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Development of a Smart Traceability System for the Rice Agroindustry Supply Chain in Indonesia

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Abstract: Rice is an essential food commodity in national and food security in Indonesia with a complex supply chain network. Various risks related to food quality and food safety occurs along the supply chain. Therefore, a tool is needed to monitor the rice production process from upstream to downstream (land-to-table) by implementing a traceability system to promote food transparency. In this system, all actors must be responsible for ensuring the quality and safety of products through various handling processes carried out from cultivation to product distribution. This paper aimed to develop a smart IT (Information Technology)-based traceability system in the rice supply chain using the System Development Life Cycle (SDLC). The actors involved in the rice supply chain consist of farmers, processing industries, distributors, bulogs, and retailers. Furthermore, this paper discussed the system architecture and the development of traceability system design using a data flow diagram (DFD). The developed prototype system shows the functional requirements of the system and can be used by stakeholders to monitor the production process and assist the decision-making process.

Keywords: rice; supply chain; smart system; traceability system

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1. Introduction

The traceability system is a management system for managing risk, proposed by the Codex Alimentarius, that is able to track the movement of food at certain stages of production, processing, and distribution [1]. Many countries are trying to implement this system in various commodities through regulations they have set to ensure the quality and safety of food [2,3]. Rice is an essential commodity in Indonesia because the majority of Indonesia's population consumes it as a daily carbohydrate intake [4]. Based on data from the Agricultural Datacenter and Information [5], the average rice consumption in Indonesia reaches 84.9 kg annually. Nevertheless, the supply chain of rice in Indonesia still faces several problems, one of them is traceability. Traceability has become a pressing issue because of the complexity of the supply chain network of rice and the rise of various quality risks along the supply chain. One of the risks that often occurs is the process of quality manipulation carried out by the rice milling industry and rice traders. In practice, Suismono [6] revealed that quality manipulation can occur in several ways. Those are, (a) mixing of rice between varieties and between qualities, (b) re-mixing of rice that has experienced a quality decline (reprocessing), (c) adding dangerous chemicals, such as chlorine and aromatic compounds in rice, and (d) the use of packaging labels that are not in accordance with the contents. Previous studies have reported the presence of hazardous ingredients in rice sold in the market. Aminah et al. [7] found that 33.33% of all samples examined in the traditional Makassar market tested positive for chlorine, while Yuda et al. [8] found that 6% of rice samples tested positive for chlorine in the Padang city market. To minimize these problems, all actors involved in the supply chain must practice excellent handling standards and record all relevant activities. Kresna et al. [9] explained that proper documentation is the key to implementing a traceability system in Indonesia.

The application of traceability systems has become an inseparable part of the food production chain, so a developed system varies depending on user requirements [10,11]. Nowadays, generally, the actors use paper-based manuals for the traceability system in the rice agroindustry in Indonesia. Nonetheless, this system has disadvantages, such as it can be manipulated, it is vulnerable to human error, and it can be physically damaged [12]. Based on these factors, the purpose of the development of an IT-based traceability system is to overcome the problems found in paper-based traceability systems and minimize the quality risks that occur. Research on the development of IT-based traceability systems has been carried out by several researchers in various industries such as the tuna processing industry [9], the ginseng industry [13], the wheat milling industry [14], and the milk processing industry [15]. Even so, generally, the developed traceability system is still limited for capturing and transmitting information. Furthermore, there is still no smart IT-based traceability system that has been developed to assist in the decision-making process, especially in the rice agroindustry. This paper aimed to develop a prototype design of smart traceability systems in the rice agroindustry in Indonesia.

The remainder of the paper is structured into six sections as follows. Section 1 describes the introduction of the study. Section 2 describes a literature review of related studies. Section 3 describes the system development method. Sections 4–6 discuss the result of research involving supply chain structure, architecture, design, and implementation of traceability systems. Section 7 describes the managerial implication. Finally, Section 8 states the conclusions and future work.

2. Literature Review

Agricultural supply chain activities are inseparable from various uncertainties that introduce risks that could affect component and material flow in the supply chain. Food contamination can occur in the products starting from the cultivation until the distribution to the consumers [16]. Therefore, the implementation of a traceability information system is very crucial to realizing the integration of quality and food safety [17]. According to Bosona and Gebresenbet [18], the traceability of food products is part of a logistics management system that provides the ability to capture, store, and transmit information related to food, feed, and all substances in the supply chain that are used to control food quality and safety that can be tracked upstream and downstream. The implementation of the traceability system involves two main principles, namely tracing and tracking. Tracing is the ability of the system to trace the origin of food, while tracking is the ability to trace the food post-production [4]. According to Kumar et al. [19], traceability acts as a link to share relevant information between actors in the supply chain. Therefore, a traceability system can realize transparency by managing all relevant information related to the production process.

In its implementation, the development of an IT-based traceability system is a widely used approach due to the ability to communicate between stakeholders in the supply chain. Many researchers have conducted studies on the development of traceability systems in the food supply chain. Vanany et al. [20,21] developed a prototype of the traceability system in the mango and mangosteen supply chain. In this study, relevant information related to cultivation, postharvest, and product distribution is recorded by stakeholders and stored in a website-based traceability system. Rizqya et al. [22] developed a traceability system of the supply chain of coconut palm sugar using desktop-based applications. Kresna et al. [9] developed a web-based traceability system on tuna supply chains start from fishing vessels to retailers. This system monitors the production process based on microbiological analysis. The traceability system can be further developed and can be used by all stakeholders in decision-making. The data in the system can be processed through data mining and statistical methods to obtain detailed information for stakeholders [10]. Nevertheless, studies on the development of smart traceability systems in the food supply chain are still limited, especially in the rice supply chain.

3. Methodology

The design and development of traceability systems are carried out using the System Development Life Cycle (SDLC) approach that consists of several steps, namely, (1) system investigation—it determined the business process by conducting a field survey in 2016–2018 in the West Java Province of Indonesia, (2) system analysis of the functional requirements of the system using Data Flow Diagrams (DFD), (3) system design—the design of the interface and database system, (4) prototype development—a stage to build programs, and (5) system evaluation—a stage to evaluate the system. Figure 1, shows the method of developing a traceability system.

