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Digitalization of Transportation 5.0 Through Robotic Fishery Frozen Supply for Enhancing Aquatic Food Distribution in Demak City

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Abstract

The transformation of fishery product distribution systems has become increasingly important in ensuring food security, supply chain efficiency, and economic resilience in coastal regions. As demand for high-quality aquatic food products continues to grow, conventional logistics systems often face challenges related to post-harvest losses, inefficient transportation, limited traceability, and inadequate cold chain management. This research investigates the application of Digitalization 5.0 in transportation logistics through an integrated Robotic Fishery Frozen Supply system to enhance the distribution of aquatic food products in Demak City, Indonesia. The proposed framework combines autonomous robotic loading and unloading technologies, Internet of Things (IoT)-based cold chain monitoring, real-time logistics management, and blockchain-enabled traceability to create a smart and sustainable fishery distribution ecosystem. The study employs a mixed-methods approach, integrating qualitative assessments through stakeholder interviews and focus group discussions with quantitative evaluations of logistics performance, distribution efficiency, cold chain stability, and operational cost-effectiveness. The findings demonstrate that the implementation of the Robotic Fishery Frozen Supply model significantly improves distribution performance by reducing post-harvest losses by 27%, shortening delivery times by 35%, and enhancing transparency and accountability throughout the supply chain. In addition, the system contributes to maintaining product quality, minimizing food waste, and improving market access for local fishery producers. The research further reveals that the Digitalization 5.0 framework supports sustainable development by integrating human-centered innovation, automation, and environmental responsibility. The proposed model aligns with the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger), Goal 9 (Industry, Innovation and Infrastructure), and Goal 12 (Responsible Consumption and Production). The novelty of this study lies in the convergence of autonomous robotic technologies, Digitalization 5.0 principles, and sustainable fishery logistics, offering a scalable and replicable model for coastal regions in developing countries seeking to modernize aquatic food distribution systems while strengthening economic sustainability and food security.

Keywords: *Digitalization 5.0, Robotic Fishery Frozen Supply, Food Distribution, Demak, Blockchain Traceability, Autonomous Transport.*

1. Introduction

The fisheries sector is a pivotal contributor to global food security and local economic stability, particularly in coastal regions such as Demak City, Indonesia. However, the inefficiencies in distribution systems, inadequate cold chain management, and fragmented supply chain monitoring have significantly hindered the optimal delivery of fresh and frozen fishery products to markets [1]. Post-harvest losses, primarily due to temperature fluctuations and transportation delays, not only compromise product quality but also lead to substantial economic losses for small-scale fishers [2].

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Digitalization 5.0, characterized by the human-centered integration of cyber-physical systems, artificial intelligence, and sustainable innovation, presents a transformative opportunity for fisheries logistics [3]. The integration of autonomous robotics into transportation, combined with IoT-enabled cold-chain monitoring and blockchain-based traceability, can establish a robust Robotic Fishery Frozen Supply framework that enhances efficiency, transparency, and product quality [4].

In the context of Demak City, a coastal area prone to tidal flooding and infrastructural challenges, the deployment of Robotic Fishery Frozen Supply could address existing logistical bottlenecks. The system's autonomous robotic units can be adapted for amphibious transport, ensuring consistent delivery even during seasonal flooding [5]. Moreover, IoT sensors enable real-time temperature monitoring, while blockchain technology provides immutable product traceability from the point of harvest to retail markets [6].

The purpose of this research is to design, implement, and evaluate the Robotic Fishery Frozen Supply model in the Demak fishery supply chain, focusing on reducing post-harvest losses, improving distribution speed, and enhancing supply chain transparency. This study fills a gap in the literature by proposing a Digitalization 5.0 framework specifically tailored for small- to medium-scale fishery logistics in a developing country setting [7].

Fig 1. Prototype of Robotic Fishery Frozen Supply

Table 1. Digitalization 5.0 Robotic Fishery Frozen Supply for Aquatic Food Distribution in Demak City

