reports throughout Indonesia with the proportional random sampling method verified from 6,025 data on food poisoning in Indonesia, 60 people died from food poisoning (see BPOM [3]). Vegetables carry bacteria such as E. Coli (see Wang et al. [40]). Food safety amid coronavirus pandemic or the COVID-19 related to the vegetable supply chain regarding the distribution from farmer to the consumer safely from COVID-19 contact is also increasing (see FAO [7]). Vegetables are horticultural product which have become the focus of attention along with an increase in knowledge of the society on the urgency of preserving health (see Suroso et al. [34]). Healthy and fresh vegetables are the main desire of consumers because there are good nutrition and food safety. Hydroponics is a plant cultivation system or technique that minimizes soil use that increases in the world and Indonesia. However, food safety problems in diseases and food poisoning cases usually occur due to food contamination. It needs a traceability system to control the supply chain of the food produced.

The provisions of laws and regulations issued by the Indonesian government in Government Regulation (see PP [27]) No. 86 of 2019 article 4 regarding the transparency of food products. There are also several examples of international regulations on the application of traceability, such as the "European Food Safety Authority" since 2002 on food safety in the European Union (see Zhang and Bhatt [42]). The regulation "The Bioterrorism Act (BTAct)" by the United States government in 2002 (see Thakur and Hurburgh [35]). Other international rules implemented on traceability systems are the "Food Safety Law of the PRC" or Food Safety Law in China has been implemented since 2009, and "Further Strengthening the Work of Dairy Quality and Safety" since 2010 in China (see Liu et al. [19]). Japan's Ministry of Agriculture Fishery and Forestry (MAFF) implements regulations on the traceability of food products in the handbook "Handbook for Introduction of Food Traceability System". The International Organization for Standardization (ISO) prioritizes the traceability system as the highest priority and strives to align various regulations by setting ISO 22000 on Food Safety Management System (see ISO [12]). This regulation triggers companies to adapt to these existing rules.

Blockchain has become one of the critical aspects of the traceability system, from security to agriculture (see Yin et al. [41], Ren et al. [29], Shrestha et al. [32], Jiang et al. [14], Kasten [15]). Blockchain is used in traceability systems to provide food supply chains such as identification, explaining, security, convenience, blockchain, and innovation (see Prashar [28], Demestichas et al. [4], Liu [18]). Blockchain also aims to increase efficiency, transparency, and low costs for the traceability system's supply chain. Besides, blockchain also has immutability and transparency to prevent fraud (see Dinesh et al. [5]). Developing an information technology-based traceability system is very important and necessary to control food and waste loss in every supply chain process. The tracking system can reduce costs and human resources related to information exchange with business partners (external) and update the company logistics data and information (internal) (see Seminar [31]). The traceability system is to provide a decision support system a more comprehensive and scheduled information. It makes the company competitively superior through its ability to document product information, especially in product sustainability and its impact on the environment (see Olsen and Borit [25]). According to Jakkhupan [13], traceability consists of two-way activities. Backward traceability or product tracing is required to search for errors in case of product defects. Forward traceability or necessary product tracking to ensure the product is following the conditions when shipped until the destination to be quickly taken action in the event of a recall. According to Vilmos [39], the key to traceability effectiveness is in the power of substantial cooperation with the relevant daily authorities and the ability to control all production, processing, and distribution.

The importance of traceability systems has to get more extensive due to the challenges of supply chain management systems and food safety scandals of hydroponic vegetables. Food counterfeit, food fraud, ineffective processes, and ethical sides like the environmental impact of food production and fair trade are some of the examples (see

Katsikouli et al. [16]). Hence, it is crucial to investigate the existing supply chain management and traceability system problems, identifying the foremost vital issues to be addressed and the key benefits of implementing blockchain technology in this system. Blockchain-based traceability systems provide more excellent solutions to solve supply chain management problems, and it is better than the existing traditional traceability systems. Many uses include enhancement coordination between supply chain entities, fulfilling government regulations, improving surveillance over the whole food supply chain, and quality assurance and management (see Nene et al. [24]).