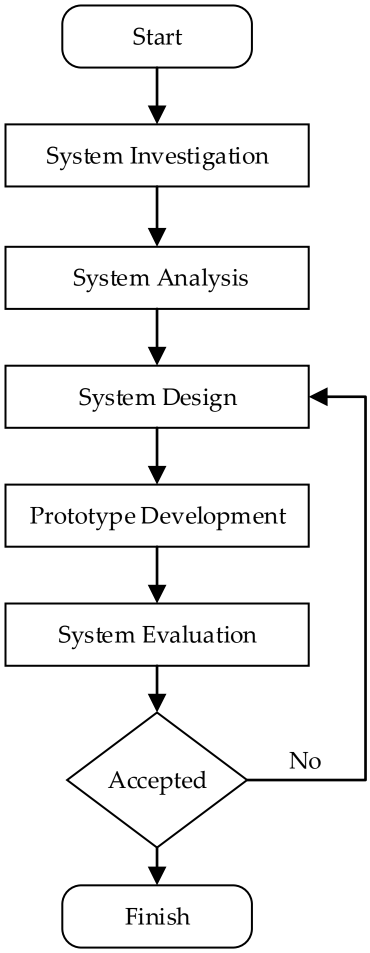

Figure 1. The method of traceability system development.

4. Rice Agroindustry Supply Chain

The supply chain of agricultural products is related to the provision of safe, healthy, and nutritious food for consumers. The entire production process starts from land cultivation, processing, distribution, and marketing, until the products are delivered to consumers. In other words, the supply chain is an integrated system from upstream to downstream to produce and distribute products with the right amount, quality, location and time. Furthermore, Marimin [23] explained that the supply chain is an integrated marketing entity between actors and products to provide satisfaction to customers. Based on previous studies conducted by Purwandoko et al. [24], the development of traceability systems in the rice supply chain is based on five actors, namely, (1) the farmer group—the smallest organization recognized by the government that plays a role in the cultivation process, (2) the rice milling industry—companies that process paddy into white rice, (3) bulog (Indonesian Logistics Agency)—a government-owned company that plays a role in food distribution and price control, (4) the distributor—companies that deal with products distribution, and (5) the retailer—companies that sell the products to consumers. An illustration of the rice agroindustry supply chain is presented in Figure 2.

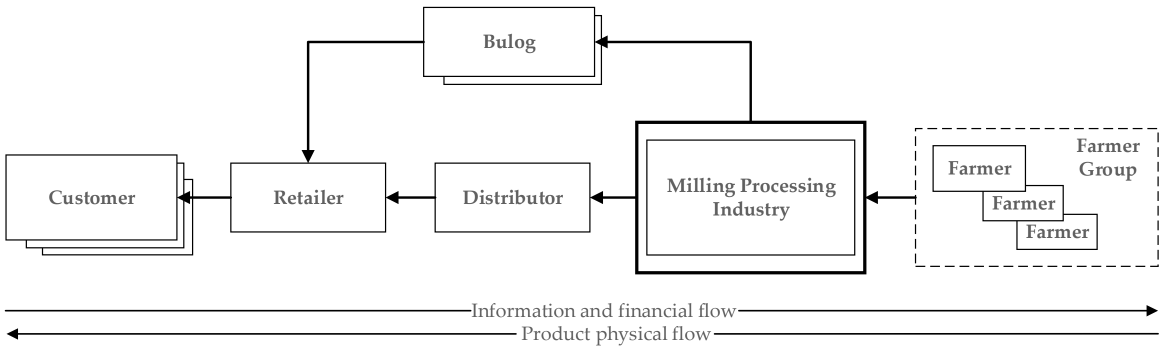

Figure 2. Rice supply chain model in Indonesia. Modifications from Purwandoko et al. [24].

5. Traceability System Development

Currently, the global food trade is growing, resulting in business processes that can occur in various geographical regions and times. It raises the complexity of the supply chain and, therefore, using traditional methods in the data recording process to facilitate product traceability is insufficient to support supply chain activities. In the current development of supply chain management, capabilities in information exchange, integration, and communication between actors are needed to guarantee food safety and quality. Therefore, it is necessary to develop an IT-based traceability system in the rice supply chain.

5.1. System Architecture

Lankhorst [25] explains that architecture is needed to manage an organization or system with high complexity. Information system architecture combines various information requirements, system components, and supporting technologies. According to [26,27], system architecture is defined as a basic framework of a system, which consists of system components that interact synergically with each other to achieve the system goal. Figure 3 shows the traceability system architecture model, which is a modification of the model from Seminar et al. [28] and Kassahun et al [29].

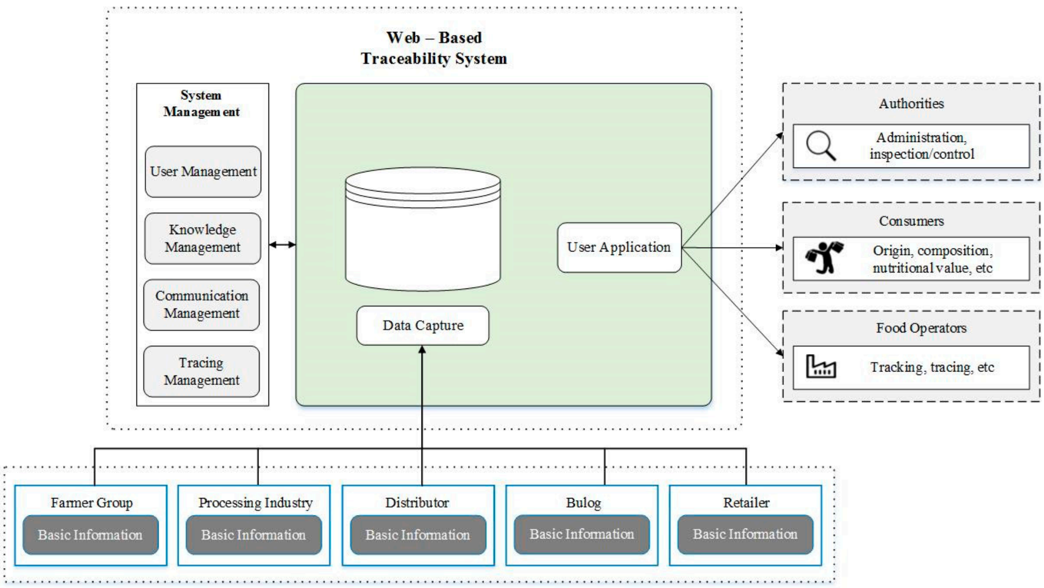

Figure 3. Traceability system architecture.

