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# TUAL DOCK TECH: An IoT-based port transformation for the optimization of the tuna industry in the City of Tual

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## ABSTRACT

**Background**: Tual City is a region with the largest tuna potential in Indonesia, which can be utilized for the escalation of maritime resource exports to various countries via sea routes. However, the utilization of this potential is still far from optimal, influenced by various factors such as the relatively low social and economic conditions of the Tual community. Furthermore, limited access to the global market due to a lack of supporting infrastructure and low technology adoption is a primary factor hindering the development of Tual City's fishing industry. In its logistical processes, the port in Tual City relies solely on manual loading and unloading, leading to distribution delays, increased logistic costs, and a decline in product quality. Therefore, there is an urgent need to maximize port performance with technology assistance to facilitate the distribution of tuna products while simultaneously enhancing the implementation of the Blue Economy concept in Tual City. **Methods**: This study employs a Systematic Literature Review (SLR) and Secondary Data Analysis methods to position TUAL DOCK TECH as a solution to the status quo in Tual City. **Findings:** This innovation is expected to strengthen Tual City's tuna potential by up to 50 percent through the revitalization of the container port and advanced infrastructure, establishing the region as economically independent and as a city that successfully implements the Blue Economy concept optimally and sustainably in Indonesia. **Conclusion**: Implementation of TUAL DOCK TECH can be the alternative solution the Tual City's structural socio-economic problems. This innovation can also bring the city's economic dependence status to be more environment friendly based, which is Blue Economy **Novelty/Originality of this article:** The novelty aspect refers to the integration of IoT into the infrastructure of the container port for loading and unloading purposes and to facilitate tuna fishermen in the fishing process. Additionally, this innovation integrates an IoT-based quality control system in the port's cold storage to ensure compliance with national export standards.

**KEYWORDS**: blue economy; container port; infrastructure innovation; Tual City.

## 1. Introduction

Tual City, a city in Maluku Province, possesses enormous fisheries potential, especially in tuna production. Its strategic geographical position makes Tual one of the national fishery

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centers, particularly as its territory is part of the Republic of Indonesia's State Fisheries Management Area/*Wilayah Pengelolaan Perikanan Negara Republik Indonesia* (WPPNRI) 718 (KKP, 2025). Tual City is also included in the Measured Fishing/*Perikanan Terukur* (PIT) zone III, with capture fisheries production reaching 30,088.18 tons in 2022 and increasing to 30,124.93 tons in 2023 (KKP, 2025). However, almost all of this amount was sold fresh/frozen, while only 1 ton (2022) and 3 tons (2023) were processed (KKP, 2025). This demonstrates that although the potential of the tuna sector in Tual City is vast, the optimization of this production remains suboptimal.

Tual City has ports that play a critical role in the utilization of tuna, namely the Tual Nusantara Fisheries Port/*Pelabuhan Perikanan Nusantara Tual* and Tual Port. These ports are key to marketing Tual City's tuna industry to consumers. They not only serve domestic tuna marketing but also act as an export gateway to foreign countries (Handoyo et al., 2024). For example, in May 2025, Tual City successfully exported 15 tons of fish to Vietnam (Ely, 2025). The potential of Tual City is supported by government facilitation.

*"We support and always facilitate the interests of fishermen in Tual."* (A.A.R, Tual Mayor)

This highlights the significant, yet unoptimized, potential of Tual City's tuna industry. Optimizing port functions still faces various obstacles. One of the biggest challenges is the social and economic condition of the Tual community. Tual City is one of the cities with the highest poverty rates in Indonesia, with 16,000 poor individuals out of a total population of 91,275 in 2024 (BPS, 2025). At low-income levels, the demand for goods is relatively small (Przywara, 2017). The low purchasing power of the community results in a lack of interest in Tual City's tuna industry. Market forces significantly influence the slowdown in productivity growth (Stiglitz, 2017). Consequently, this leads to innovation stagnation, where port optimization in Tual City cannot be maximized.

