International Journal Science and Technology
IJST Vol 3 No. 3 | November 2024 | ISSN: 2828-7223 (print), ISSN: 2828-7045 (online), Page 22-32

# ENHANCING EFFICIENCY AND TRANSPARENCY IN COFFEE SUPPLY CHAIN THROUGH BLOCKCHAIN-INTEGRATED TRACEABILITY PLATFORM

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**Article History**
Received : November 2024
Revised : November 2024
Accepted : November 2024
Published : November 2024

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**Cite This Article:**
Jagad Raya Ramadhan and Donny Avianto, "ENHANCING EFFICIENCY AND TRANSPARENCY IN COFFEE SUPPLY CHAIN THROUGH BLOCKCHAIN-INTEGRATED TRACEABILITY PLATFORM", *IJST*, vol. 3, no. 3, pp. 22–32, Nov. 2024.

**DOI:**
doi.org/10.56127/ijst.v3i3.1686

**Abstract:** Coffee is a global commodity that plays a significant role in the economy of many countries, including Indonesia. As the world's fourth-largest coffee producer, Indonesia has a vast potential to increase its coffee exports. This economic impact is not only a source of foreign exchange but also a significant source of income for smallholder farmers. However, recent inefficiencies have led to declining exports and quality control issues. This issue is exacerbated by the lack of transparency and traceability in the coffee supply chain, which makes it difficult for stakeholders to monitor the movement of coffee beans from farm to market. Thus, this research aims to address these problems by developing a blockchain-integrated traceability platform enhanced with IoT technology. The platform connects all stakeholders in the coffee supply chain, including farmers, processors, distributors, sellers, and consumers, ensuring real-time monitoring and data transparency throughout the coffee supply chain. This benefitted not only the involved stakeholders but also the end consumers. The system's provided QR code allows consumers to access information about the coffee's origin, quality, and processing details, increasing customer awareness and trust in the product.

**Keywords**: coffee, supply chain, blockchain, internet of things, traceability, transparency.

## INTRODUCTION

Coveted worldwide, coffee is a global crop with substantial financial importance. Grown in more than 80 countries, it is the second most traded commodity in the world after petroleum [1]. Over the last 30 years, a rising trend in coffee production and exports has been observed by The International Coffee Organization (ICO), suggesting that the market is growing steadily [2]. This requirement is in addition to the demand for coffee as a consumer beverage and an ingredient for instant coffee and other derivative products [3].

The economic consequences of coffee not only lie in the fact that we consume it, but it remains the principal source of income for most developing countries. For example, it is challenging to overestimate Indonesia's economic potential heavily relies on coffee exports. Indonesia is one of the largest coffee producers in the world, and it is currently ranked number four after Brazil, Vietnam, and Colombia [4]. The economic stimulation of the sector in Indonesia essentially goes beyond the concept of foreign exchange. Instead, it is one of the most significant sources of income for most smallholder farmers across the archipelago [4][5]. It also remains one of the central aspects of the socioeconomic life of rural areas, as it creates jobs and sustains local populations [6][7].

On the other hand, even though the coffee industry is hugely beneficial for Indonesia's economy, it has undergone a range of significant problems in recent years. Over the past few years, one of the most prominent issues has been the perceptible drop in coffee exports. According to the Ministry of Agriculture, in 2022, Indonesia exported 330,978 tons of coffee; in 2023, the number plummeted to 272,360 tons, which is 17.71 percent less. As the Ministry of Agriculture explains, the continuation of the surplus in production levels and the lack of efficacy in their distribution were the catalysts for reducing the levels of export. As a result, the quality of the shipped coffee varies significantly from the quality that the world market expects [8][9]. On a more significant level, the designated tendency illustrates the critical issue of the distribution of coffee from when it was grown to when it reached the market as a packaged and branded product [10][11]. Due to the need for an effective mechanism for delivering coffee from a farm to a market, including a range of affordable

intermediaries, Indonesia's coffee backslide is inevitable. As a result, there is a need to develop innovative solutions that can facilitate the specified process and make the distribution of coffee more efficient.

Research indicates that the performance of the existing coffee supply chain management in places such as Ciamis is regarded as average. This means there is a need to enhance the levels of performance and efficiency [12]. In addition, it is essential to note that the dynamics of sustainability risks in the context of the coffee supply chain are rather critical as they need to be recognized. The latter is directed at guaranteeing that the means to improve the process do not put the life conditions of coffee producers under threat [13]. The IoT should be integrated so that the parties involved can monitor the process of coffee distribution in real-time to see how the coffee beans move from the provider to the target market. It will also promote more transparency.