The information system architecture, shown in Figure 3, describes application systems and their role in supporting supply chain business processes, which include (a) key application concepts that are needed, (b) logical structure of information systems that can provide an overview of information exchange between systems and the roles of each actor, and (c) designing modules from information systems. The architecture of rice traceability system consists of several management systems: User management, knowledge management, communication management, and traceability management. User management consists of modules that can be accessed by every actor, including system administration (government), consumers, and food operators. Knowledge management is part of the traceability system in the agroindustry, used to assist in decision-making for supplier selection and customer relationship management. Communication management provides communication facilities between actors, while traceability management is part of the system used to trace the products. Furthermore, the data acquisition device used is a QR Code, which is developed according to the needs of the actor. In the traceability system, data obtained during recording is stored on the traceability server on either local storage or cloud storage.

5.2. Traceability System Analysis

Based on the proposed architecture, the next step is to analyze the traceability system that will be built. A system analysis was carried out to determine a system that will be built into elements to identify and evaluate system requirements. Satzinger [30] explained that system analysis is a process to document in detail the functional requirements of a business from a new system or an existing system. Data flow diagrams (DFDs) were used in this study to obtain a general description of the system, which was built according to the needs of supply chain actors in the field. Analysis of functional requirements of the system using DFD describes the graphical representation of system components, data streams and data storage in the traceability system. More fully, the analysis of the functional requirements of the traceability system using DFD is described in the picture and explanation below.

The DFD on the rice traceability system consists of context diagrams, DFD level 1, DFD level 2, and DFD level 3. The context diagram is the highest level DFD that describes the environmental space of the entire system. Based on Figure 4, traceability system actors can be divided into three groups, namely (a) actors who are directly involved in the rice production process (farmer groups, milling industry, BULOG, distributors, retailers) who receive transaction and stock reports, (b) system administrators who are external actors that regulate the system and issue policies, as intended by the government through the Ministry of Agriculture, and (c) general users, the people who purchase milled rice products and try to conduct traces.

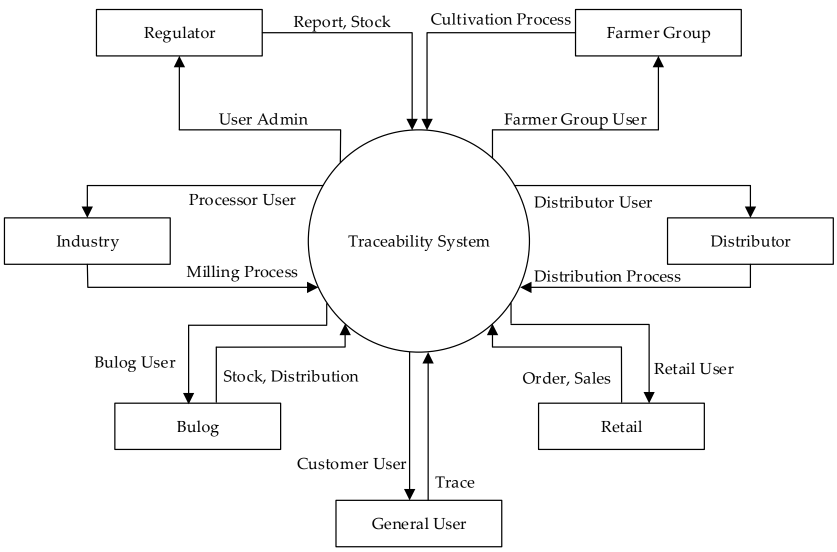

Figure 4. Context diagram of the traceability system. Data flow diagram (DFD) level 0.

Level 1 DFD in Figure 5 is a decomposition to the context diagram that describes the traceability management system in the rice agroindustry. Level 1 DFD describes the four processes found in traceability information systems: The process of registration, management, transaction, and product tracking. All actors must first go through the login process to carry out management and transaction processes, except for product tracking, which is carried out by general users (consumers). Furthermore, management processes and transactions can only be carried out by actors that are registered in the system.

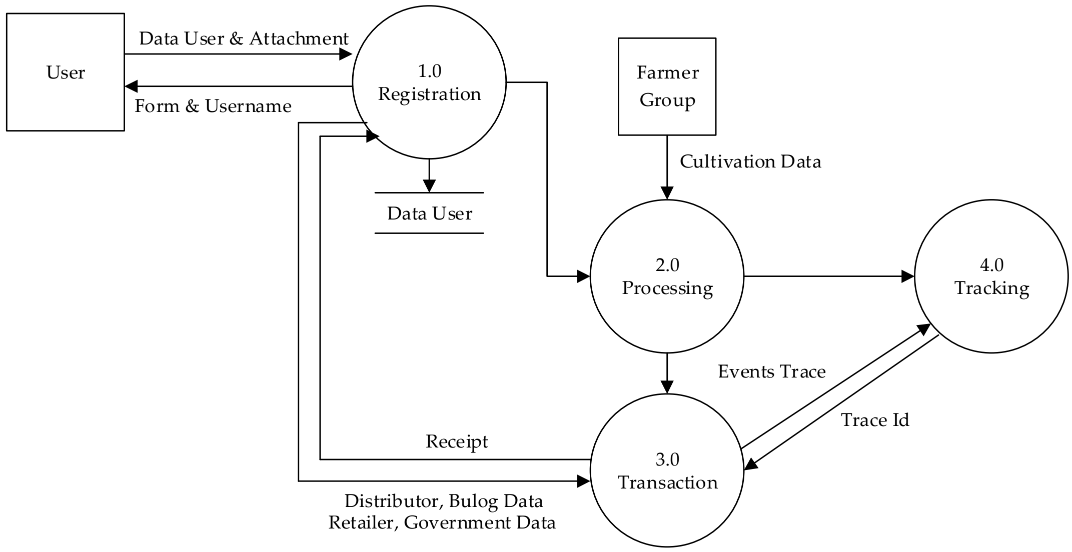

Figure 5. DFD level 1.