Huque et al. [11] had to utilize the QR Code to authenticate agricultural product transparency. We will develop a prototype using blockchain technology to enhance the security and authorization of the data in a distributed ledger system so that openness is guaranteed without any interruptions in this traceability system. Surasak et al. [33] had developed the traceability system using blockchain and the internet for agricultural products, but no actors related are mentioned in the supply chain. In this system, we will use blockchain technology to investigate the actors in the supply chain to maximize the decision support system. The blockchain-based traceability systems have an advantage for allowing consumers and every actor involved to witness hydroponic vegetables supply chain transactions without any scams, vulnerabilities, and threats. Torrisi et al. [37] had proposed a traceability system for the certification and supply chain of food, but the procedure is vulnerable to possible attacks. We will present blockchain-based traceability systems that could improve safety, security, scalability, trust, privacy, and authentication to counter any vulnerabilities attacks so that hackers could not reveal confidential business information on the prototype.

The traceability system that will be developed has several advantages. First, the prototype will be available on the Android platform to be used anywhere and anytime without any hassle. Second, the information can be traced in real-time by scanning the product QR Code. Everything related to the traceability of hydroponic vegetables will be seen in this system with just one click. Third, it is a novelty product because the blockchain traceability systems for hydroponic vegetables have never existed in Indonesia, especially in Bogor, West Java (see Meidayanti et al. [21]). Hence, the prototype will provide a traceability system using blockchain technology for the industry of hydroponic vegetable supply chain management.

Based on the Central Statistics Agency (see BPS [1]), the accumulated performance of food from 2016 to 2018 increased by 29%, food inflation in 2014 of 10.57% decreased to 1.26% in 2017. Then, investment rose 110% in value of IDR 94.2 trillion. The agricultural sector increased national economic growth (GDP), up 47.2%, or Rp1,375. From the 2016 BPS data, the export trend value to Singapore is 3.28%, and Malaysia's 3.88% is in horticultural products, which are the countries with the enormous destination value for Indonesia. The increase in food exports is apparent that vegetables' demand continues to increase, including hydroponic vegetables. The trend of Indonesian vegetable exports with 716 in 2013 and 620 in 2014, although the latest issues continue to decline, the movement need to be considered (see Hariyadi [10]).

The traceability system implementation using blockchain technology to track supply chain traceability, protect consumers and people involved in the supply chain, complete company manual systems, streamline and improve company performance against the supply chain, and encourage a faster decision support system. This study's objectives were (1) to analyze the traceability system in the hydroponic vegetables business process, (2) to review the authenticity of the product by developing a traceability system prototype using blockchain technology.

2. Literature Review

The development of information technology generates many benefits for food product traceability standards. There are also other benefits of a traceability system besides sustainability, namely maximizing product quality and minimizing product defects. Research by Huque et al. [11] utilizing the QR Code can authenticate agricultural product authenticity. This study focuses on hydroponic vegetables that use QR Code traceability and related actors in more detail. Meidayanti et al. [21] have reviewed the supply chain traceability system's analysis and design based on blockchain technology. This research is to develop a prototype traceability system using blockchain technology. Surasak et al. [33] have reviewed the traceability system for agricultural products using blockchain and the internet. The benefits provided from all information are collected in real-time and stored in a very secure database. Still, they do not yet have complete actors in the supply chain to maximize the decision support system at any traceability stage. Torrisi et al. [36] proposed a prototype for the certification and traceability of food products, aiming at tracing the origins of the raw materials without revealing confidential business information. Supposedly, blockchain-based traceability systems could improve safety and security against possible attacks and vulnerabilities to disclose personal business information on the prototype. Hao et al. [9] have proposed a system combining blockchain technology with visualization technology. However, there remain deficiencies that need to be improved related to the speed and scalability of generating blocks issues by considering effective methods to settle these problems to achieve more accurate results.