Moreover, blockchain technology is the technology by which the participants of the coffee market can improve the traceability and transparency of the coffee supply chain. It ensures that all transactions are securely stored, cannot be falsified, and can be verified that the transaction is valid [14]. It is essential in this context, named the “Coffee Paradox,” when producers do not receive the deserved share of the value [15]. To solve this problem, blockchain technology is used as it provides transparent traceability accessible to all stakeholders and, in this way, balances the distribution of profit [16]. In addition, another study reveals that blockchain technology can provide ecological embeddedness in the coffee sector [17].

Although several studies have investigated the applicability of IoT and Blockchain in the supply chain in general, the research on their use in the case of the coffee supply chain in Indonesia is limited. The available research is mainly aimed at enhancing the efficiency of the coffee supply chain on the part of each stakeholder. Thus, the current study aims to contribute to this research gap by developing an integrated platform that connects the coffee supply chain stakeholders like farmers, processors, distributors, sellers, and consumers. This platform will offer a novel solution focusing on increasing efficiency and establishing high transparency in the coffee supply chain. The platform will optimize distribution and traceability processes by connecting the entire chain. As a result, it will enable customers to be confident in the quality and authenticity of the coffee they buy.

## RESEARCH METHOD

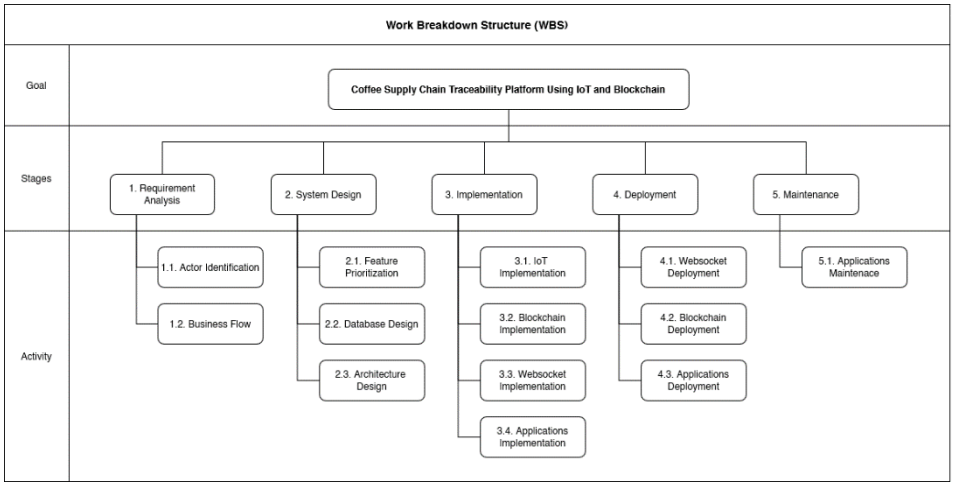



**Figure 1.** Research Method

The research method used by Work Breakdown Structure illustrates the process of creating a Coffee Supply Chain Traceability Platform using IoT and Blockchain in a stepwise technique. The process has been divided into five broad stages: Requirement Analysis, System Design, Implementation, Deployment, and Maintenance. First, the process is initiated, and the critical actors in the coffee supply chain platform are identified. In the same phase, the business flow was defined stepwise. Secondly, features were identified in the system design stage, and the databases and the system architecture of the application were designed. Thirdly, the implementation of IoT, Blockchain, Websockets, and applications were deployed. Lastly, the application is checked frequently in the maintenance stage to ensure it runs smoothly. This systematic method/process ensures that the objective of the application is realized.

A Work Breakdown Structure (WBS) is one of the critical elements of project management that helps create a hierarchical organization of a work project, breaking down a total scope into small components. Such

a clearly defined decomposition helps a researcher see what work is done and what result is achieved according to the project's planning, controlling, and execution, which is made easier [18].

The first stage is requirement analysis, which defines all the system's needs. It consists of two parts: actor identification and definition of business flow. In the first part, the actors involved in the coffee supply chain are identified to make sure all the stakeholders, such as farmers, distributors, processors, sellers, and consumers, are considered. This is important in terms of business requirements for the system to meet. In the second part, the business flow is designed to define how coffee and data will flow through the supply chain. This results in a plan of how the IoT and blockchain systems will keep the data at each stage.

