

Design of An Aquaculture Traceability System For Meeting Large-Scale Freshwater Fish Demand

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ABSTRACT

Indonesia is a maritime country with a large potential in fisheries, however it has a big challenge to fulfill the market needs, especially for the commodities of freshwater fish like tilapia, catfish, and carp. Capital constraints, technology and small-to-medium scale producers mean that capacity aquaculture production cannot reliably fulfill the demands of industry. Additionally, the lack of supply chain integration, distribution inefficiencies, and low transaction transparency often lead to price fluctuations and potential fraud. To address these issues, this research designs and implements an integrated information system called Iwak Nusantara. The system is developed as a web-based platform to support large-scale order management, real-time production recording, and distribution coordination among aquaculture farmers. The traceability system for aquaculture is incorporated as well to enable traceability from upstream to downstream of products, thus contributing to transparency, accountability and security of transactions. By demonstrating a replicable model for integrating order aggregation, production recording, and traceability into a single platform, this study offers practical guidance for system developers, policymakers, and aquaculture extension practitioners seeking to strengthen the digital readiness of small-scale fisheries actors, while also contributing a concrete empirical reference point for future research on information system design in resource-constrained, multi-stakeholder food supply chains.

Keywords: Information System Development, Aquaculture Traceability, Fisheries Supply Chain, Order Management

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INTRODUCTION

Indonesia is the world's largest island country with more than 17,000 islands and has a coastline of more than 99,000 km. Covering more than 70 per cent of its land by water, Indonesia is considered a maritime state in its geographical and historical aspects. Encircled by vast oceans, the fisheries industry is a vital pillar of the country's economy. Indonesia's Ministry of Maritime Affairs and Fisheries has the statistics that hundreds of millions of Indonesians rely on fisheries for their livelihoods, either as fishermen, aquaculture workers, fish farmers, seafood processors, or in the trading and exporting of marine commodities. As the economic center with the highest population density in Indonesia, Java has a great influence on the national aquaculture output. Fish production consumption from the fish farming subsector experienced a considerable increase in 2020 as reported in data from Central Statistics Agency of Indonesia (BPS) that is an evidence of high domestic demand and export prospect *Oreochromis niloticus* Tilapia was the first with the total production of 1,172,633 tons and catfish (*Clarias* spp.) was the second position held with the production of 993,768 tons. Carp (*Cyprinus carpio*) accounted for 560,689 tons and patin (*Pangasius* spp.) 327,146 tons. East Java Province was the largest producer of tilapia, at 532,007 tons), while Jakarta Province was the largest producer of catfish (at 247,200 tons) (Badan Pusat Statistik, 2020). While still facing a

range of dramatic structural obstacles, the fisheries sector in Indonesia has vast resource potential, both ecologically and demographically. Among the key problems identified is the small production capacity of freshwater fish farmers like tilapia, catfish and carp to satisfy the demand from the market at the industrial scale. This is due to the fact that the majority of aquaculture companies in Indonesia are still small and medium-sized, due to limited capital, technology, and access to markets. This scattered system of production led to small volume of output so that the existing production/supply could not regularly fulfill the big market demand (Salsabilla et al., 2025).



Fig. 1. Fresh Fish Distribution Patterns

Furthermore, the lack of integration between farmers, distributors, and downstream sectors such as processing and exports leads to disconnected supply chains. This results in logistical inefficiencies and price fluctuations and the uncertainty in fulfilling trade contracts. And social problems, like fraud in fish trade transaction, (due to lack of transparency and accountability between sellers and buyers, refer figure 1 (Susilawati & Zain, 2023) are boiling this situation up more. To overcome this obstacle we have developed and realized a holistic integrated information system, which we call Iwak Nusantara. The system is designed to improve efficiency, transparency and accountability in aquaculture production and distribution of fresh water fishery products. This platform will allow to track, manage and monitor orders of big size in real-time and also will connect with different actor within aquaculture ecosystem such as fish farmers, distributor and supplier. Through the development of the integrated information system Iwak Nusantara, our study seeks to provide a technological foundation for the implementation of an aquaculture traceability system in Indonesia (El Sheikha & Xu, 2017).