DFD level 2 consists of four diagrams where each process is explained in a more detailed DFD. Diagram 1 level 2 in Figure 6 describes the flow of the traceability system user registration. The registration process has four stages: Choosing a user type, registration form, verification, and approval. First, new users must choose the type of user according to the role of each actor in the supply chain. Second, users must then fill out the registration form on the system. Third, the system admin (government) will carry out the data verification process, and if approved, the user can log in to the system. Diagram 2 level 2 in Figure 7 describes the documentation of processing activities in the rice agroindustry. The data recorded during the processing process is the receipt of raw materials, entry orders, processing, product sales, and master data (basic data that provides additional information for subsequent data management). In the rice agroindustry, there is also a traceability function that traces information on raw materials received by the industry. Also, in the rice agroindustry, the system helps in decision-making for supplier selection using fuzzy TOPSIS and customer segmentation with parameters R, F, M. Furthermore, Diagram 3 level 2 in Figure 8 shows the transaction process contained in the traceability system. Three actors can carry out these process, namely, bulog, distributor, and government. This transaction process is called the order system, where the system connects information exchanged between the involved supply chain actors. This transaction involves purchase order transactions conducted by bulog and distributor. Additionally, the government can conduct transactions to find out the rice production done by the rice milling agroindustry.

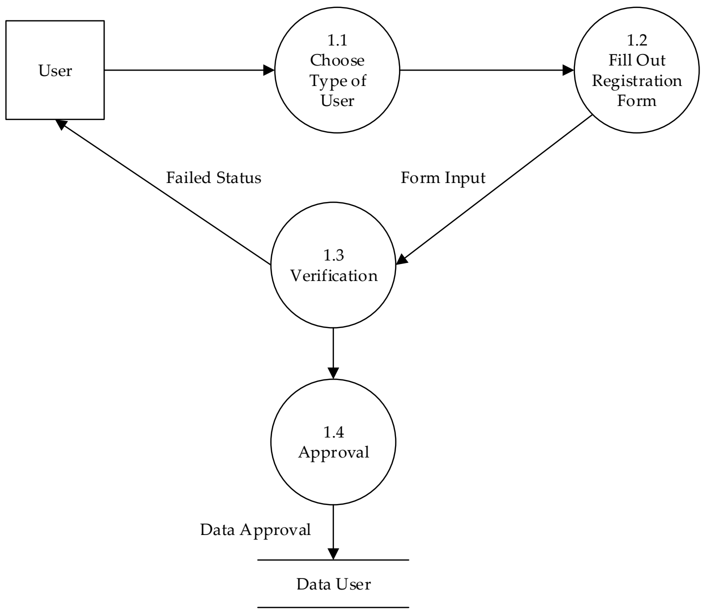

Figure 6. Diagram 1 level 2.

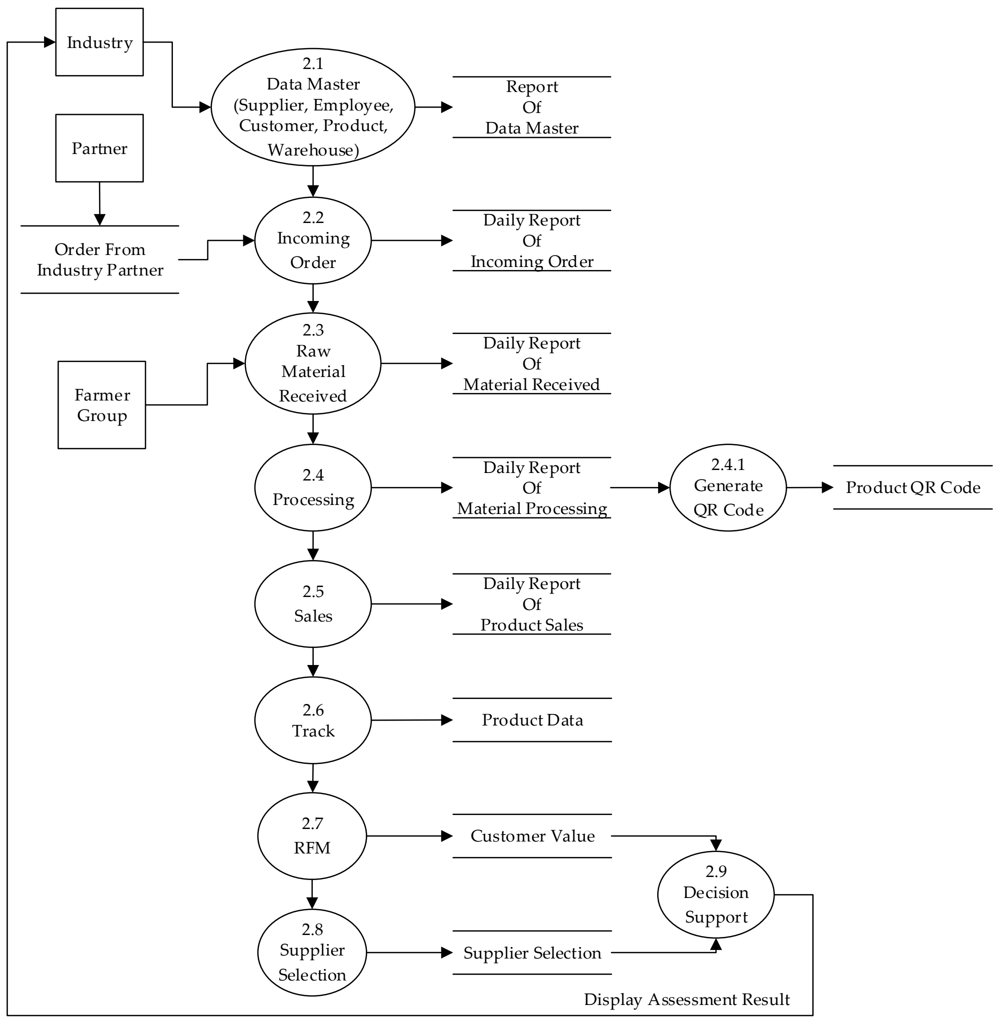

Figure 7. Diagram 2 level 2.