The second stage is System Design. At this stage, a detailed plan for the way in which the system will operate is created. Feature prioritization is conducted first to ensure that the most important parts of the system are developed. A complete database design takes second place in the system design. With their help, the huge quantity of data created by the IoT devices and applications of the system will be processed. Finally, the overall system architecture is developed to ensure that all the parts, including IoT, blockchain, and all other applications, will work together.

The third stage is the Implementation and technical infrastructure of the system. The required IoT devices are mounted and configured based on the location, temperature, humidity, and other data to follow and monitor the coffee distribution process. Simultaneously, the blockchain records the transaction data and guarantees perpetual transparency or lack of trust. In addition to that, the WebSocket system is deployed to create a real-time connection between the IoT and the application sides. Finally, the application is developed to enable the user to access the front end of the traceability data.

The fourth stage is deployment, including releases, often in a live deployed environment. In such a case, we first deploy web sockets to secure continuous data flow from the application to the IoT devices in real time, which is highly profitable for this industry. Then, I deploy the blockchain to secure all the information and necessary transaction data. Finally, the applications are deployed, and the users can communicate with the system. They can review all the information and data relating to the supply and manage their operations there.

The final stage is Maintenance, its main purposes is to keep the platform reliable and closes to the users' requirements. Its goals are to control the proper work of it and facilitate frequent testing. To measure maintenance, it is necessary to check the applications performance and fix new bugs opened.

## RESULT AND DISCUSSION

### *Requirement Analysis*

In the Requirement Analysis phase, a list of actors involved in the coffee supply chain was identified, and their responsibilities were defined. There are at least three direct actors in the coffee supply chain, which are farmers, processors and sellers. This information is obtained from interviews with local coffee farmers in Magelang and also some study literature with similar topics to this research. First research that has been conducted by Amilia Azzahro in East Java mentioned that there are at least three actors in the coffee supply chain, which is farmers, processors and sellers [19]. Another research conducted by Onang Ligar in Indonesia also in line with the first research, supporting this information [20]. However, there are some indirect actors that are also involved in the coffee supply chain, such as distributors and consumers. Those two actors now have been added to the list of actors in the coffee supply chain to further enhance the transparency and traceability of the coffee supply chain.

**Table 1.** Requirement Analysis

| Actor | Responsibility |
|---|---|
| Farmer | Harvesting and processing the raw coffee beans.<br>Input data about coffee variety, quantity, method used, price, and harvesting date into the system. |
| Processor | Processes the raw coffee beans into finished or semi-finished products.<br>Records information about the coffee profile roast.<br>Input processed coffee data into the system (e.g., profile roast, quantity, price) |
| Distributor | Responsible for transporting coffee products from farmers to processors and processors to sellers.<br>Uses IoT devices to track shipment conditions (e.g., location, temperature, humidity) during transportation. |

| | |
|---|---|
| | Inputs logistics data (e.g., delivery time, arrival date) into the system. |
| Seller | Purchase products from processors.<br>Sells the finished or semi-finished coffee products to consumers. |
| Consumer | The final actor in the supply chain purchases the coffee product.<br>Access information on the coffee's origin, quality, and processing details via the QR code. |

The following design is business flow, it demonstrates where coffee and data move over the supply chain. Farmers are the ones who take raw coffee beans and process them. Then, processed coffee is transmitted to processors. Processors will convert raw beans into final or half-finished subsists and submit the data to the system. Distributors transport coffee products from farmers through processors to sellers and use IoT devices to monitor the condition of coffee in the transportation process. The seller will purchase a product from the processor and sell the product over to the customer. Customers may use a coffee QR code to find the quality of coffee, its origin, and how it has been processed.