Demestichas et al. [4] have discussed blockchain in the traceability agriculture system, where implementation is successful if it reduces costs, reduces risk, saves time, and increases trust and transparency. Mirabelli et al. [22] suggested that blockchain and agricultural supply chains in traceability will have promising trends and challenges in the future but still require much energy to reach the desired stage. Blockchain minimizes fraud, errors in the supply chain and improves food product quality and safety. Behnke and Jansen's research [2] states that different food regulations in each country are critical to the supply chain, where volatile boundary conditions are needed to adopt blockchain optimally. Kumperščak et al. [17] described a combination of RFID and blockchain used for fresh fruit and meat. RFID for production, processing, storage, distribution, and sale, on the other hand, blockchain is used to provide traceability information, but the drawback is the high cost of blockchain technology. Thiruchelvam et al. [36], adopting blockchain technology in coffee traceability, can create fair agreements and reasonable prices for all partners because blockchain makes the transaction process transparent from start to the consumer. Still, there needs to be an addition of certification information related to food safety. Fran et al. [8] stated that blockchain technology is not suitable for storing extensive data because scalability is the biggest problem. It takes ample time to confirm or verify transactions. Blockchain technology is guaranteed in the traceability system where private blockchain stores detailed data and public blockchain stores block hashes.

3. Materials and Methods

The research started from March to September 2020 at CV. Garuda Farm, Bogor, West Java, Indonesia. The research covered the farmer (supplier) to the production process (manufacturer), then distributors such as exporters who buy hydroponic vegetables.

In this research, the methods were rapid structured prototyping (a combination of SDLC and prototyping) to develop the system, namely investigation, analysis, system design, prototyping, implementation, and evaluation. The evaluation utilized the User Experience Questionnaire (UEQ) questionnaire model, a questionnaire to measure the user experience (see Schrepp et al. [30]).

This approach is beneficial to have system requirements validation and evolution via a prototype model of a system that can describe concepts, find requirements errors and possible solutions, and discover system requirements without leaving documentation activities. Furthermore, descriptive research methods with case studies were also carried out in this study by collecting various information about hydroponic vegetable traceability systems, products, and functions needed to develop hydroponic vegetable traceability systems.

Materials types and sources of data used in this study are primary and secondary data sources. Primary data was obtained through observation, in-depth interviews, and surveys. Secondary data was obtained through literature studies and internal data of the company. For the research framework, see Figure 1.

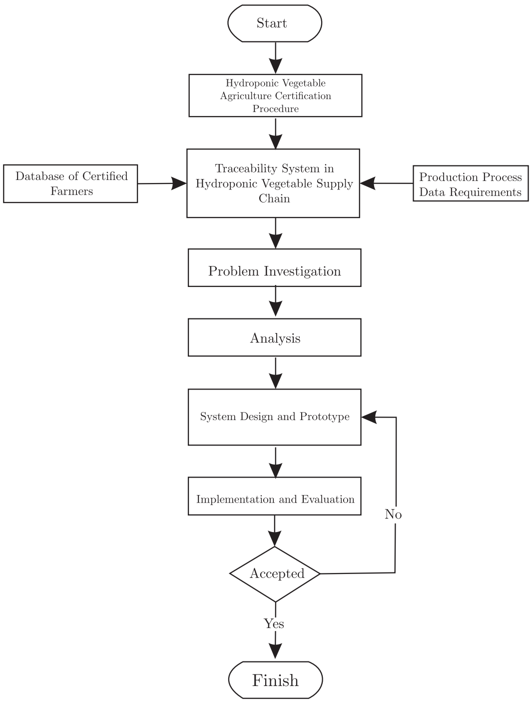

Figure 1: Research Framework.

4. Results and Discussion

4.1. Investigation

Investigating the problem began by collecting data and information by direct observations in the field, checking documents, and interviewing the current supply chain process. At the identification stage of the existing tracking and tracing functions, the company has recorded each hydroponic vegetables production process. The existing traceability system does not run efficiently and effectively because the system cannot adequately demonstrate the traceability process in the hydroponic vegetable supply chain. Product information is recorded with plain paper, and shipping documents are written using a pen. Therefore, when one wants to search for a product, the information is unclear and requires much time to check various documents. Therefore, the system is still manual to trace and track data from farmer to retailer. After identifying the entities involved, the traceability system requires development since it will track and trace functions from upstream to downstream, i.e., farmers, suppliers, processors, exporters, and retail.