Despite the growing body of research on digital solutions for fisheries and aquaculture, a closer review of prior work reveals several recurring limitations that the present study seeks to address. Blockchain-centred traceability frameworks, such as the conceptual model proposed for fish supply chains by Ismail et al. (2023) and the blockchain-enabled seafood traceability system evaluated by Shamsuzzoha et al. (2024), demonstrate strong capability for end-to-end product verification but are typically designed around export-grade or single-commodity supply chains and rarely incorporate large-volume order aggregation across many dispersed small-scale producers. Similarly, the seafood traceability assessment conducted by Al Mandhari et al. (2025) emphasizes compliance and food-safety auditing but stops short of addressing how fragmented production from small farmers can be consolidated to meet industrial-scale buyer demand. On the marketplace side, the Indonesian case study by Kruk, Bush and Phillips (2024) shows that digital aquaculture platforms tend to remain fragmented around private, farm-level production data, with limited integration of downstream order management, distribution coordination, and transaction transparency in a single system. This fragmentation mirrors findings from the broader digital-agriculture literature: Abate et al. (2023) report that, although many market-oriented digital tools have been piloted for smallholder producers, very few have been designed and empirically tested to operate reliably at the large-order, multi-actor scale required by industrial buyers, while Salsabilla et al. (2025) confirm that dispersed small-scale producers consistently struggle to satisfy aggregate market demand without a coordinating mechanism. Finally, from a systems-engineering perspective, Di Francesco et al. (2019) and Rodrigues, Silva and Avritzer (2025) document that microservices-based architectures are increasingly adopted to support scalability in large information systems, yet such architectural approaches have seldom been applied or evaluated within the specific operational context of freshwater aquaculture supply chains. Taken together, these studies point to a clear research gap: no existing system simultaneously combines (1) consolidation of fragmented small-scale freshwater fish production to fulfil large, industrial-scale orders, (2) end-to-end traceability from upstream production to downstream distribution, and (3) a scalable microservices-based

architecture suited to the resource constraints of Indonesian aquaculture stakeholders. The present study addresses this gap directly by designing and implementing Iwak Nusantara as an integrated system that unifies large-scale order management, real-time production recording, distribution coordination, and traceability within a single, scalable platform.

Closing this gap is important for at least three reasons. First, without a mechanism to consolidate fragmented small-scale production, freshwater fish farmers remain structurally unable to compete for large industrial contracts, limiting their income and bargaining position despite Indonesia's substantial aquaculture resource base. Second, the absence of integrated traceability leaves the supply chain vulnerable to the transparency and trust failures documented in the global seafood-fraud and mislabeling literature, which directly undermines consumer confidence and the credibility of domestic fishery products in both local and export markets. Third, from a system-design standpoint, demonstrating that a microservices-based, web-accessible architecture can be feasibly deployed for small-to-medium aquaculture actors provides practical evidence for extending similar digital infrastructure to other fragmented agri-food sectors in developing economies.

Building on this rationale, this study aims to design, develop, and evaluate Iwak Nusantara, an integrated web-based information system intended to (1) consolidate fragmented small-scale freshwater fish production to meet large, industrial-scale market demand; (2) provide real-time production recording and distribution coordination among fish farmers, distributors, and buyers; and (3) embed an upstream-to-downstream traceability mechanism that enhances transparency, accountability, and transaction security. The novelty of this study lies in its combination of large-scale order aggregation, production traceability, and a microservices-based three-tier architecture within a single operational system tailored to the institutional and resource constraints of Indonesian freshwater aquaculture, an integration that, to the authors' knowledge, has not been jointly addressed and empirically validated in prior fisheries information-system research. The resulting contribution is twofold: practically, it provides fish farmers, distributors, and buyers with a concrete tool for coordinating large transactions transparently; and academically, it extends the literature on digital traceability and microservices-based system design by offering an empirically tested case from a developing-country, small-scale aquaculture context.