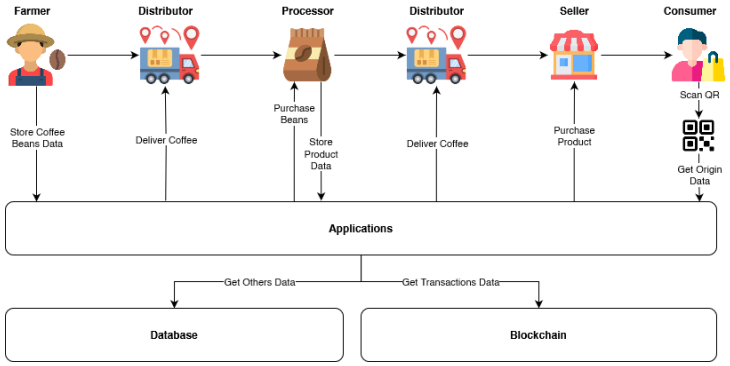



**Figure 2.** Business Flow

***System Design***

The second stage, System Design, involves outlining the system's functionality in terms of feature prioritization, database design, and architecture to verify effectiveness in terms of transparency and traceability within the coffee supply chain. In this document, the features have been mapped using an entity-relationship diagram.

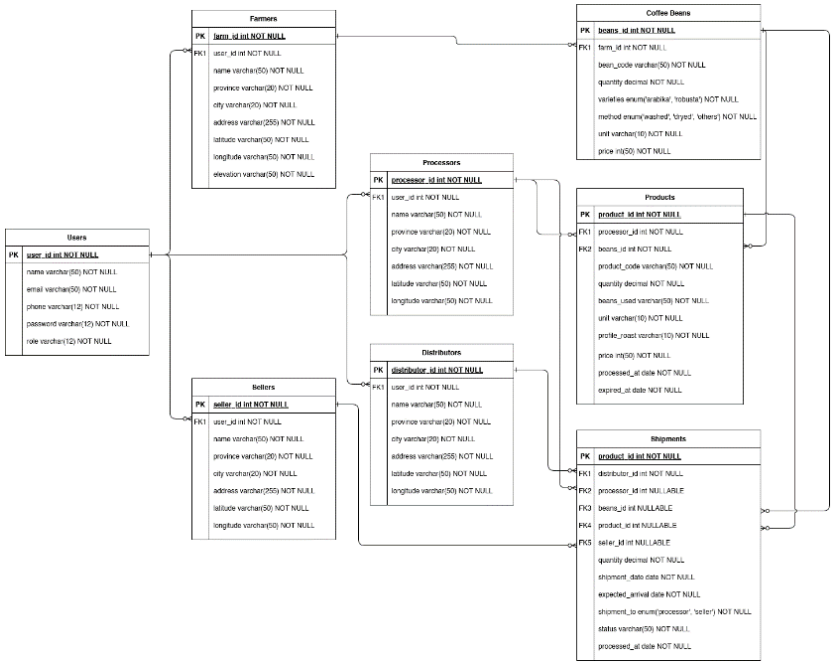



**Figure 3**. Entity Relationship Diagram

The next step is the design of system architecture. This system architecture diagram reflects the platform, which consists of Laravel-based dashboards and React Native mobile apps for stakeholders and consumers. MySQL database is used as a primary database for storing all the data and for handling transactions data Ethereum Blockchain is used. To ensure the system's connectivity, IoT devices are connected via WebSockets, namely Express-ws, which receives real-time GPS tracking data.

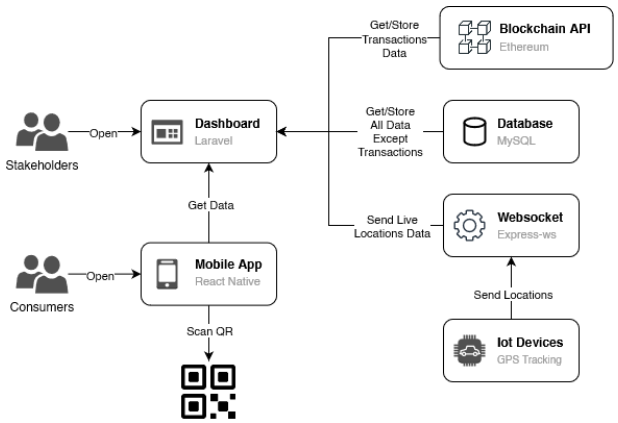
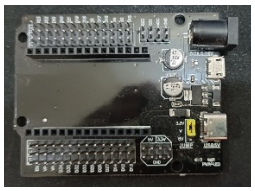
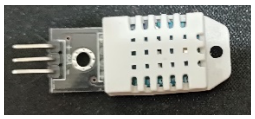



**Figure 4.** System Architecture

***Implementation***

At this stage, the initial step is to list the IoT components or modules that are used in the research. The Complete list of IoT components used in the research can be seen in the table below. IoT is a modern technology that allows to connect and communicate between different devices using the internet [21].