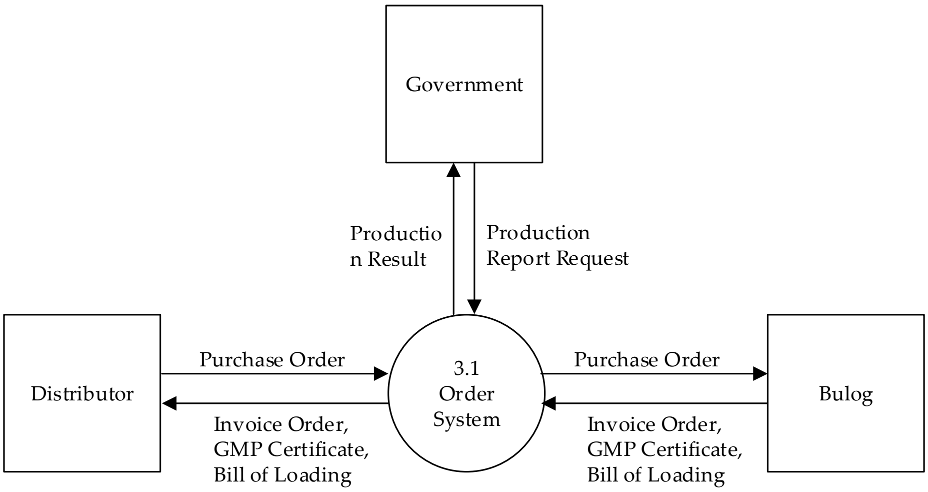

Figure 8. Diagram 3 level 2.

Diagram 4 level 2 in Figure 9 shows the search process carried out by general users (consumers) to find out product information. Product tracking is conducted by scanning the QR Code on the product packaging to get the processing code. Furthermore, the processing code is used as input to the search process so that information is obtained regarding the products purchased. The DFD for product tracking is presented in Figure 9.

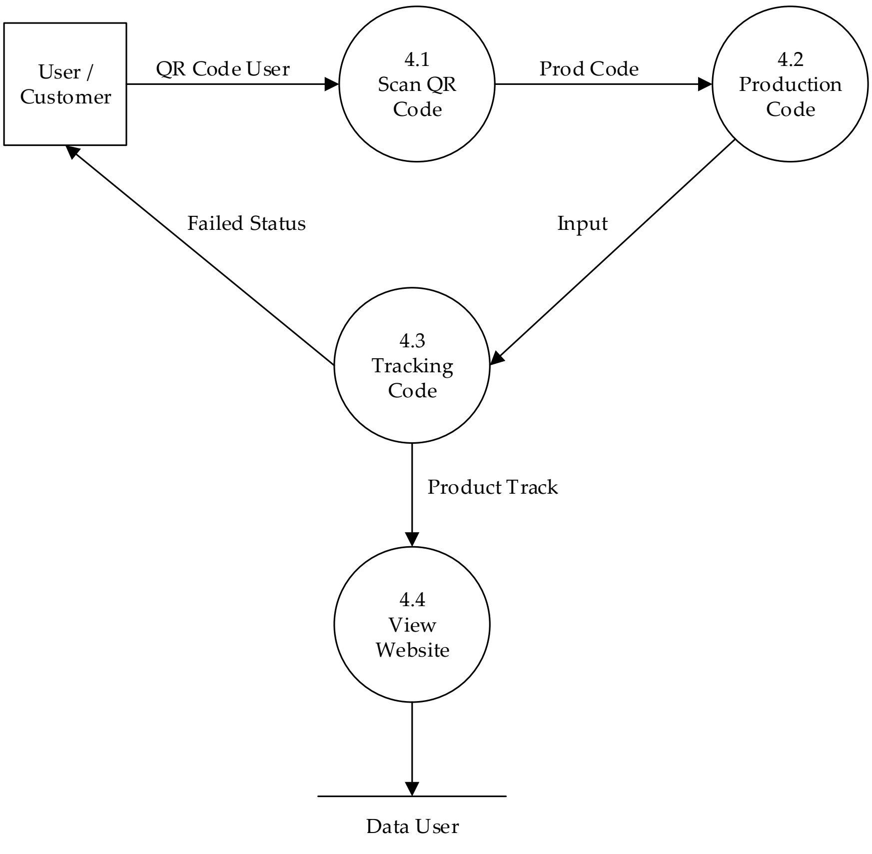

Figure 9. Diagram 4 level 2.

5.3. Analysis of Business Intelligent Systems

A traceability system is a tool used for the process of recording data during production. Data collected on the rice agroindustry is then stored in the data warehouse and can be further analyzed to make decisions. According to Isik et al. [31], business intelligence (BI) can be defined as a collection of business elements that use historical data from internal and external sources to be extracted into information that is more useful in the decision-making process. Implementation of business intelligence for the agroindustry can help companies to make the right decisions for suppliers, employees, consumers, logistics, and others [32]. In this study, we developed a traceability information system in the rice agroindustry supply chain combined with a business intelligence system for customer relationship management and supplier selection. The analysis of the business intelligence system developed is explained in the description below.

5.3.1. Customer Relationship Management

Customer Relationship Management (CRM) is a method utilized to determine consumer characteristics. This concept is used so that agroindustry companies can provide appropriate services by following consumer characteristics information. Customer Lifetime Value (CLV) is one of the tools in the CRM concept that can be used to identify customer characteristics [33]. To calculate the consumer life cycle value (CLV), the RFM model can be used, where (a) Recency (R) refers to the last purchase period, (b) Frequency (F) refers to the number of purchases made, and (c) Monetary (M) refers to the total value of the product in the form of money [34]. Using traceability information systems, an RFM-based CRM analysis can be developed for the rice agroindustry. The DFD for customer relationship management analysis of the rice agroindustry is presented in Figure 10.