Literature Review

1. Aquaculture Traceability System A management information system that functions to record, track, and verify the journey of an aquaculture product from production, harvest, processing, to distribution, with the aim of ensuring food safety, supply chain transparency, sustainability, and consumer trust (Al Mandhari et al., 2025).
2. Fish for Consumption Food fish are fish that are farmed or caught for human consumption (Luciana et al., 2017)
3. Marketplace A marketplace is a digital place that brings together sellers and buyers under certain rules, functioning as an intermediary for transactions (Franck & Peitz, 2021).
4. Micro Services Microservices is a design in software engineering style that involves separating applications into smaller individual services (Di Francesco et al., 2019).
5. REST-ful Web API RESTful is a web service development technology that utilizes various protocols, especially HTTP, to build Web APIs (Bojinov, 2016).
6. Node.js Node.js is a runtime environment for executing JavaScript on the server side with an event-driven and non-blocking I/O model, suitable for real-time applications such as chatting and streaming (Kamal & Gunaryati, 2023).
7. NoSQL NoSQL is designed to manage large and unstructured data, making it ideal for web applications with real-time rendering and fast analytical needs (Fadli et al., 2020).
8. Unified Modelling Language (UML) UML is a visual language for modeling object-oriented systems, combining graphical notation and semi-formal language for requirements specification (Muhamad et al., 2019).
9. Docker Docker is an open-source platform for building, delivering, and running applications in containers, simplifying deployment and avoiding dependency conflicts (Fadlulloh & Bik, 2017).
10. Message Broker It is middleware software that manages the delivery of messages between system components efficiently and at scale (Dobbelaere & Esmaili, 2017).
11. Elasticsearch Elasticsearch is a distributed search engine based on Lucene, storing documents and enabling fast searches at large scale (Gheorghe et al., 2016).
12. Golden Rules of User Interface Design The

eight golden rules of interface design include consistency, universal usability, informative feedback, closure, error prevention, reversal of actions, user control, and reduction of memory load (Shneiderman et al., 2018). 13. Responsive Web Design Responsive web design enables websites to adjust their appearance according to screen size, orientation, and user devices (Parlakkiliç, 2021). 14. Software Development Life Cycle SDLC is a systematic method for designing, developing, testing, and maintaining information systems (Muay et al., 2024). 15. Payment Gateway A payment gateway is a secure technology service provided by e-commerce applications or financial institutions that facilitates authorization, encryption, and transmission of payment data between customers, merchants, and acquiring banks (Koerniawan & Salini, 2024).

METHOD

The study aims to develop an aquaculture information management system, which we named Iwak Nusantara. This system is designed to meet the needs of recording, monitoring, and managing freshwater fish production, distribution, and transaction data in an integrated manner, with the goal of efficiency and transparency in the fisheries supply chain. As illustrated in Figure 2, the methodological approach used in the system design is the Software Development Life Cycle (SDLC) using the waterfall model.

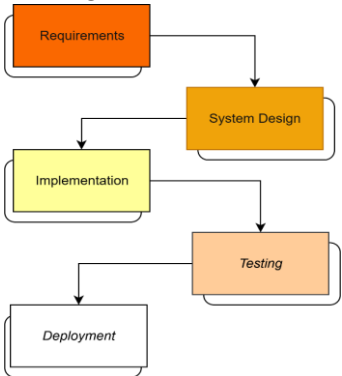


Fig. 2. Software Development Life Cycle

1. Requirements

The initial stage involves analyzing the system's functional and non-functional requirements. The system's functional and non-functional requirements are identified and documented based on the needs of the freshwater fish industry stakeholders. The first group consists of fish sellers, represented by fish farmers or fishermen. The second group consists of buyers, consisting of consumers, fish distributors, retailers, and businesses requiring freshwater fish. System requirements were gathered through direct interviews and field observations at fish farming facilities. The results of the requirements analysis were then systematically documented in the form of a Software Requirements Specification (SRS).