Component	Technology Used	Function in Supply Chain	Key Performance Indicators (KPIs)	Expected Impact
Autonomous Robotic Loading/Unloading System	AI-powered robotic arms and conveyors	Automates the loading and unloading of frozen fish products	Loading speed (kg/min), labor reduction (%)	Reduces human handling time by 40%, increases throughput
IoT-Based Cold Chain Monitoring	Wireless temperature and humidity sensors	Tracks product condition in real-time during transport	Temperature stability (°C variance), data transmission reliability (%)	Maintains product freshness, reduces spoilage by 25–30%
Blockchain Traceability System	Distributed ledger technology	Records and verifies product journey from harvest to market	Traceability accuracy (%), consumer trust index	Increases supply chain transparency and buyer confidence
Digital Route Optimization	AI-based GPS and predictive analytics	Determines the shortest and safest delivery routes	Delivery time reduction (%), fuel efficiency (%)	Reduces transportation cost and CO_2 emissions by 15–20%
Amphibious Autonomous Vehicles	Electric-powered amphibious cargo units	Enables distribution during tidal floods or road disruptions	Delivery continuity rate (%), downtime reduction (%)	Ensures year-round delivery reliability
Integrated Data Dashboard	Cloud-based logistics management platform	Centralizes monitoring and decision-making	Real-time decision accuracy (%), data integration success rate	Improves operational coordination across stakeholders
Renewable Energy Integration	Solar-powered refrigeration units	Provides sustainable energy for cold storage in transit	Energy cost reduction (%), carbon footprint reduction (%)	Lowers operational costs and supports green logistics
Predictive Maintenance System	AI-driven equipment health monitoring	Prevents breakdowns in robotic and refrigeration systems	Mean time between failures (hours), maintenance cost reduction (%)	Minimizes downtime and repair expenses
Automated Quality Inspection	Computer vision and machine learning	Detects damage or spoilage before delivery	Defect detection rate (%), false positive rate (%)	Enhances quality assurance for end consumers
Stakeholder Digital Engagement	Mobile applications for fishermen, distributors, and buyers	Facilitates transparent communication and transactions	User adoption rate (%), satisfaction score	Strengthens network trust and reduces transaction disputes

2. Literature Review

The fisheries sector is undergoing a paradigm shift driven by advances in digitalization and automation to address challenges related to post-harvest losses, inefficient distribution, and a lack of transparency in supply chains [8]. Previous research emphasizes that cold chain management is critical for maintaining fish quality during transportation, especially in regions with underdeveloped infrastructure. The integration of Digitalization 5.0 principles, which emphasize human-centredness, resilience, and sustainability, has been increasingly applied to agri-food and fisheries logistics. Studies have shown that adopting Industry 5.0 technologies can improve both operational efficiency and environmental performance in supply chains. Digital route optimization, powered by AI and real-time analytics, significantly reduces transportation time and energy consumption, while ensuring reliable delivery in challenging conditions. Blockchain technology is emerging as a transformative enabler for traceability in seafood supply chains. By providing immutable and verifiable records, blockchain ensures authenticity, reduces fraud, and fosters consumer trust. IoT-enabled cold chain monitoring systems allow for real-time temperature and humidity tracking, reducing spoilage rates and improving compliance with food safety standards [9]. The deployment of autonomous robotic systems in logistics, particularly in cold chain operations, has shown significant promise in enhancing labor productivity, reducing handling time, and mitigating contamination risks [10]. Amphibious autonomous vehicles have been proposed for disaster-resilient logistics in flood-prone areas, ensuring continuity of distribution even during extreme weather events. In the Indonesian context, coastal regions like Demak City face compounded logistical challenges due to tidal flooding, limited road infrastructure, and the dispersed nature of small-scale fisheries operations. Innovative approaches combining renewable energy-powered refrigeration, AI-driven predictive maintenance, and mobile stakeholder engagement platforms can deliver sustainable, inclusive solutions. Despite advancements, a research gap persists in integrating Digitalization 5.0, blockchain, IoT, and autonomous robotics into a unified Robotic Fishery Frozen Supply framework tailored to small- and medium-scale fisheries in developing countries. This study addresses this gap by proposing and evaluating a Robotic Fishery Frozen Supply model specifically designed to address logistical challenges in Demak City.

Table 2. Literature Review Themes for Digitalization 5.0 in Fishery Logistics

Theme	Key Technologies	Main Findings from Literature	Representative Studies
Cold Chain Management	IoT sensors, cloud monitoring	Reduces spoilage and maintains freshness during transport	[11]
Industry 5.0 Digitalization	AI, human-centric automation	Improves efficiency, sustainability, and resilience in logistics	[12]
Blockchain Traceability	Distributed ledger systems	Ensures authenticity, reduces fraud, and builds consumer trust	[13]
Digital Route Optimization	AI-based GPS, predictive analytics	Reduces delivery time, energy use, and costs	[14]
Autonomous Robotics	AI-powered robotic handling	Enhances labor efficiency, reduces contamination risks	[15]
Amphibious Transport	Electric-powered amphibious vehicles	Maintains delivery continuity during floods	[16]
Renewable Energy in Cold Chains	Solar refrigeration, hybrid energy systems	Reduces operational costs and carbon emissions	[17]
Predictive Maintenance	AI-based equipment health monitoring	Minimizes downtime, improves asset lifespan	[18]
Disaster-Resilient Logistics	Flood-adaptive vehicles and routes	Maintains supply chain flow in extreme conditions	[19]
Stakeholder Digital Engagement	Mobile apps, cloud-based dashboards	Strengthens coordination and transparency	[20]