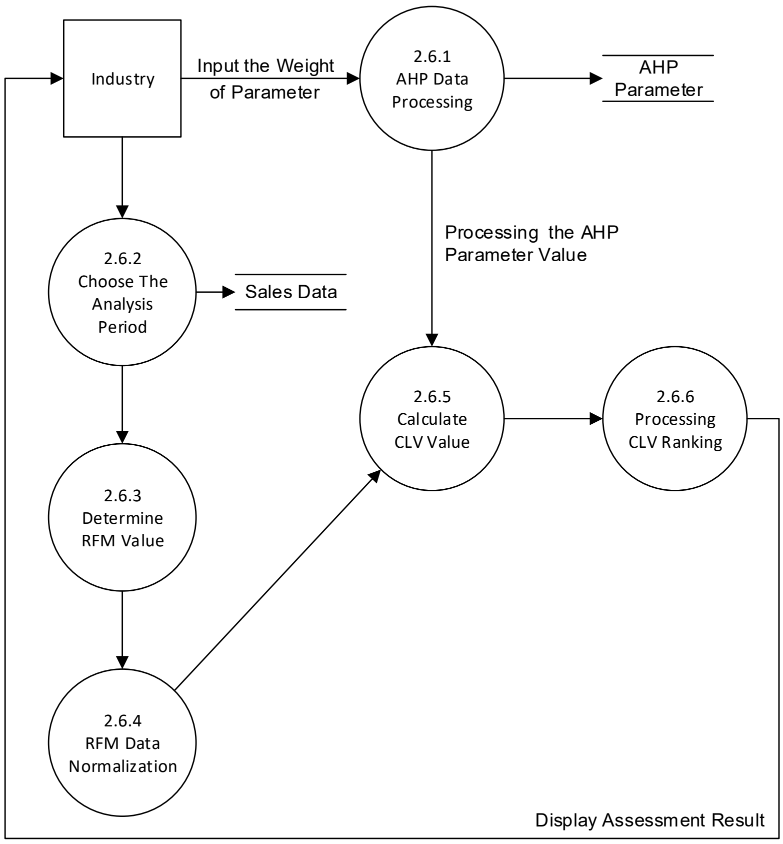

Figure 10. Diagram 2.7 level 3.

5.3.2. Supplier Selection

Continuity and raw materials resource are very crucial in agroindustries. Problems in supply such as uncertainty of shipment volume or inconsistency in raw material quality have driven agroindustries to become more resilient and meticulous in finding the right suppliers. It is imperative for rice agroindustry companies to be able to make the right decision. This study proposes the application of the fuzzy TOPSIS method for supplier decision making in the rice agroindustry to overcome this problem. According to Ozbek [35], this method can be used to solve problems with multiple criteria using basic principles by choosing alternatives that have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The design of a decision support system for supplier selection in rice agroindustries is presented in Figure 11.

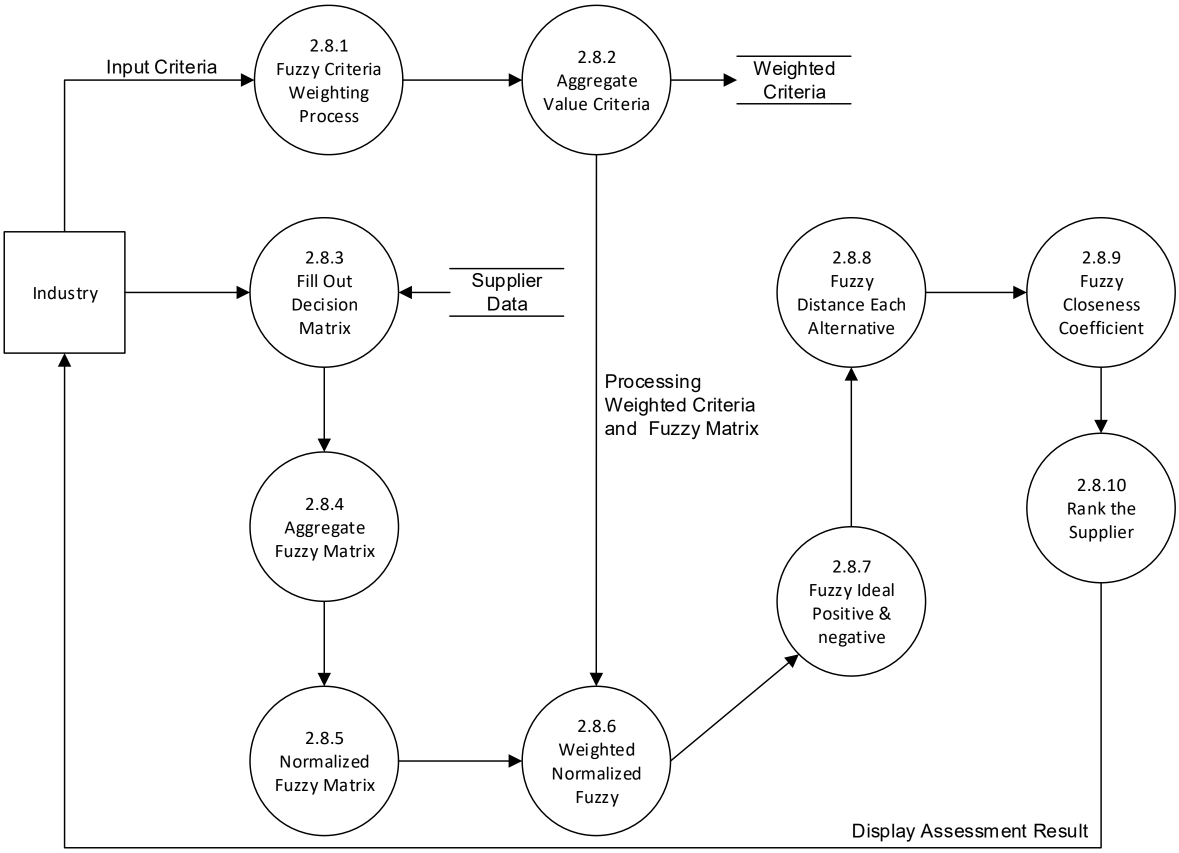

Figure 11. Diagram 2.8 level 3.