2. System Design

The design phase includes a design of the system architecture, database, and user interface, based on the requirements identified in the previous phase. This design follows the principles of microservices development guided by Domain-Driven Design (DDD) [24]. The system is designed using a 3-tier architecture, consisting of:

- Presentation Layer: A responsive web-based interface that follows the Eight Golden Rules theory.
- Logic Layer: Backend microservices with clearly separated domains, structured according to the bounded context of each business function.
- Data Access Layer: A database management system that supports data storage and retrieval tailored to the needs of each microservice.

Figure 3 below illustrates the 3-tier architecture.



Fig. 3. 3-tier Architecture

The database design uses an Entity Relationship Diagram (ERD) that depicts the main entities in the Iwak Nusantara system domain. The user interface design is based on the Eight Golden Rules principle with user needs at the center of every design decision-making step. To promote cross-platform availability, the system is developed with a responsive design.

3. Implementation

The system implementation utilizes modern technologies that support microservices architecture and web application development. The technologies used to build the Iwak Nusantara system are as follows: • Frontend: React.js • Backend: Node.js • Database: MySQL, MongoDB, Redis, PostgreSQL

4. Testing

The test was performed to verify that the system works as specified and there is no error (bug) in the system. The initial stage involved performing Unit Testing, which covered the verification of each functional component within the Iwak Nusantara system (Hermansah et al., 2025).

5. Deployment

The minimum specifications required to implement the Iwak Nusantara system are presented in the table 1 below.

Table 1. System specifications

Component	Minimum Specifications
Processor	Intel Xeon E5-2620 v4 (8 cores, 2.1Ghz)
Memory (RAM)	8 GB DDR4
Storage	500 GB SSD
Network	1 Gbps Ethernet
Operating System	Ubuntu Server 20.04 LTS
Database Server	MySQL 8.0, MongoDB 5.0, PostgreSQL 16.0 , Redis 7.2
Container Runtime	Docker 20.10+
Load Balancer	Nginx 1.8+
SSL Certificate	Encrypt SSL
Backup Storage	1 TB External Storage
Monitoring Tools	Basic System Monitoring

RESULT AND DISCUSSION

The result of this research is a system architecture design capable of functioning as a freshwater fish market platform to meet large-scale market demand. A schematic representation of this design is illustrated in Figure 4 below.

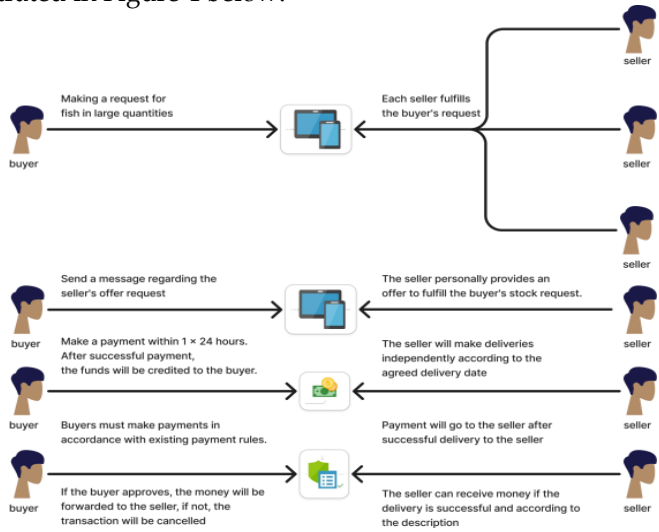


Fig. 3. Rich Picture

The first process begins with a request, where a buyer submits a request for a large quantity of fish through the system. The system then distributes this request to several sellers,