3. Methods

This study adopts a mixed-method research design that integrates qualitative stakeholder analysis and quantitative performance evaluation of the Robotic Fishery Frozen Supply system in Demak City. The methodology consists of five sequential phases: needs assessment, system design, prototype development, pilot testing, and performance evaluation.

3.1. Phase 1: Needs Assessment

A field survey was conducted to identify existing challenges in the fishery distribution sector, focusing on cold chain management, transportation delays, and product quality degradation. Data collection involved structured interviews with fishermen, distributors, and retailers, as well as secondary data analysis of local fisheries output.

3.2. Phase 2: System Design

Based on the needs assessment, the Robotic Fishery Frozen Supply framework was designed to incorporate IoT-enabled cold-chain monitoring, blockchain-based traceability, autonomous robotic loading/unloading, and amphibious transport capability (Huang et al., 2022; Lee and Park, 2023). Design considerations included flood resilience, energy efficiency, and human-centered usability.

3.3. Phase 3: Prototype Development

The prototype consisted of an electric-powered amphibious transport vehicle equipped with solar-assisted refrigeration units and AI-based route optimization (Kumar et al., 2021; Nguyen et al., 2022). Hardware and software integration was achieved using a modular architecture to enable scalability.

3.4. Phase 4: Pilot Testing

Pilot trials were carried out over 3 months in two selected coastal villages in Demak. The testing evaluated delivery time, temperature stability, energy consumption, and user acceptance (Ismail et al., 2023; Zhou et al., 2023). IoT data was streamed to a cloud-based dashboard for real-time monitoring and analysis.

3.5. Phase 5: Performance Evaluation

Quantitative data analysis employed paired t-tests to compare pre- and post-implementation performance indicators, including post-harvest loss rate, delivery time, and CO_2 emissions (Patil et al., 2021; Wang et al., 2023). Qualitative analysis was conducted using thematic coding of stakeholder interviews to capture perceived benefits and challenges (Rahman et al., 2022; Tan et al., 2024).

Table 3. Research Methodology for Robotic Fishery Frozen Supply Implementation

Phase	Activities	Tools & Technologies	Outputs
Needs Assessment	Field surveys, interviews, and secondary data review	Survey questionnaires, GIS mapping	Identification of logistical bottlenecks
System Design	Technology selection, system architecture design	CAD modeling, blockchain platform design	Robotic Fishery Frozen Supply framework blueprint
Prototype Development	Hardware assembly, software integration	Autonomous robotic units, IoT sensors, and an AI route planner	Functional Robotic Fishery Frozen Supply prototype
Pilot Testing	Controlled field trials in the Demak villages	Solar refrigeration units, amphibious vehicles	Operational performance dataset
Performance Evaluation	Statistical and thematic analysis	SPSS for t-tests, NVivo for coding	Impact assessment report

4. Results and Discussion

The pilot implementation of the Robotic Fishery Frozen Supply system in two coastal villages of Demak City yielded significant improvements in cold chain performance, delivery efficiency, and supply chain transparency. Quantitative and qualitative results are discussed below.

4.1. Improvement in Cold Chain Stability

The IoT-enabled monitoring system maintained the average internal storage temperature at −18.5 °C with a variance of ±0.4 °C, compared to the pre-implementation variance of ±2.1 °C. This enhanced stability contributed to a 27% reduction in spoilage rates (Ali et al., 2021; Chen et al., 2022).

4.2. Reduction in Delivery Time

AI-powered route optimization and amphibious vehicle deployment reduced average delivery times from 6.8 hours to 4.4 hours, representing a 35% improvement. This reduction was particularly evident during tidal flood events, where amphibious transport maintained uninterrupted operations (Zhou et al., 2023; Rahman et al., 2022).

4.3. Enhanced Supply Chain Transparency

Blockchain-enabled traceability improved the accuracy of transaction and logistics data to 99.3%, fostering greater buyer confidence and reducing disputes (Huang et al., 2022; Chen and Xu, 2023). Stakeholders reported improved trust in product authenticity and quality verification.

4.4. Operational Cost Savings

Integration of solar-powered refrigeration reduced fuel-based generator usage by 42%, resulting in a 15% decrease in operational costs. This aligns with sustainable logistics goals and lowers carbon footprint (Santos et al., 2023; Park et al., 2024).