The next stage was analyzing the activities and traceability business processes of the company. It is necessary to design an integrated traceability system starting from cultivation to purchases made by retail. All transactions made from the farmer, supplier, processor, exporter, and retailer are stored in one traceability system database, as shown in Figure 2. Blockchain technology aims to improve the traceability and transparency of transactions. Blockchain brings transparent, distributed, and reliable information to

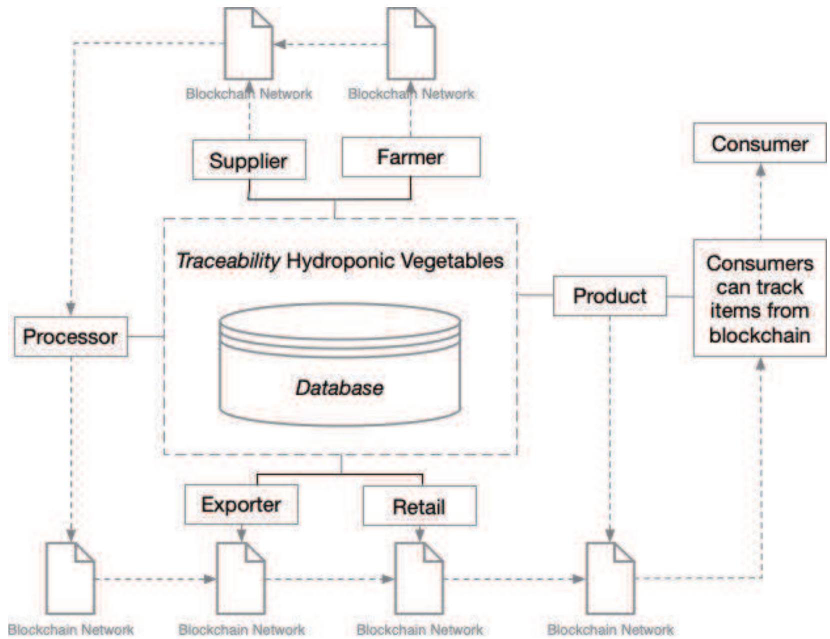

Figure 2: Proposed Traceability System Using Blockchain.

the traceability system. For example, if there is a problem with the product through the supply chain of hydroponic vegetables, the actors in the traceability system can verify and validate the safety of transactions and make a quick decision. Users can enter the QR Code found on the product or production code packaging to search for hydroponic vegetable products.

4.2. Analysis

A Computer Based Information System (see Seminar [31]) approach with modified blockchain technology was employed to support traceability needs. CBIS is a supporting resource owned by CV Garuda Farm in the hydroponic vegetable supply chain, adapted to the needs of the system's traceability. CBIS integrates software and hardware resources to convert data into information along the hydroponic vegetable supply chain to transparency hydroponic vegetables. For more detail, see Figure 3.

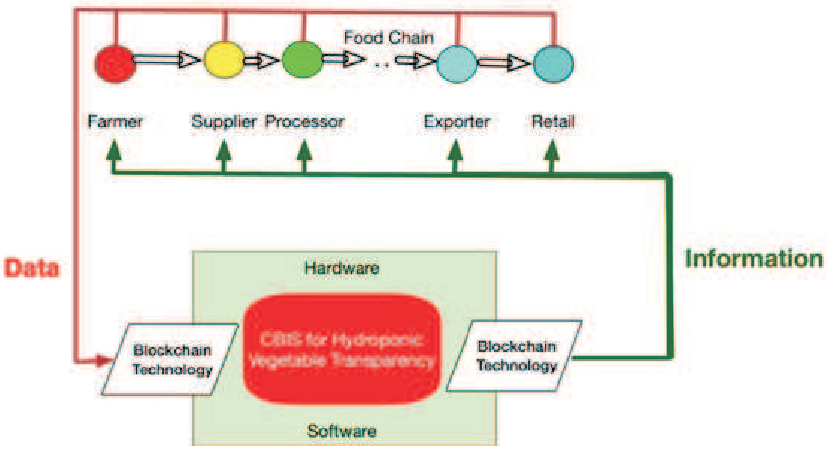

Figure 3: CBIS Hydroponic Vegetables Traceability System.