who respond based on available stock. In the bidding stage, sellers submit bids, including details such as stock availability and price, to meet the buyer's request. Sellers with sufficient capacity then proceed to prepare shipments according to the agreed-upon schedule. Next is the payment stage, where the buyer reviews and accepts an offer if it meets their needs. Once accepted, the buyer completes the payment through the system within 24 hours. After payment, the delivery process takes place, during which the seller delivers the fish based on the agreed schedule and terms. If any issues occur during delivery, the seller can submit a request through the system for resolution. Following delivery, the transaction validation stage is carried out. The purchaser checks to see if the delivered products are the same as that ordered. If the delivery satisfies the buyer's expectations, the payment is released to the seller as a final settlement. But in case the products do not satisfy the need or issues occur, the buyer can deny the deal and the payment will be returned. At last, in the stage of transaction ending, the seller gets the final payment, the buyer makes sure that the transaction is successfully ended and the received goods has been agreed upon. The design of this system employs the Software Development Life Cycle (SDLC) approach, as discussed in the research methodology section.

1. Unified Modeling Language

a. Use Case Diagram

The Use Case Diagram of the Iwak Nusantara information system illustrates the interactions between the two main actors, namely the seller and the buyer, with the system, as shown in Figure 5 below

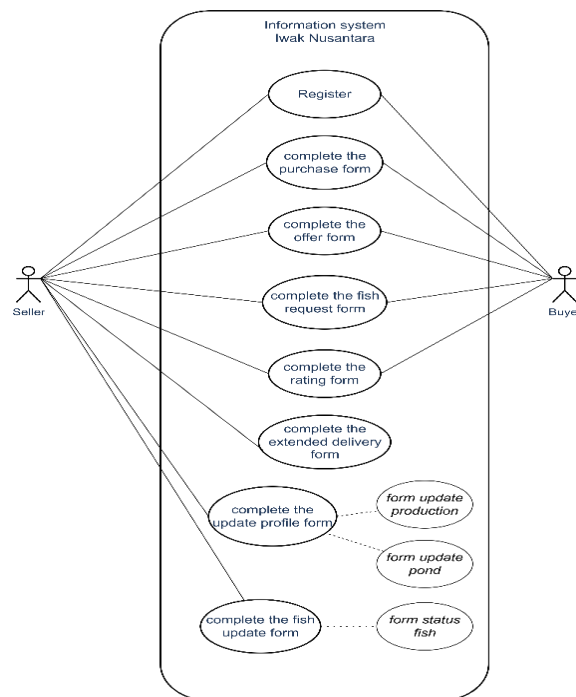


Fig. 5. Use Case Diagram

b. Entity-Relationship Diagram

Figure 6 below illustrates the data structure and the relationships between entities within the system