4.5. Stakeholder Perceptions

Interviews revealed strong acceptance of Robotic Fishery Frozen Supply technology, with 91% of stakeholders reporting improved income stability due to reduced post-harvest losses and better market access. However, concerns were raised about the initial capital investment and the need for ongoing technical support (Prasetyo et al., 2023; Simanjuntak et al., 2022).

Table 4. Infographic Summary of Robotic Fishery Frozen Supply Pilot Results in Demak City

Performance Indicator	Before Robotic Fishery Frozen Supply	After Robotic Fishery Frozen Supply	Improvement (%)	Key Enabling Technology
Cold chain temperature variance (°C)	±2.1	±0.4	81%	IoT-based cold chain monitoring
Spoilage rate (%)	14.8	10.8	27%	Solar refrigeration, autonomous transport

Average delivery time (hours)	6.8	4.4	35%	AI route optimization, amphibious vehicles
Transaction data accuracy (%)	84.5	99.3	17%	Blockchain traceability
Fuel-based generator usage (%)	100	58	42%	Renewable energy integration
Stakeholder satisfaction (%)	63	91	44%	Mobile stakeholder engagement

4.6. Discussion

The results confirm that integrating Digitalization 5.0 principles into Robotic Fishery Frozen Supply significantly enhances the efficiency and resilience of fishery product distribution in coastal, flood-prone regions. The cold chain stability improvements align with findings by Patil et al. (2021) and Wang et al. (2023), demonstrating that IoT-based monitoring reduces post-harvest losses by maintaining optimal storage conditions. The notable reduction in delivery time, particularly during flood conditions, supports the argument by Tan et al. (2024) that amphibious autonomous vehicles are critical for climate-resilient logistics. Additionally, blockchain traceability results mirror the benefits outlined by Huang et al. (2022), ensuring transparency and authenticity in seafood supply chains. Operational cost reductions achieved through renewable energy adoption reinforce Santos et al. (2023) and Park et al. (2024), highlighting the sustainability potential of solar-powered refrigeration in fisheries logistics. Stakeholder interviews indicate strong acceptance, but as noted by Simanjuntak et al. (2022), the high initial investment and need for technical capacity building remain barriers to widespread adoption. Overall, this study provides empirical evidence that Robotic Fishery Frozen Supply not only addresses logistical inefficiencies but also aligns with the Sustainable Development Goals, particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

5. Conclusion

The integration of Digitalization Transportation 5.0 with Robotic Fishery Frozen Supply Systems demonstrates a transformative impact on the efficiency, reliability, and sustainability of fishery product distribution in Demak City. By combining advanced robotics, Internet of Things–based monitoring, and blockchain-enabled traceability, the proposed model reduces post-harvest losses, ensures cold chain integrity, and shortens distribution times. These innovations directly address the long-standing challenges in the fishery supply chain, particularly in maintaining product quality during transport and optimizing energy consumption through autonomous route planning. Moreover, the system supports regional food security policies by ensuring a steady and safe supply of fishery products to both local and external markets. The research outcomes suggest that Demak has strong potential to become a national model for sustainable and digitally integrated fishery logistics.

Recommendation:

1. Scalability and Replication – The system should be expanded beyond Demak to other coastal regions in Indonesia facing similar cold chain and distribution challenges.
2. Policy Integration – Collaboration with local and national governments is essential to develop supportive regulations, incentives, and standards for adopting digital fishery logistics systems.
3. Capacity Building – Fishermen and logistics operators should be trained in the operation, troubleshooting, and optimization of the robotic frozen supply system to maximize technology adoption.
4. Integration with Renewable Energy – Future iterations should incorporate solar-powered refrigeration and autonomous vessels to enhance sustainability and reduce operational costs.
5. Continuous Monitoring and Data Analytics – Implement big data analytics to improve predictive maintenance, demand forecasting, and dynamic distribution adjustments in real time.
6. Public–Private Partnership Models – Encourage investment from private sector logistics and e-commerce companies to accelerate infrastructure and technology deployment.

Community Empowerment – Local cooperatives should be empowered as primary stakeholders to ensure economic benefits remain within fishing communities.

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References

[1] A. Pratama and R. O. Firdaus, "Logistical And Operational Challenges In Cold Chain Systems For Fishery Products In Developing Countries: A Literature Review: English," *J. Akuntansi, Ekon. Dan Manaj. Bisnis*, vol. 13, no. 2, pp. 234–245, 2025.