4.3. System Design and Prototype

The use case diagram in Figure 4 describes the interaction between actors in an application called GAHITA (Garuda Farm Hydroponics Traceability Application).

The interface design uses the NetBeans IDE X system development software with the Java programming language based on Android applications. The interface consists of the main page, login page, and main menu. The interface for end consumers or the public has a search box to perform product searches, then a login page for actors included in the supply chain. The main menu consists of a form filling menu, master data, and a product search menu.

The system prototype was tested by checking the system and the device, whether it is functioning correctly. This test utilized three different Android smartphones, specifications, and operating system versions, with the results running well and smoothly.

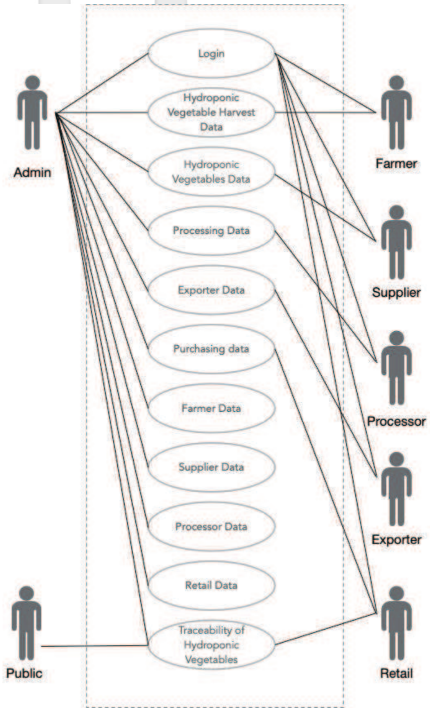

Figure 4: Use Case Traceability System.

4.4. Implementation and Evaluation

This stage applied a traceability system that can be used by the public and tracing product transactions. The public's traceability of product information is scanning or entering a QR Code in the final product packaging. After the scan, detailed information and supply chain details will appear in real-time. Blockchain will protect all the information about the product in real-time (see Popova and Butakova [33]).

The implementation of the transaction for this traceability system can be done by users who have logged in first. After logging in, there is a product search menu option that actors can access. The entered production code will retrieve data related to the existing production code. This search is divided into three pieces of information: product information, shipping or exporter information, and supplier information. Product information from search results consists of product name, production code, production date, expiration date, product certificate, packaging lot code, product nutrition, product equipment, maps, and other product information. Traceability information from the exporter process compromises information on exporter actors, vehicle specifications, receipt places, delivery places, and additional information. Subsequent tracking information from the supplier consists of processor name, telephone number, certificate, e-mail address, and map. The area map explains where the supplier is and which garden the hydroponic vegetables or produce is harvested (green polygon).