The second factor hindering the optimization of Tual City's tuna industry is the limitation of port infrastructure. In improving export performance, infrastructure aspects such as connectivity and logistics pathways, as well as non-infrastructure aspects like the ease of export procedures, are key supporting factors. The ports in Tual City still have facilities that are far from modern. Most facilities, ship handling, and production management in Tual City still rely on manual systems. Manual systems are prevalent in activities such as docking, fish counting, and quality-checking processes. This condition causes the catching, storage, and distribution of fish to be inefficient. The risk of operational errors, such as miscounting and recording, economic losses due to distribution delays, and the potential for decreased fish quality, are more prone to occur. In the context of exports and the globalization of Tual's tuna market, the delay in digital transformation at Tual's ports means the great tuna potential has not been maximally exploited.

To realize the optimization of the industry in Tual City, technological renewal is necessary, especially at the port. The TUAL DOCK TECH concept is present as an innovation to transform the Port in Tual City into a smart port based on the Internet of Things (IoT), with the main goal of optimizing the tuna industry in Tual City. The application of IoT at the port introduces innovations that include temperature and humidity sensors to maintain fish quality in cold storage, fish quality sensors, GPS-based ship tracking systems, real-time integration of catch data, sonar systems to assist fishermen in catching fish, data-based distribution monitoring, and e-commerce, as well as the automation of logistics and docking processes (Yang, 2021).

Optimization in the context of Tual City's ports covers three main aspects; operational efficiency, increased added value, and strengthening global competitiveness. First, operational efficiency means minimizing technical and administrative barriers through the implementation of digital-based systems, so that processes like ship docking, catch recording, and distribution can proceed effectively. Second, increasing added value is realized through the use of technology to maintain tuna quality from landing at the port through the distribution chain. This includes quality checking, cold storage, until the fish is ready for distribution in prime condition, while also opening opportunities for processing-

based industrialization through e-commerce and other platforms. Third, strengthening global competitiveness is directed at the ability of Tual City's ports to meet international standards in product quality and distribution. Many ports in maritime countries have already implemented the IoT concept. The goal is none other than to optimize import-export activities. With TUAL DOCK TECH, it is hoped that tuna production in Tual City will become more efficient. The implementation of this technology is expected to strengthen Tual City's position as a world-class, modern, and competitive tuna exporting industry, while also providing a significant economic impact on the community.

With this digital transformation, the port, which previously focused only on manual loading and unloading, can function more optimally. The number of ships docking at Tual City Port will also increase, as targeted port optimization will attract more vessels for logistical loading and unloading. Furthermore, the maximization of the processed tuna industry for transport to the global market is also an indicator of regional economic improvement by opening export channels for Tual City's processed tuna commodities abroad.

Tual City has a population of at least 90,470 people in 2025 (BPS, 2025), with the largest population residing in the Pulau Dullah Selatan District at 51,185 people, making it the most densely populated district in Tual City (BPS, 2025). However, Tual City is experiencing complex social problems, with at least 20.01% of its population classified as poor (BPS, 2024). The realization of Tual City's regional revenue and expenditure, which experienced a deficit in 2023 by IDR 162.34 billion and in 2024 by IDR 184.46 billion (BPS, 2025), is a potential contributing factor to why poverty has not significantly decreased. The trend of an increasing deficit between regional revenues and expenditures from 2023 to 2024 indicates that Tual City's economy cannot yet operate independently, requiring fund transfers from the central government to maintain economic circulation.

Based on data compiled by the Tual City Fisheries Service (2025), the region produced fishery commodities worth IDR 1.6 billion per ton throughout 2024, from both marine and aquaculture fisheries. This quantity decreased from the previous year, which amounted to IDR 1.9 billion per ton. This decline in fisheries empowerment is also a concern in Tual City's sluggish economy. Furthermore, the economic decline in Tual City's fisheries can also be analyzed through its fish-catching facilities and supporting infrastructure for the fisheries economy. The fishing profession only increased by 0.85% in 2024, with the number of residents working as fishermen recorded at 3,992 people. Generally, raw tuna production in Tual City's market is sold at IDR 16,000. In the fourth quarter of 2024, Tual City produced 403,177 kg of raw tuna, generating a sales value of IDR 16.7 billion. This figure is a major contribution to Tual City, considering that the profit from raw tuna sales alone ranks second after the sales of cutlassfish at IDR 17.9 billion (Tual Archipelago Fisheries Port, 2025).