**Table 2**. IoT Components

| Component Image | Component Name | Component Function |
|---|---|---|
|  | Esp32 WROOM 30 Pins | Esp32 is used as the core processing unit that enables other components to sense, compute, and communicate with other devices |
|  | Expansion Board 30 Pins | Expansion Board adds extra functionality to a main IoT board (Esp32). It can provide additional I/O pins, actuator control and power management. |
|  | GY-GPS NEO-7M | GY-GPS NEO-7M is a GPS module used in IoT to provide real-time location tracking. It offers accurate positioning data, including latitude, longitude, altitude, and speed. |
|  | Dht22 | DHT22 is a sensor used to measure temperature and humidity. |
|  | GPS Active Antenna | GPS Antenna is used to enhance the reception of GPS signals. It contains an internal low-noise amplifier (LNA) that boosts weak GPS signals, improving signal strength and accuracy, especially in areas with poor reception. |

| Component Image | Component Name | Component Function |
|---|---|---|
|  | Two Batteries with Holder | Two Batteries with Holder is a device that holds and connects two batteries in series or parallel. It provides a secure way to power electronic devices, allowing easy battery installation and replacement. |

After that the IoT Implementation is conducted, where various devices are installed and properly configured to track and monitor the process of coffee distribution. To be more specific, GY-NEO-7M GPS modules, DHT22 temperature and humidity sensors, ESP32 microcontrollers, GPS active antenna and an external battery are used to gather the relevant data, location along with the temperature and humidity. This offers real-time information about the process within the given supply chain.

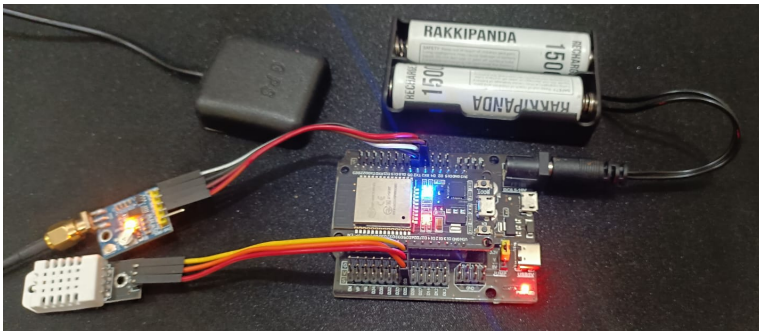



**Figure 5.** IoT Implementation

Following that, the next step is Blockchain Implementation. It ensures the safety and transparency of the transaction data. By using blockchain technology, the system securely records the data. No one can change it since the data is stored in many blocks. This point is essential to maintaining transparency and building trust in the coffee supply chain. The blockchain used in this research is Truffle and Ganache. They are both Ethereum frameworks specially made for development purposes.

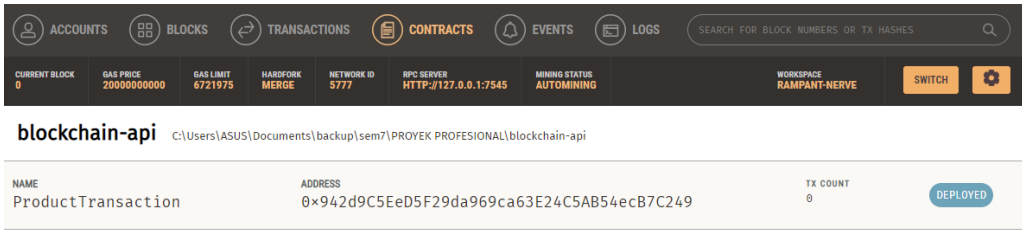



**Figure 6.** Blockchain Smart Contract

Next, is to add an Express-ws based Websocket system to make the communication between the IoT devices and the application in real-time. This will help to keep the data flowing smoothly between the devices and application benefiting all the stakeholders with real-time knowledge of what is exactly going on with the process of distribution of the coffee.

```
const app = require("express")();
const appWs = require("express-ws")(app);

app.ws("/TRK-001", (ws) => {
  ws.on("message", (msg) => {
    console.log("Received: ", msg);
    appWs.getWss().clients.forEach((client) => {
      client.send(msg);
    });
  });
});

app.listen(3005, () => console.log("Server has been started *:3005"));
```

**Figure 7.** Websocket Implementation

Farmer is the first actor on the coffee supply chain that is responsible for harvesting the raw coffee beans. Data that can be recorded are the data about the coffee variety, method, amount of harvested raw beans, price, and the date of harvesting. The data is then saved in the database.