The prototype of the GAHITA traceability system was designed to adapt to the supply chain at CV Garuda Farm according to five actors along the hydroponic vegetable supply chain: farmers, suppliers, processors, exporters, and retailers. The arrangement of the prototype users described has been adapted to the use case diagram. There are activities according to the actors in the system involved to search for information. It starts with the Admin, who manages every hydroponic vegetable traceability activity and manages the actors involved in the system. The supplier collects hydroponic vegetable data and information. The data obtained from the supplier are the supplier's name, telephone number, electronic mail, certificate, geolocation, and certificate. Supplier if they want to update their search, can make processing settings, namely selecting vegetables to be processed for delivery, selecting packaging, materials, pallets, production and expiration times, taking geo photos containing location information, providing nutritional information, equipment, storage temperature, adhesive temperature, weight, and average mean. The processor makes an order, namely making an order by entering retail, vehicle number, time-ordered, taking geo-photo locations in real-time, and adding order items by selecting orders, pallets, materials, and packaging. The processor carries out the delivery in the system, i.e., entering the receipt, delivery place, vehicle type, exporter selection, trip number, package details, and geo photos of the vehicle's real-time location that takes hydroponic vegetables. The exporter data that can be tracked and traced are name, telephone number, electronic mail, address, and the geolocation of the exporter. Vehicle data that can be tracked and traced are vehicle type, capacity, payload, and vehicle dimensions. Retail data that can be traced and tracked are retail name data, telephone number, electronic mail, address, and geolocation. Product data that can be traced and tracked are product identity, product name, product description, and geo photos that store location in real-time.

Fulfillment of requests or orders for hydroponic vegetables also requires vehicles or exporters to deliver hydroponic vegetables updated in real-time in the system. The public has rights access to track hydroponic vegetables using the QR Code provided in the package. The QR code is generated automatically after the order is made and installed in the hydroponic vegetable packaging.

Besides storing transaction data and information, every photo taken in the application will automatically store pictures and their location in real-time since it is automatically equipped with geo photo or geolocation features. The system also requests application user access to GPS and the internet to know the actual location. If a product is damaged or recalled, its position can be identified briefly and quickly to make management decisions immediately in the hydroponic vegetable supply chain. The blockchain traceability implementation prototype for further detail is seen in Figure 5.

The evaluation used the User Experience Questionnaire (UEQ) questionnaire model to measure the user experience (see Schrepp et al. [23]). The standard questionnaire from UEQ is 26 questionnaires with 7 points on a Likert scale. The instrument (questionnaire) research was performed in a Google Form to 50 respondents involved in GAHITA. The evaluation results of GAHITA were at a positive level, as shown in Figure 6. This evaluation could describe the user's feeling that the application is excellent to use, especially in stimulation and attractiveness. One of the respondents' comments regarding the system