## 2. Methods

This study adopts a methodology integrating a Systematic Literature Review (SLR) with an analysis of available secondary data. The SLR component examines a corpus of literature focused on the integration of high-technology solutions for optimizing port performance in various countries. This review serves as a comparative analysis to identify development models and optimization strategies suitable for enhancing the performance of Tual City's port. The objective is to position the port as the region's new economic engine, fostering its path toward economic self-sufficiency. Concurrently, the secondary data analysis is utilized to establish a baseline understanding of the current socio-economic conditions. This includes an assessment of the existing mechanisms for ship loading and unloading activities at Tual Port, alongside other relevant data points. Collectively, this information provides a clear framework to support the practical implementation of the proposed technological integration for the port.

## 3. Results and Discussion

### *3.1 Secondary data analysis*

Speaking of an economy that relies on the port as the main engine of economic activity, Tual City has seen a significant decline in ship visits, followed by a reduction in the logistical supply for distributing goods out of Tual City, especially in the fisheries sector, which is one of the largest contributors to Tual City's GRDP (Gross Regional Domestic Product).

Table 1. Number of ship visits and loading/unloading at Tual port 2021-2024

| Detail | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|
| Number of Ship Visits | 2,568 | 4,365 | 2,279 | 2,023 |
| Unloaded Logistics ($t/m^3$) | 931,874 | 544,146 | 3,773,796 | 167,039 |
| Loaded Logistics ($t/m^3$) | 200,345 | 308,792 | 7,547,592 | 220,873 |

(Tual City Fisheries Service, 2025)

This data shows several setbacks in Tual City's maritime world, especially in the management of the port area, which should be a strength in boosting the regional economy and implementing the Blue Economy concept, given that 93% of the area is ocean, followed by the abundant and high-value tuna resources in the Banda Sea waters (Nugraha & Chodriyah, 2010), both in national and international markets.

Based on these problems, there is an urgency to implement an innovation to overcome the complex issues in guiding Tual City to become an economically independent region by implementing the Blue Economy concept, focusing on port optimization and the utilization of processed tuna products for export as a form of Tual City's future self-sufficiency. We propose TUAL DOCK TECH, which combines several advancements in container port management to support export facilities, warehouse upgrading for storing processed tuna commodities, and technological assistance for local fishermen in Tual City to catch tuna. Moreover, the global market demand for processed tuna products is increasing. Kawamoto (2022) estimates that the demand for tuna products, especially canned processed forms, will increase to 2,466,000 tons by 2050, with 62% of the products being canned tuna. High demand will cause market prices to adjust. In the United States, the price of canned tuna reached USD 34.58, while in the European Union, it reached USD 14.39 per unit in the same year. Therefore, the initiative to increase the utilization of tuna potential in Tual City is a key to escalating regional income, followed by regional progress towards economic independence through the implementation of the Blue Economy in exporting tuna sea commodities.

### *3.2 Systematic literature review (SLR)*

The concepts of systematic port integration, port area optimization, and product commercialization design will be discussed in this chapter. This study observed how this potential could be realized through several previous studies that successfully applied parts of a similar concept, which will help design a more significant idea followed by improvisations on the research gaps that emerged in previous researchers' studies. Therefore, this study used the Systematic Literature Review (SLR) research method along with conceptual analysis to find the latest breakthroughs so that the designed innovation can answer the complex problems occurring in Tual City in order to align with the goals of the Blue Economy.

To address the multifaceted challenges identified in the baseline analysis, TUAL DOCK TECH is proposed as an integrated, multi-layered technological framework. Each layer is designed to resolve a specific bottleneck in the value chain, from port logistics and harvesting to quality control and market access. The entire system is conceived as an interconnected ecosystem powered by IoT, AI, and blockchain, transforming Tual's port into

a genuine smart port. Table 2 provides a summary of the key technological components and their strategic objectives.