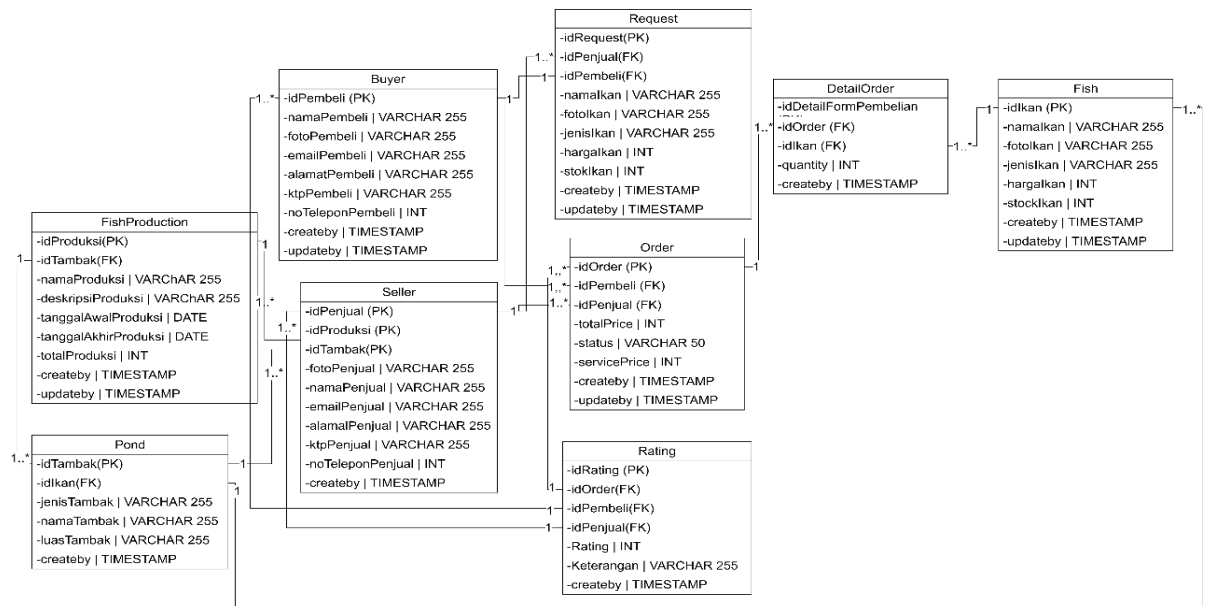


Fig. 6. ERD

2. Implementation

Figure 7 below illustrates the user interfaces of the system.

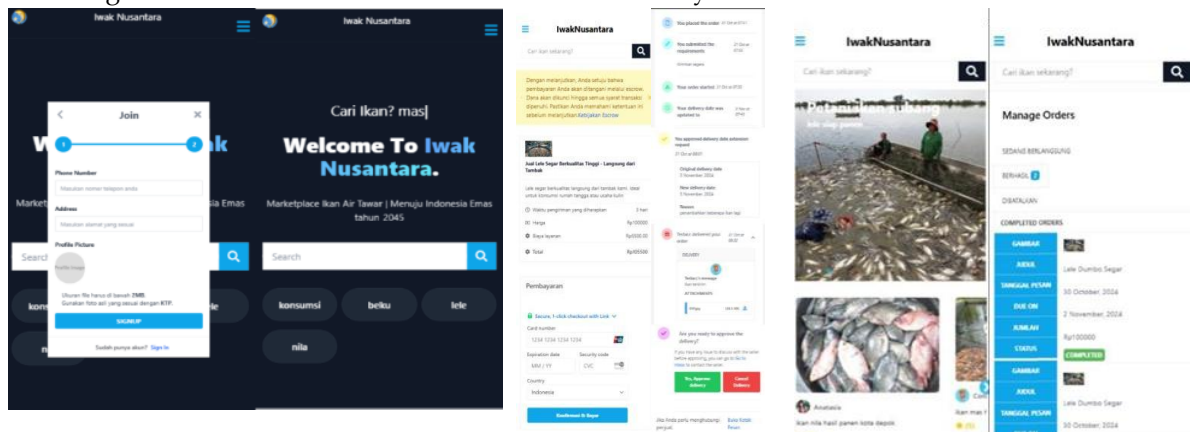


Fig. 4. User Interfaces

3. User Accepting Testing

This testing was conducted through interviews with 10 fish farmers in the Jabodetabek area, incorporating the 8 Golden Rules of User Interface Design to ensure that the system application is acceptable to the fish farmers. Table 2 below presents the list of interview questions.

Table. 2. Interview Question

No	Aspect	Question
1	Consistency	What is your first impression regarding the consistency of the application's appearance & process flow?

2	Universal Usability	Is the interface easy to use, even for tech-savvy users?
3	Informative Feedback	Does the app provide sufficient feedback/notification when actions are performed?
4	Closure in Dialogs	Does the application indicate that the process is complete?
5	Error Prevention	Does the app prevent misuse?
6	Reversibility of action	Is it possible to cancel or correct incorrect input?
7	User control	Do users feel they have full control over their data and settings?
8	Reduction short-term memory load	Does the app help reduce memory load by displaying important info?