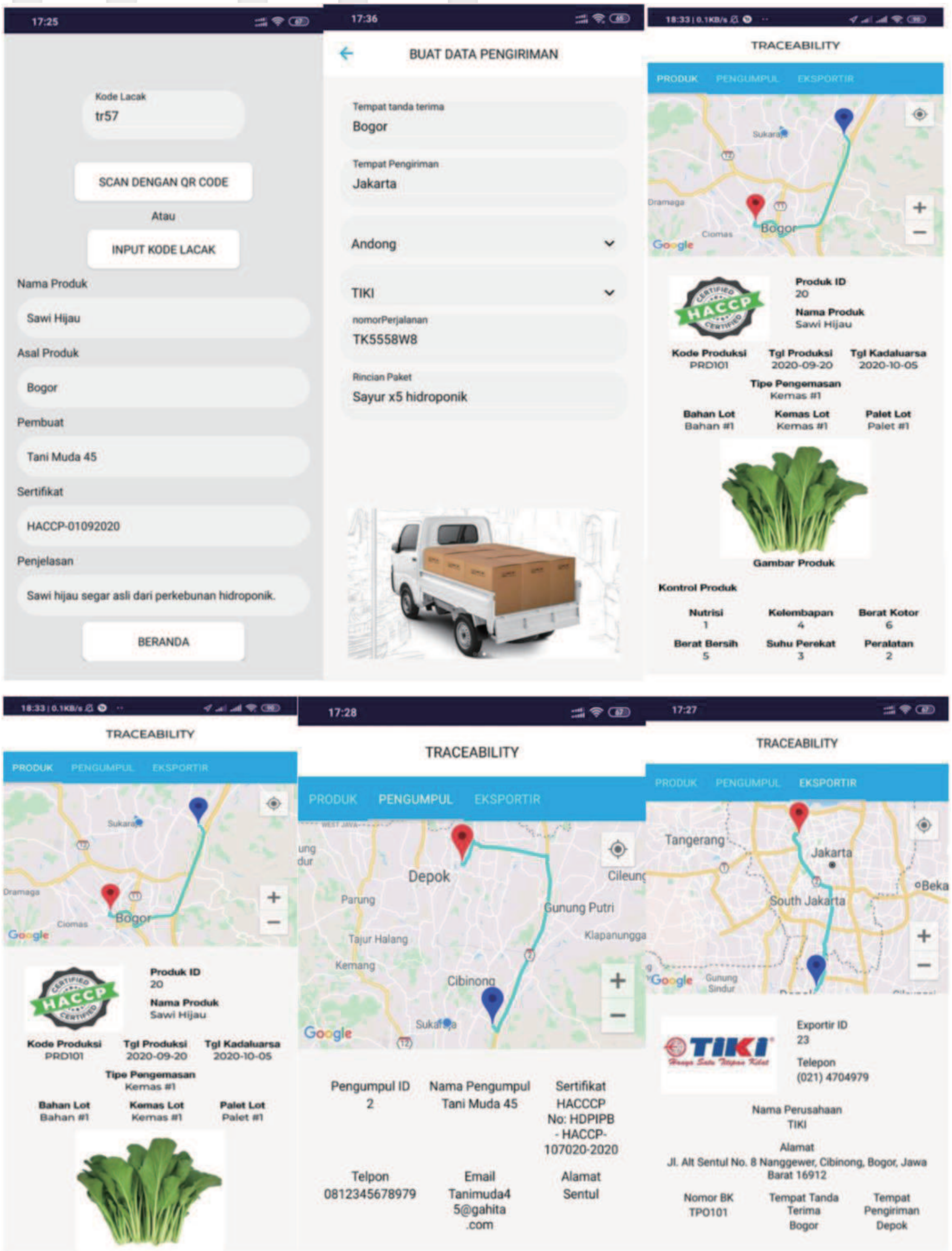

Figure 5: Prototype Traceability System.

that has been built is the ease in the process of entering data from suppliers to retail. The application looks very attractive and friendly, displaying a menu that is easy to understand and indulges the user's feeling. Thus, stimulating users to continue using this application in the future.

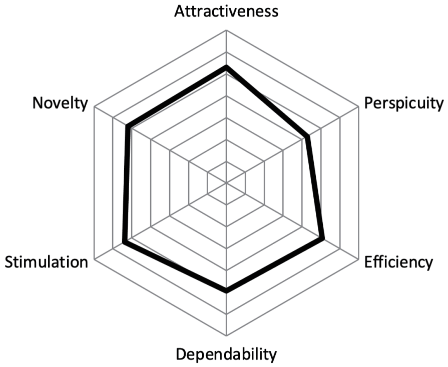

Figure 6: Evaluation Results of GAHITA.

4.5. Hydroponic Vegetables Traceability System Using Blockchain Technology

The five actors along the hydroponic vegetable supply chain designed the GAHITA traceability system prototype adaptation to the existing supply chain, namely farmer, supplier, processor, exporter, and retailer. This traceability system prototype can guarantee authenticity and transparency by recording the product's journey from upstream to downstream and quickly performing forward and backward analysis in one application on the Android platform (see Mann et al. [34]). Utilizing blockchain technology can create authenticity and transparency during the hydroponic vegetable supply chain process. This blockchain technology will store the GAHITA application in a distributed system data storage technology (see Du et al. [35]). This technology could make the data will be secured for a specific user. Actors with login access can communicate, transact, and verify transactions directly with other parties in the system without the need for third intermediaries. Data or information stored in a system that uses blockchain will be irreversible. An actor makes a transaction in the prototype stored in the GAHITA traceability system. The record cannot be changed again by anyone at any time. This ability is an added value to increase public or consumer confidence in the hydroponic vegetable supply chain. It avoids people or parties who want to take advantage of system weaknesses for destructive purposes. The proposed prototype using blockchain technology has met the critical requirements for hydroponic vegetable traceability, such as scalability, trust, transparency, security, privacy, authorization, and authentication (see Uddin et al. [38]). The proposed solution by performing security and cost analysis of blockchain-based prototype solutions shows that performance evaluation results reveal that the proposed traceability system solution is affordable and safe enough against possible attacks and vulnerabilities (see Musamih et al. [23]). The proposed blockchain traceability system also provides a valuable roadmap for supply chain management or food traceability researchers in general to build prototype solutions in the hydroponic vegetable industry. For more details, see Figure 7.