Table 2. TUAL DOCK TECH technology stack and strategic objectives

| Technology Component | Description | Strategic Objective | Key Performance Indicator (KPI) |
|---|---|---|---|
| Smart Quay Cranes | AI-controlled cranes for automated loading and unloading of containers from vessels (Ahmed et al., 2021). | Increase port throughput and reduce vessel turnaround time. | Increase in container moves per hour; Reduction in average vessel berthing time. |
| Automated Guided Vehicles (AGV) | Unmanned electric vehicles for transporting containers between the quay and storage yards. | Optimize horizontal logistics, reduce operational costs, and improve safety. | Reduction in container transfer time; Decrease in labor costs per container move. |
| Multi-Beam Sonar Systems | Advanced acoustic systems on fishing vessels for fish school identification and sizing. | Enhance fishing efficiency and promote sustainable harvesting by reducing bycatch. | Increase in catch per unit effort (CPUE) for target species; Reduction in bycatch ratio. |
| IoT Cold Storage System | Real-time monitoring of temperature, humidity, and product quality (color/texture) using sensors and AI cameras. | Minimize post-harvest spoilage and ensure compliance with international export standards. | Reduction in product quality loss (Target: 30%) (BPS, 2025); Increase in percentage of catch meeting Grade A export standards. |
| Blockchain Traceability | A distributed digital ledger to record the entire journey of the tuna from catch to consumer immutably. | Provide end-to-end transparency, build trust with international buyers, and combat illegal fishing. | 100% traceability for all exported batches; Reduction in time for regulatory compliance checks. |
| Integrated B2B E-Commerce Platform | An online marketplace directly linked to the blockchain system for transparent, data-driven sales. | Connect Tual producers directly with global buyers, eliminating intermediaries and increasing price transparency. | Increase in direct export sales volume; Increase in average sale price per kilogram for traceable tuna. |

### *3.2 1 Tual City port concept*

The existence of a Hi-Tech Port System in a Smart Quay Crane Port is the main concept in designing a smart port integrated with AI in Indonesia. The port will be facilitated by Quay Cranes controlled by AI to perform the loading and unloading of containers from cargo ships that dock. Additionally, the big data available in the port headquarters provides real-time specifications for arriving and departing ships to minimize ship waiting times at the port, like in majority of Chinese automatic crane port operations (Ding et al., 2023)

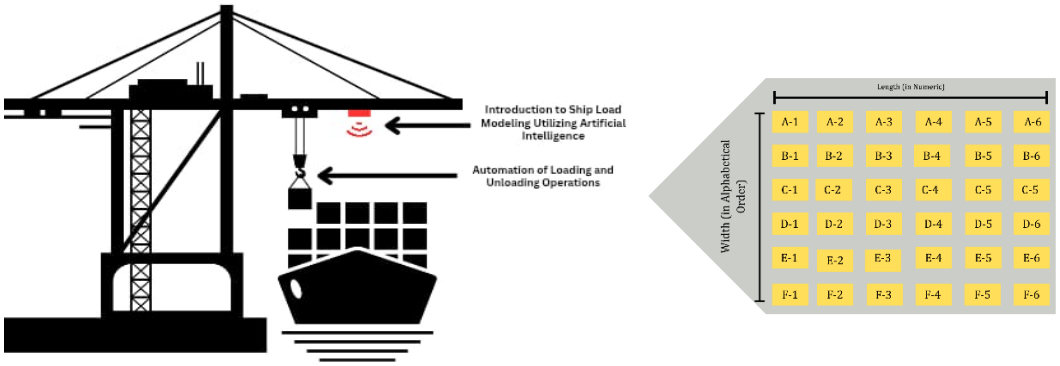


Fig.1. AI-based ship load modeling and automated cargo handling system

### *3.2.2 Sonar system*

Next is the assistance of a sonar system for fishing activities in the open seas of Tual City. The fishing process in Tual City is somewhat difficult and dangerous, as these waters face the Indian and Pacific Oceans directly, which have strong sea waves. The preparation for integrating this sonar involves modifying fishing boats with several electronic devices for the procurement of sonar and AI during the fishing process. A study by Lubis & Anurogo (2017) on the use of Side Scan Sonar (SSS) with the Beam Pattern Discrete-Equi Spaced Unshaded Line Array method has several advantages, namely the instrument's ability to produce two-dimensional images of the seabed surface, allowing for detailed identification of seabed structures. However, a weakness was found in that study. The movement of the tow vehicle is difficult to control in waters with physical currents. Strong currents can cause the tow vehicle to move off its planned track or change its degree of position, thereby reducing the precision of the seabed imaging, which in turn increases the risk of equipment damage. The sonar system works by reflecting sound waves across the entire reachable sea surface and back to a sensor to identify objects struck by the sound waves.