The score assessment for the interview respondents answers is presented in Table 3 below.

Table. 3. Assessment Weight

Weight	Information
1	Strongly Disagree
2	Don't agree
3	Neutral
4	Agree
5	Strongly agree

The following is the formula used to evaluate the score summary table from the User Acceptance Testing.

Equation 1. Acceptance percentage

$$\text{overall percentage} = \frac{\text{Total Score}}{\text{Total Achieved}} \times 100 \quad (1)$$

Equation 2. Total score percentage

$$\text{total score percentage} = \frac{\text{Average}}{\text{Number of respondents}} \times 100 \quad (2)$$

Based on the above formula, the results are presented in Table 4 below.

Table. 4. User Testing Results

User acceptance testing aspects	Respondents 1-10 (Score 1-5)	Total score	Average	Presentation
Consistency	5,5,4,5,5,4,5,5,5,4	48	4.8	96%
Universality	5,4,4,5,5,5,4,5,5,5	47	4.7	94%

al	4			
Usabilit				
y				
Informa	4,4,5,4,4,5,4,4,5,	43	4.3	86%
tive	4			
Feedba				
ck				
Closure	5,5,4,5,5,5,4,5,5,	48	4.8	96%
in	5			
Dialogs				
Error	4,4,4,5,4,5,4,4,4,	43	4.3	86%
Prevent	5			
ion				
Reversi	5,5,5,5,4,5,5,5,5,	48	4.8	96%
bility of	4			
Action				
User	4,4,4,5,4,5,4,4,5,	43	4.3	86%
Control	4			
Review	5,5,4,5,5,5,5,5,5,	49	4.9	98%
service	5			

The overall percentage reached 92%, indicating that the majority of respondents found the Iwak Nusantara application to be easy to understand, consistent, and supportive of operations.

DISCUSSION

The findings of this study confirm that Iwak Nusantara successfully enables fragmented small-scale freshwater fish producers to jointly fulfil large, industrial-scale orders while embedding traceability from upstream production to downstream distribution. The User Acceptance Testing results, with an overall acceptance rate of 92% across the eight usability dimensions, indicate that fish farmers in the Jabodetabek area found the system consistent, informative, and easy to control. The principal novelty of this research lies in the integration of three functions that prior systems have generally treated separately: large-scale order aggregation among dispersed small-scale producers, real-time production and distribution recording, and end-to-end traceability, all delivered through a single, scalable microservices-based platform. By demonstrating that this combination can be implemented and positively received by small-scale aquaculture actors, the study offers a concrete reference point for both researchers and practitioners working on digital transformation in fragmented, developing-country food supply chains.

These findings are broadly consistent with, yet also extend, results reported in similar prior studies. The 92% overall acceptance score obtained in this study is comparable to the 84.6% “Strongly Agree” rating reported for the BBHealthy MSME e-commerce platform evaluated through User Acceptance Testing in Indonesia, suggesting that waterfall-developed, React-based web platforms tend to be well received by Indonesian micro and small business users when interfaces follow established usability heuristics. The result also aligns with Kruk, Bush and Phillips (2024), who found that Indonesian small-scale aquaculture farmers are receptive to digital platforms that connect production data with market actors, although their case study centred on private farm-level data rather than large-order consolidation. Likewise, Shamsuzzoha et al. (2024) and Ismail et al. (2023) similarly report that blockchain- and IoT-enabled traceability frameworks for seafood supply chains are perceived by stakeholders as improving transparency and trust, reinforcing the relevance of traceability as a core design feature. In the digital-agriculture literature more broadly, Abate et al. (2023) note that successful market-oriented digital tools in Africa tend to score well on usability and adoption intent during pilot phases, mirroring the consistency and informative-feedback scores obtained here, while Di Francesco et al. (2019) and Rodrigues, Silva and Avritzer (2025) confirm that microservices architectures, when properly bounded by domain context as applied in this

study's 3-tier design, support the responsiveness that end users associate with positive usability outcomes.