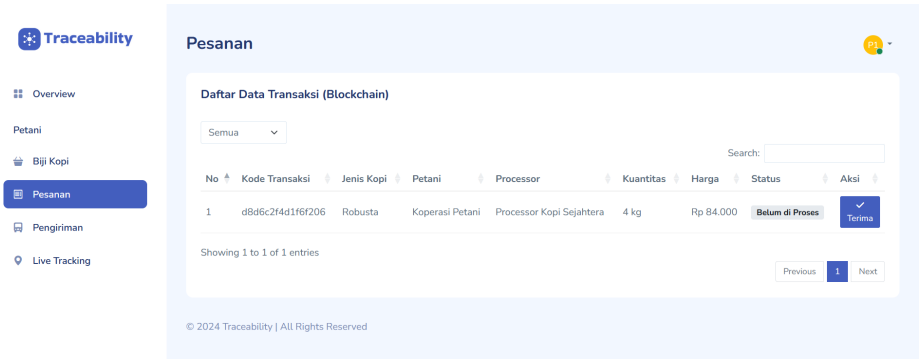



**Figure 8.** Implementation for Farmer Role

The second actor is a processor. They are responsible for processing green coffee beans in raw condition to finished or semi-finished products. The processor stores data in the systems that contain information on profile roast, quantity, price, and expiration date. The data is stored in the database and will be purchased by the next actor.

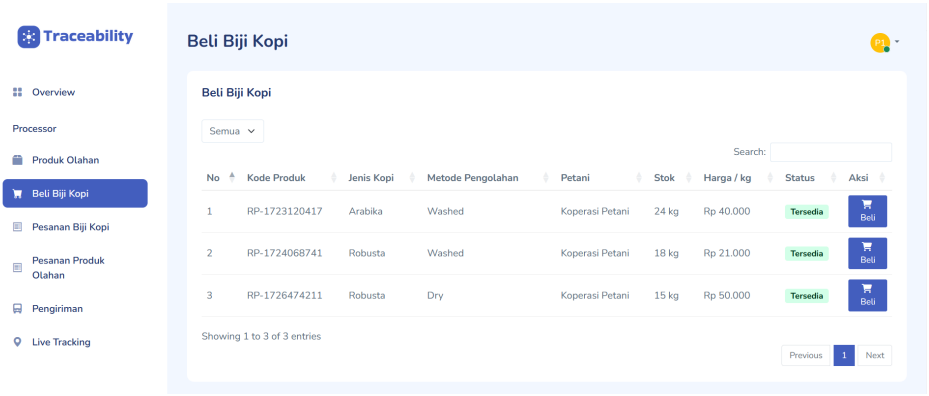



**Figure 9.** Implementation for Processor Role

The next actor is a distributor that ships coffee beans from farmers to processors and from processors to sellers. Distributors use IoT devices to track shipment conditions, such as shipment location, temperature, humidity during transportation. A distributor enters logistics data, such as delivery time, arrival date, the shipment's current status into a system. This information can be seen by a sender and a receiver.

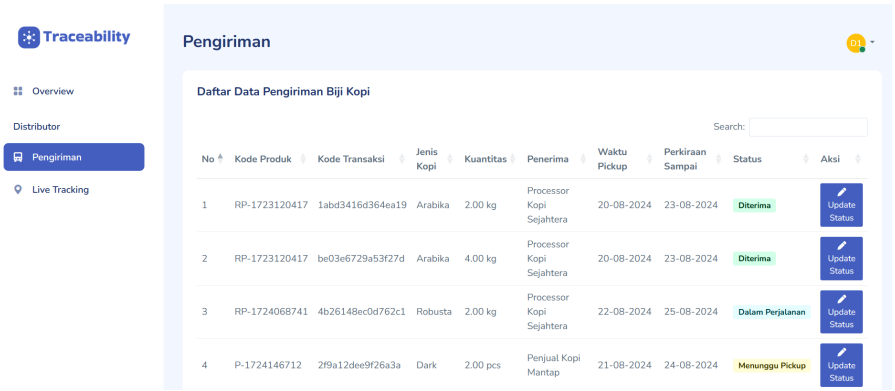



**Figure 10.** Implementation for Distributor Role

The next feature is live tracking. This feature helps the stackholder to track down their shipment. Not only do they have an opportunity to see the position of the coffee, but also, the stakeholders are able to check the temperature and humidity's conditions of the shipment. Such a feature makes the process of drip easier and scaffolds that the coffee is delivered in the proper way.