### *3.2.3 Automatic guided vehicles (AGVs)*

The primary function of AGVs is to transport logistics that have been produced from the industry to the container port with the help of a Remote Vehicle, where this vehicle can be controlled by a system-operated by port staff remotely. This certainly streamlines the time frame because coordination from the port authorities regarding the transport and release of containers is directly provided by the port system to the designated dock terminal. The final and perhaps most crucial layer of TUAL DOCK TECH is a digital ecosystem designed to preserve product quality and connect producers directly to high-value markets. This system is built on three integrated technologies. First, an IoT-enabled cold chain management system will be implemented in the port's warehouses and cold storage facilities. This system goes beyond simple refrigeration. Each batch of tuna will be tagged with a Radio Frequency Identification (RFID) chip for unique identification. Throughout the storage and transit process, a network of IoT sensors will continuously monitor critical environmental parameters like temperature and humidity in real-time. Simultaneously, AI-powered cameras will perform visual inspections, analyzing the color and texture of the fish to detect early signs of quality degradation. If any parameter deviates from the pre-set standards for export-grade tuna, the system will automatically trigger an alert to facility managers, enabling immediate corrective action to prevent spoilage.

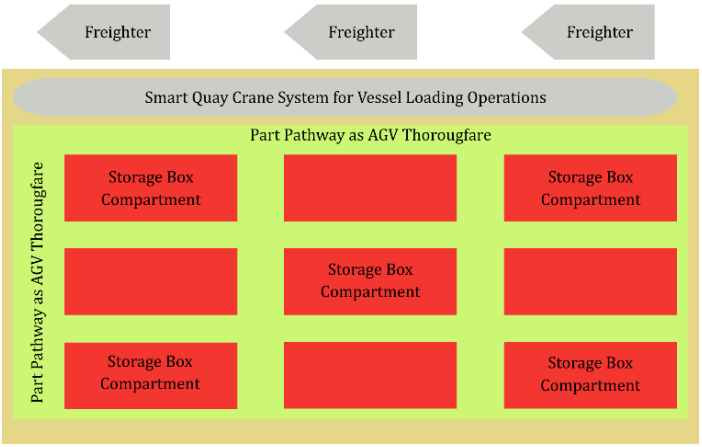


Fig. 2. Layout of smart quay crane system and storage box compartments for vessel loading operations

Second, all data generated by the IoT system, from the moment of catch (including GPS location and time) to every temperature reading in the cold chain will be recorded on a blockchain-based traceability platform. Blockchain's distributed ledger technology creates an immutable and fully transparent record of the product's entire journey. This provides an unforgeable "digital passport" for each batch of tuna, offering absolute proof of its origin, handling conditions, and quality. For international buyers and regulatory bodies in markets like the EU and US, this level of traceability is increasingly a non-negotiable requirement. It builds immense trust, combats illegal, unreported, and unregulated (IUU) fishing, and provides the verifiable proof needed to command a premium price.

Finally, this verifiable data will feed directly into an integrated B2B e-commerce platform. This is not merely a digital marketplace but a transparent sales portal. Potential buyers from anywhere in the world can log in, select a specific batch of Tual tuna, and instantly access its complete blockchain-verified history—from the exact fishing ground where it was caught to its entire temperature log in storage. This system disintermediates the supply chain, allowing Tual's producers to engage directly with global buyers, enhancing price transparency and capturing a greater share of the final market value.

### *3.2.4 Warehouse optimization/cold storage quality control system*

Quality control in modern management is a primary strategy for creating a competitive advantage by leveraging technological changes (Jumawati et al., 2025). The use of renewable technologies like AI and IoT can be a major breakthrough to improve quality control assurance at Tual Port. With tuna as the main commodity for the Tual community, they urgently need modern warehouses and cold storage as a place to store their products before being shipped by sea. The use of technology in these storage warehouses can facilitate the distribution of goods and maintain the quality of the main commodity (tuna) to prevent freezer burn, which can damage the quality of fresh tuna (Azzahra et al., 2025). According to previous research, the application of digital systems based on sensors and data analytics in cold storage has been proven to reduce the risk of quality loss by up to 30% (Raji et al., 2021). In improving quality assurance in the warehouse/cold storage at Tual City Port, the application of several technologies is necessary.