Where the present results converge with these prior studies, most notably in overall acceptance scores and the perceived value of traceability, the similarity can plausibly be attributed to a shared design philosophy: all of the comparable systems were built using user-centred, iterative development methods (waterfall or agile) and tested directly with the intended end users rather than with proxy respondents. Where differences emerge, for instance the relatively lower scores recorded in this study for Informative Feedback, Error Prevention, and User Control (each at 86%) compared with Consistency and Reversibility of Action (each at 96%), these are more likely attributable to methodological and contextual factors than to fundamental weaknesses in the system. Unlike the BBHealthy and MyASN evaluations, which assessed platforms already embedded in established digital ecosystems, Iwak Nusantara was tested with first-time users whose digital literacy and prior exposure to e-commerce-style ordering systems vary considerably, a contextual factor consistent with the digital-divide challenges documented by Abate et al. (2023) for African agricultural digital tools and by Kruk, Bush and Phillips (2024) for Indonesian aquaculture platforms more broadly. Differences in sample size and respondent population, only ten fish farmers were interviewed in this study compared with larger samples in some comparator studies, may also account for the narrower spread of scores observed here.

The contribution and novelty of this article to the field stem from its integrative system design rather than from any single technological component in isolation. While blockchain- and IoT-based traceability frameworks such as those of Ismail et al. (2023) and Shamsuzzoha et al. (2024) focus primarily on verifying product provenance, and digital marketplace studies such as Abate et al. (2023) focus primarily on market access, Iwak Nusantara demonstrates that order aggregation, production recording, distribution coordination, and traceability can be jointly operationalised within a single, microservices-based 3-tier architecture that is feasible to deploy for small-to-medium aquaculture actors in a developing-country setting. This integrative approach addresses the explicit research gap identified in the Introduction, namely the absence of a system that simultaneously consolidates fragmented small-scale production for large-order fulfilment and embeds upstream-to-downstream traceability. In doing so, the study extends the information-systems literature on traceability beyond compliance-oriented seafood safety applications (Al Mandhari et al., 2025) toward a transaction-and-trust-oriented model suited to domestic supply chains characterised by numerous small producers and large, infrequent buyers.

These findings carry several practical, academic, and policy implications. Practically, fisheries cooperatives, local governments, and aquaculture extension agencies can use the Iwak Nusantara design as a reference model for organising small-scale producers into larger, traceable supply groups capable of meeting industrial buyer requirements, particularly given its demonstrated usability among first-time farmer users. Academically, the study contributes empirical evidence to the still-limited body of research on microservices-based information systems applied specifically to small-scale fisheries supply chains in developing countries, complementing the largely conceptual or pilot-stage contributions of Abate et al. (2023) and the farm-level focus of Kruk, Bush and Phillips (2024). From a policy perspective, the results support continued investment in digital infrastructure and farmer digital-literacy programmes, since the lower scores observed for error prevention and user control suggest that technology alone is insufficient without accompanying training and support mechanisms. For future research, it is recommended that subsequent studies extend the User Acceptance Testing to a larger and more geographically diverse sample of farmers and buyers, incorporate longitudinal data on actual transaction volumes and farmer income changes after adoption, and explore the integration of IoT-based production monitoring and blockchain-based verification, as proposed by Ismail et al. (2023) and Shamsuzzoha et al. (2024), to further strengthen the traceability guarantees offered by the platform.

CONCLUSION

This research demonstrates that the Iwak Nusantara application allows fish farmers to work together to meet large orders, address the issue of limited production capacity, and the collaboration also extends to distribution and transaction recording. The system leverages supply chain transaction, delivery and payment information to enhance transparency and efficiency in real time, which brings more trust to all stakeholders

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