6. System Implementation

The rice traceability system prototype was built based on system architecture, data flow diagrams (DFD) and database designs that have been made before. The database of the traceability system was designed using MySQL for the backend, and user interface (UI) systems used a Hypertext Preprocessor (PHP), Hypertext Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript. A traceability system was built on a website platform that allows near real-time data acquisition processes that can integrate and communicate with all actors. This system is controlled by the government as the administrator and is managed by each actor according to their role in the supply chain. The actor must first register in order to carry out the management process on the system so that it is registered in the system. After the registration process is successful, the actor can log in to enter the system.

The actor who successfully enters the system can then carry out the management process by recording or documenting all production activities carried out. This documentation system will be integrated with others so that it describes each stage of production correctly. The complexity of the traceability system built is found in the rice agroindustry because the information captured by the rice agroindustry is more than the other actors. The process of recording data on the rice agroindustry includes incoming orders, raw material purchases, processing, sales, and master data (suppliers, warehouses, officers, products, customers). Besides, in the rice agroindustry, a business intelligence system was added to determine the characteristics of customers using the RFM model and supplier selection with fuzzy TOPSIS. During rice processing, data recording is carried out when the raw material starts to be milled, after which there is product testing for the final product until product packaging and storage phases are reached.

General users (consumers) can track the products they buy by accessing the website and selecting the tracking section. Product tracking can be done by entering the production code in the search section. The results of this tracking will display the entire history of the product produced. A web-based traceability information system developed will allow consumers to access applications anytime and anywhere. The final product tracking involves all activities and processes carried out from upstream to downstream. Complete information about the implementation of the traceability system in the rice agroindustry supply chain is shown in the Appendix A.

7. Managerial Implication

The result of literature study and field observations conducted in this research have shown that the supply chain in the rice agroindustry in Indonesia still faces some obstacles, such as quality manipulations carried out by irresponsible actors and the yet-to-be optimal logistical control management to ensure the quality and safety of food production. Furthermore, the traceability system used in the supply chain is still conducted manually, where it has several disadvantages such as (1) human intervention that results in potential errors and manipulation of massive data, (2) it cannot provide the information related to supply chain activities among actors, (3) the upstream to downstream process is not transparent, and (4) it does not have the ability to integrate all the actors into the supply chain. This research has analyzed and developed a smart IT-based traceability system to resolve the problems found in the rice agroindustry supply chain.

The development of a traceability system prototype in this research will have a positive impact on science and all the actors in the rice agroindustry supply chain in Indonesia. For science, this research can act as a foundation in the further development of traceability systems where the database is further processed by data mining or statistical methods as the decision-making process. For supply chain actors, this system creates safety and fair business processes because the implementation of a traceability system can be integrated and all actors can obtain the handling process information transparently. On the other hand, the traceability system will also increase added value for all supply chain actors because it can produce better quality and safer products as an effect of monitored activity from upstream to downstream. Furthermore, the development of traceability systems can also be a risk mitigation tool for all the actors since it can identify the nonconformities of the handling process. For the government, this research is useful for monitoring the food production process and providing protection to the public from dangerous products.

8. Conclusions

The prototype of the traceability system in the rice supply chain has been successfully developed based on five actors who play roles in the supply chain, e.g., the farmer group, the rice milling industry, the national logistics agency, distributors, and retailers. The system developed is based on a website that can provide information from upstream to downstream to facilitate supply chain transparency. The traceability system also helps to ensure that production activities comply with operational standards. Besides, this system facilitates the agroindustry in the decision-making process for customer relationship management and supplier selection. Through this research, we have designed a smart IT-based traceability system in rice agroindustry using data flow diagrams (DFD) based on the proposed system architecture. Future work can discuss data modeling on the traceability system that has been developed and its implementation in the MVC (Model View Controller) model.

Author Contributions: The research idea was conceived by K.B.S. P.B.P. conducted the investigation, conceptualization, formal analysis and software. P.B.P. also wrote the original manuscript. Further revisions and reviews were carried out by K.B.S., S. (Sutrisno) and S. (Sugiyanta).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Figure A1. User login.

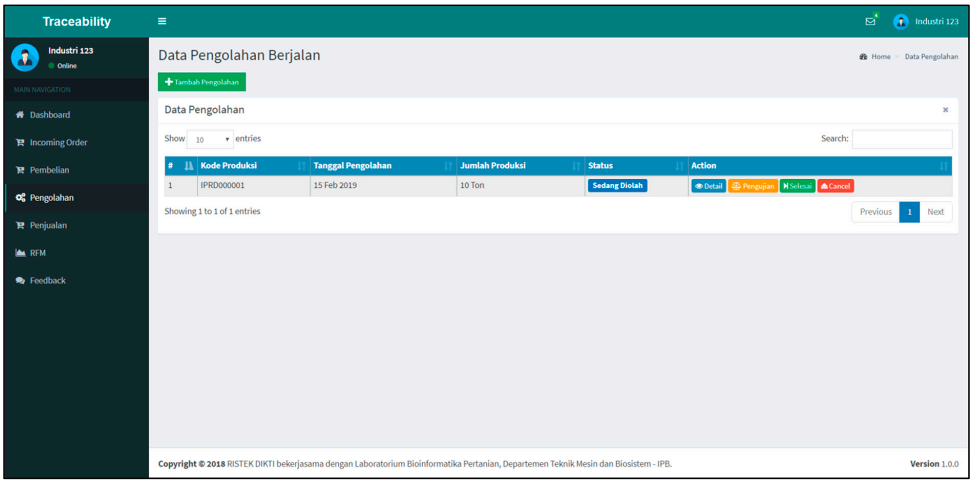

Figure A2. Documentation interface on rice processing.