[2] H. Zhang, X. Zuo, L. Zhang, B. Liang, and X. Li, "Automatic gas dynamic volumetric system for aquatic products' MA preservation," *Comput. Electron. Agric.*, vol. 199, p. 107188, 2022.

[3] S. Manetti, M. Ni, S. Supino, and O. Troisi, "Rethinking the circular economy in agri-food: Human-centered AI for a new circular economy 5.0 paradigm," *Br. Food J.*, pp. 1–22, 2025.

[4] S. Ismail, H. Reza, K. Salameh, H. Kashani Zadeh, and F. Vasefi, "Toward an intelligent blockchain IoT-enabled fish supply chain: A review and conceptual framework," *Sensors*, vol. 23, no 11, p. 5136, 2023.

[5] F. Hakimi, N. Idris, and Z. Bin Yusof, "Climate Change Adaptation Strategies for Coastal Communities: Lessons from Indonesia,"

Contemp. Res. Glob. Challenges, Cult. Dyn. Sustain. Solut., vol. 15, no. 6, 2025.
[6] J. Fottner *et al.*, "Autonomous systems in intralogistics: state of the art and future research challenges," *Logist. Res.*, vol. 14, no. 1, pp. 1–41, 2021.
[7] C. Castillo, T. Otero-Romero, and E. J. Alvarez-Palau, "Navigating the transition to industry 5.0: advancing sustainability, resilience, and human-centricity in Spanish supply chain management," *Discov. Sustain.*, vol. 6, no. 1, p. 331, 2025.
[8] A. Abdullahi, U. N. Muhammed, C. C. Nworie, D. C. Nwangwu, and Y. Zakari, "Digital transformation for small-scale fisheries: an integrated framework to overcome adoption barriers and enhance economic sustainability," *Int. J. Sci. Bus.*, vol. 48, no. 1, pp. 55–74, 2025.
[9] W. A. Müller, S. B. Ferreira, and S. da Silva, "Enhancing food safety in the cold chain through Internet of Things and artificial intelligence," *J. Food Sci.*, vol. 91, no. 2, p. e70871, 2026.
[10] L. N. K. Duong *et al.*, "A review of robotics and autonomous systems in the food industry: From the supply chains perspective," *Trends Food Sci—Technol.*, vol. 106, pp. 355–364, 2020.
[11] S. Negi and S. Trivedi, "Factors impacting the quality of fresh produce in transportation and their mitigation strategies: empirical evidence from a developing economy," *J. Agribus. Dev. Emerg. Econ.*, vol. 11, no. 2, pp. 121–139, 2021.
[12] M. Klumpp and D. Loske, "Sustainability and resilience revisited: Impact of information technology disruptions on empirical retail logistics efficiency," *Sustainability*, vol. 13, no 10, p. 5650, 2021.
[13] M. N. Mukabbir, "Consumer Trust in E-Commerce: The Role of Personalization, Security, and Brand Authenticity," *Br. J. Multidiscip. Stud.*, vol. 2, no. 2, pp. 18–26, 2024.
[14] M. Woody, M. T. Craig, P. T. Vaishnav, G. M. Lewis, and G. A. Keoleian, "Optimizing future cost and emissions of electric delivery vehicles," *J. Ind. Ecol.*, vol. 26, no. 3, pp. 1108–1122, 2022.
[15] X. Yu, A. Dilanchiev, and S. Bibi, "Enhancing labor productivity as a key strategy for fostering green economic growth and resource efficiency," *Heliyon*, vol. 10, no. 3, 2024.
[16] C. Marolla, "Urban flood resilience: Risk and business continuity management systems strategic approach," 2024.
[17] C. O. Okuh, E. O. Nwulu, E. Ogu, P. I. Egbumokei, I. N. Dienagha, and W. N. Digitemie, "A Strategic Model for Carbon Emission Reduction through Process Optimization in Energy Sector Operations," *Int. J.*, vol. 5, no. 1, pp. 1309–1317, 2024.
[18] M. Yazdi, "Maintenance strategies and optimization techniques," in *Advances in computational mathematics for industrial system reliability and maintainability*, Springer, 2024, pp. 43–58.
[19] S. Bag, M. S. Rahman, H.-L. Chan, and J. Sharma, "Effect of supply chain flexibility and supply chain endurance on supply chain resilience in extreme weather events: An empirical study," *IEEE Trans. Eng. Manag.*, 2025.
[20] N. Jiang and J. Huang, "Can transparency governance promote interregional coordinated carbon emission reduction? A new perspective from China's provincial transparency index," *Energy Strateg. Rev.*, vol. 58, p. 101649, 2025.