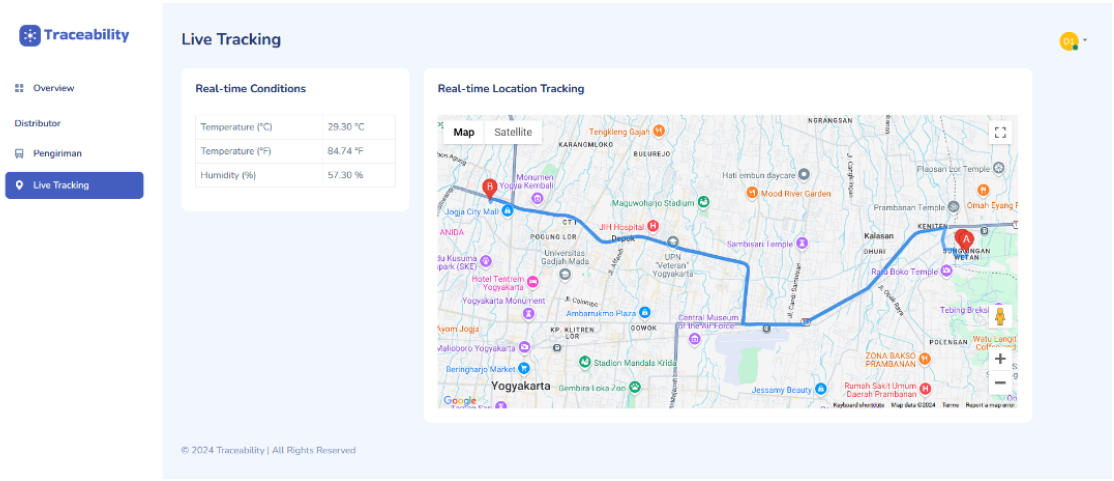



**Figure 11.** Implementation for Live Tracking

The next actor is the seller, who purchases products from processors via the system and sells the finished or semi-finished coffee products to consumers. Sellers also have the ability to track the current status of their shipment. This includes the location, temperature, and humidity of the shipment. By applying this feature, the seller can ensure that the coffee is delivered in the proper way, further increasing the transparency and efficiency of the coffee supply chain.