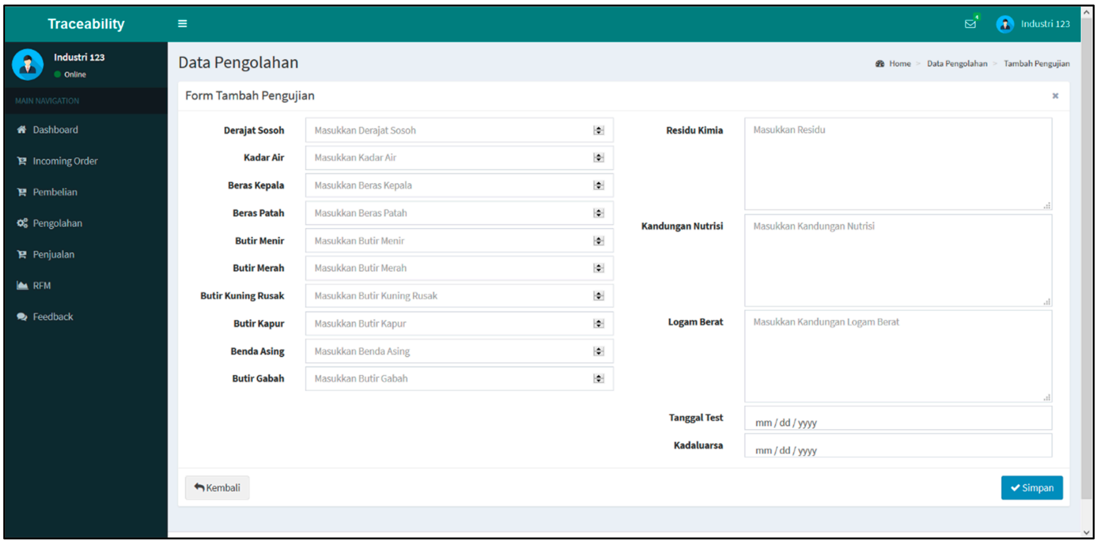

Figure A3. Interface on the product testing form.

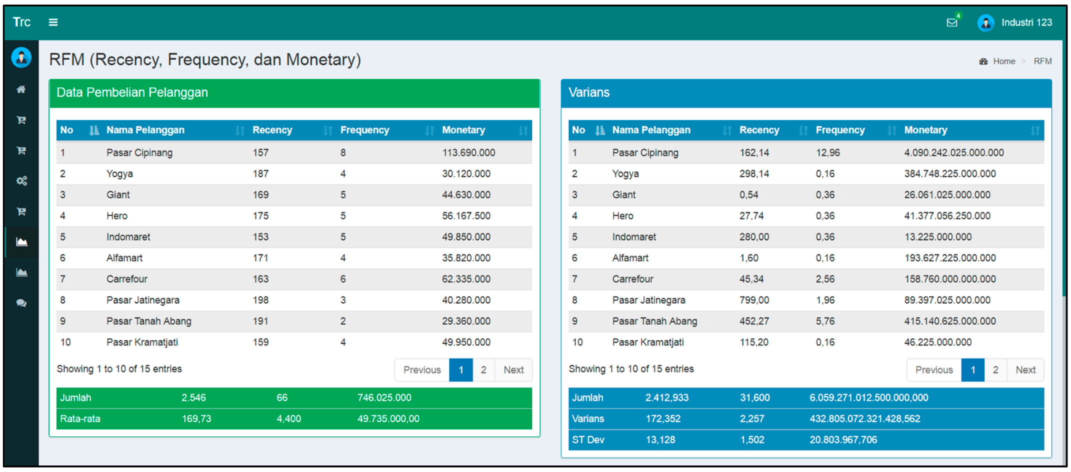

Figure A4. Interface for customer relationship management using the RFM model.

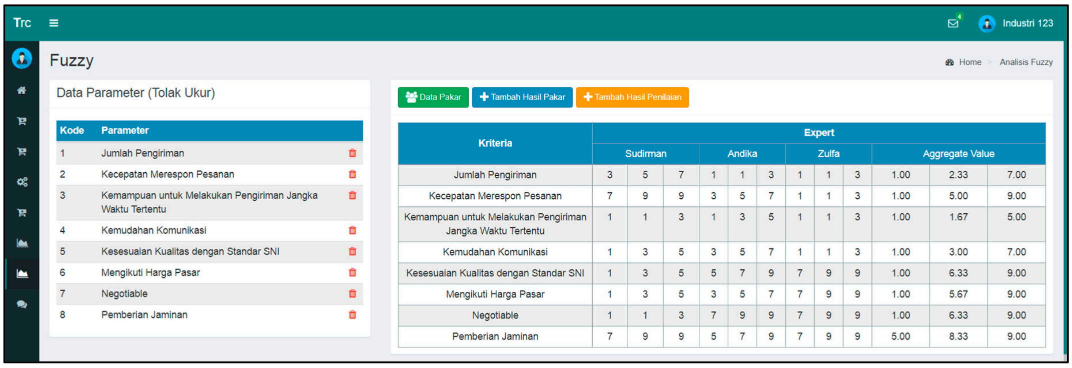

Figure A5. The page for supplier selection uses fuzzy TOPSIS.

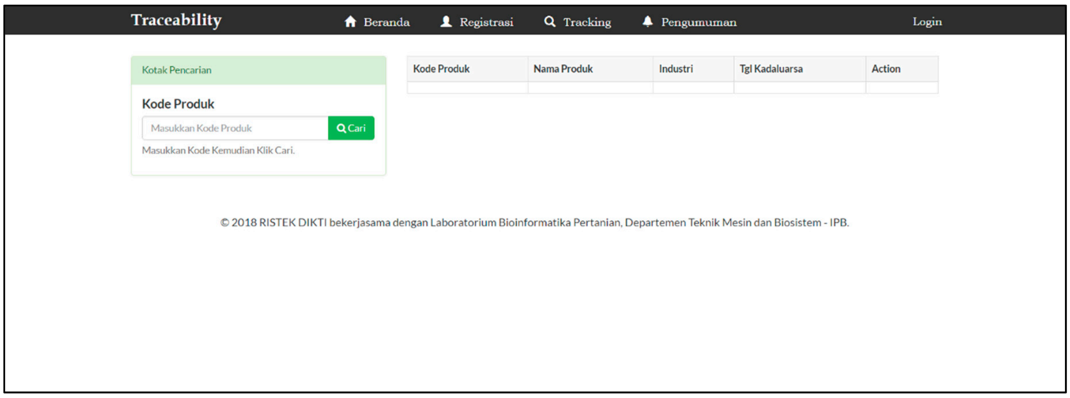

Figure A6. Tracking process for consumers.

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