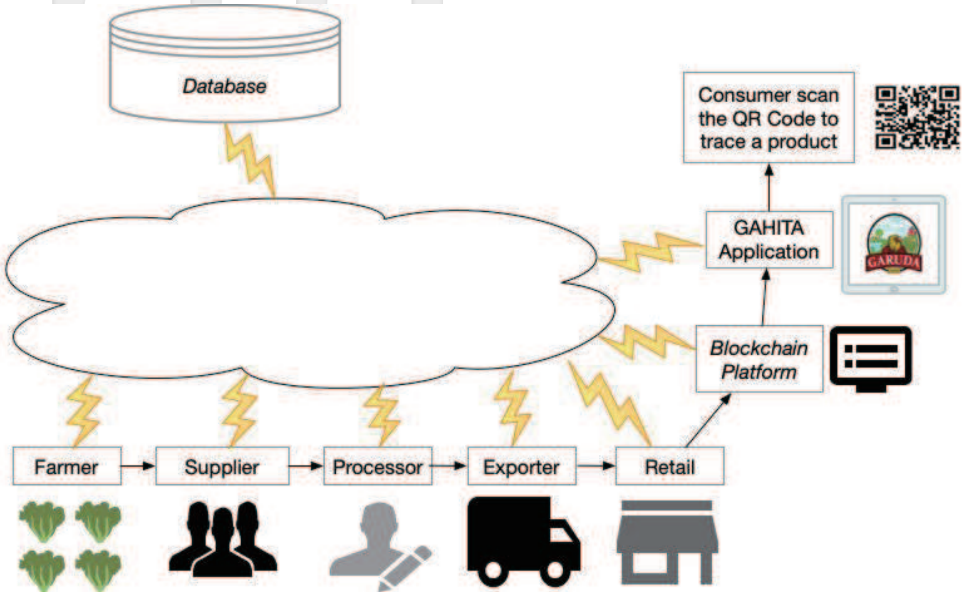

Figure 7: Hydroponic Vegetables Traceability System Using Blockchain Technology.

5. Conclusion

The traceability system is designed for manufacturers to ensure the authenticity and transparency of the products. Actors could enter the data on the process that occurs along the hydroponic vegetable supply chain. Utilizing blockchain technology in this system will make third parties cannot interrupt the stored data. After creating the data, the record cannot be replaced again by anyone. In addition to storing transaction data and information, a traceability system designed can also make consumers or the public seek and obtain information about the authenticity and transparency of the products consumed by scanning the QR Code.

The traceability system using blockchain technology encourages a faster decision support system. The hydroponic vegetables traceability system results create added value and innovation for the business. Data manipulation and errors due to each individual's association with the use of manual systems are also quite large. The development of a traceability system is to minimize the limitations of the existing manual system. Traceability blockchain-based technology will make the supply chain in the food safety and transparency process an innovative feature that adds value to ensure recorded information authenticity.

For future works, the prototypes can be developed into other platforms to make the system accessible. As expected, the next traceability system is to take advantage of more advanced technologies such as artificial intelligence and more advanced blockchain. The limitation of this research is the range of the traceability system's business process using blockchain technology only in Bogor hydroponic vegetables. It must be expanded to the typical hydroponic vegetable business in another research about traceability systems.

Therefore, all actors are still incomplete, such as the lack of involvement of government actors in the system. The supply chain activities do not represent Indonesia as a whole country. Application development is limited to the Android platform. Thus, the application needs to be developed on other platforms to reach more audiences.

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