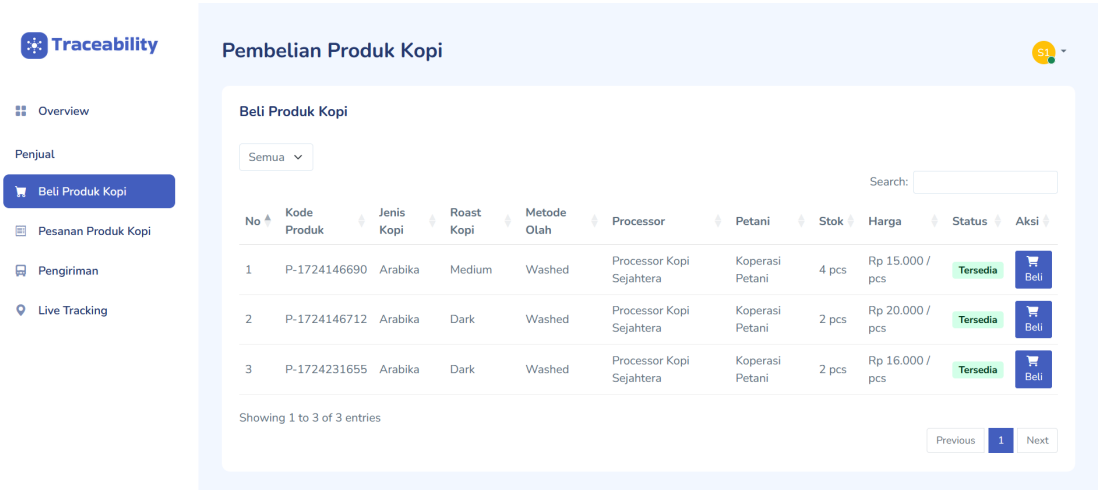



**Figure 12.** Implementation for Seller Role

The last actor in the supply chain is the consumer. The product is the final product that most of us experience. The coffee product is acquired by the consumer from the seller. A QR code gives accessibility to the destination, quality, processing, and other details of the coffee. This allows more transparency and traceability, implying that the individual who bought the coffee can be sure that the coffee product they bought is from a trustworthy origin. This is an excellent example of end users' self-governance via technology. Other than that, the stakeholders involved in this system can also increase their brand value by providing information about the coffee to the consumer. This will make the consumer more confident in buying their product.


**Figure 13.** Consumer Track the Coffee Origin Using a QR Code

***Deployment***

The next phase is Deployment, in which all the system components are made operational. To this end, first, the WebSocket system is deployed, securing the real-time flow of the required data between the IoT devices and the application. It guarantees that stakeholders' command over the information regarding coffee distribution is as up to date as possible. Secondly, the blockchain is deployed, ensuring the utmost security of the vital transaction details related to the process with the guaranteed incorruptibility of the data. Finally, the applications are deployed, enabling the users to access the system and adjust the supply chain and production processes as required. The deployment phase allows the system to be entirely operational to permit stakeholders access.

**Table 3.** Deployed Applications URL

| Service | Deployed URL |
|---|---|
| Dashboard | https://traceability.jagadraya.cloud |
| Websocket | http://socket.jagadraya.cloud |
| Blockchain | http://blockchain.jagadraya.cloud |

***Maintenance***

The final stage, Maintenance, focuses on ensuring the long-term stability and functionality of the platform. In this sense, it involves continuous testing, which will help detect and eliminate any newly emerged bugs and issues and prevent any critical breach concerning updates, which will improve the platform's functionality or, in some cases, security. Maintenance is vital due to the change in the coffee supply chain after a significant period. As long as Maintenance is performed regularly, the platform will remain relevant to the customers regarding security and function.

**Table 4**. Application Testing Scenarios

| Actor | Scenario | Expected Outcome | Status |
|---|---|---|---|
| Farmer | Inputs raw coffee bean data into the system. | Successfully save the data into the database. | Passed |
| | | | Passed |

| Actor | Scenario | Expected Outcome | Status |
|---|---|---|---|
| | Accept incoming purchase requests from the processor. | Successfully accepts the purchase request. | Passed |
| | See the current status of the shipment. | Successfully tracks the current shipment condition. | |
| Processor | Purchase raw coffee beans from the farmer. | Successfully sent the purchase request for coffee beans. | Passed |
| | Inputs processed coffee data into the system. | Successfully save the data into the database. | Passed |
| | Accept incoming purchase requests from the seller. | Successfully accepts the purchase request. | Passed |
| | See the current status of the shipment. | Successfully tracks the current shipment condition. | Passed |
| Distributor | Update logistics data in the system. | Successfully save the data into the database. | Passed |
| Seller | Buy coffee products from the processor. | Successfully sent the purchase request for coffee products. | Passed |
| | See the current status of the shipment. | Successfully tracks the current shipment condition. | Passed |
| Consumer | Scan the QR code to access coffee information. | Successfully retrieves the information about coffee's origin. | Passed |

## CONCLUSION

As a result, the research has successfully developed a Coffee Supply Chain Blockchain-Integrated Traceability Platform with IoT technology. The platform is developed to increase the efficiency and transparency of the coffee supply chain in Indonesia by connecting all coffee supply chain stakeholders: farmers, processors, distributors, sellers, and consumers. The greatest beneficiary of the platform in the end was the customers buying the product. They could read and access the information about the product they purchased. The research has developed the platform and achieved its purpose. However, it should be noted that its feasibility will highly depend on the business flow of the coffee supply chain. The current use case of this platform is for the packaged coffee market. We can identify that this is a limitation of our research. Therefore, there is room for more potential research to develop a platform for other specific use cases. Moreover, the IoT device implemented in this research still has a limitation regarding internet connectivity. The device will only send data when connected to Wi-Fi. This limitation allows future research to develop a device that uses a cellular network to send data. Therefore, the device is more flexible and can be used in a broader area.

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