Before entering the warehouse/cold storage, the product will be given an identification mark (RFID tag) as the product's identity, which will contain data on the production date, warehouse/cold storage entry date, expiration date, product condition upon entry, and lab test results. Based on Yusianto (2010), by identifying products using RFID, the application of the First in First Out (FIFO) principle can be facilitated, thereby reducing the risk of product spoilage in the warehouse/cold storage. Furthermore, the use of RFID in the fishery supply chain can also increase tracking efficiency by up to 40% and reduce human error in the logistics process (Kamble et al., 2020).


Fig. 3. Radio frequency identification (RFID)

IoT sensors are placed in the storage room to detect temperature changes in real time. Integration with the RFID system allows for direct temperature tracking of each product batch. If a temperature deviation is detected, the system provides an automatic alarm, thus maintaining product quality. Such IoT systems have been proven effective in supporting food (seafood) supply chain transparency and maintaining the integrity of quality data (Roh et al., 2022).

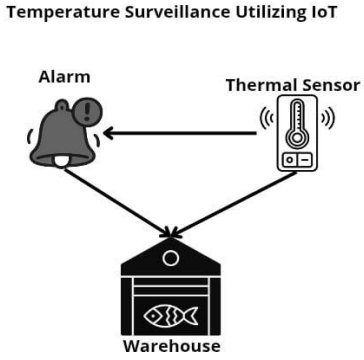


Fig. 4. RFID Steps

AI Cameras are placed at the entry and exit lanes of the warehouse/cold storage. These cameras automatically analyze the color of the tuna meat, identify freshness levels, and detect anomalies such as texture changes or black spots on the meat. Data from the AI Camera is connected to the RFID and blockchain system, so each product can be monitored both in terms of its physical condition and its digital record. This AI-based computer vision technology has been widely used to detect the freshness of fish and seafood products with an accuracy rate of up to 95% (Li et al., 2021).

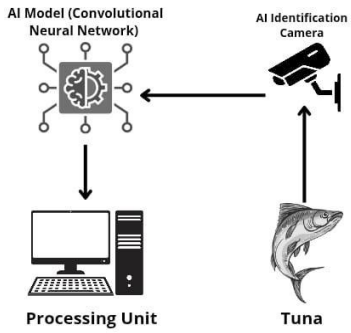


Fig. 5. AI-based tuna identification system using convolutional neural network (CNN)

These three technologies will be integrated into a blockchain system to make it easier for managers to regulate goods in the warehouse/cold storage by providing transparency about the movement of goods and easily tracking their origin (Indraprakoso, 2023). Additionally, the use of this blockchain system can also provide greater data security and the use of smart contracts (Wang et al., 2019).

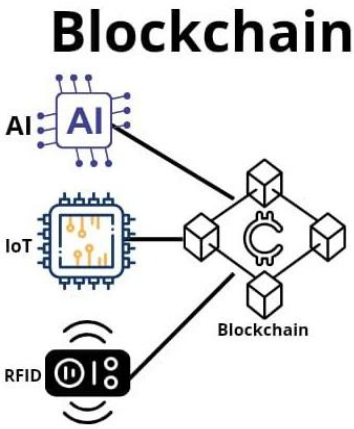


Fig. 6. Blockchain System

*3.2.5 E-Commerce services as a marketing strategy*

Once the quality of the resulting products is assured, the next step for the Tual City government, through the port as the distribution center, is to develop a marketplace, one of which is using e-commerce as a marketing medium. An e-commerce platform can be an effective step in a business strategy to increase sales and company profitability (Fitri, 2022). Through this e-commerce, the modern marketing concept refers to four important elements; product, price, place, and promotion, which can be optimally applied in a digital context (Cheng, 2020; Kotler & Keller, 2016). In an effort to increase the income of the Tual City community through the sale of their main commodity (tuna), the Tual City Port authority can provide a marketplace for fishermen, industry, and the Tual community as an effort to expand their market share.

From the product aspect, this e-commerce can provide a guarantee of tuna quality maintained through the blockchain system, which is directly connected to the warehouse/cold storage. This allows potential importers or buyers to select and monitor the product's condition in real time, both while the product is still in storage and while it is being distributed. This system can provide strict supervision at the port and display quality certifications that guarantee freshness and product safety for international consumers (Algharabat et al., 2020). Meanwhile, from the price aspect, this system allows for higher price transparency by utilizing blockchain technology to record transactions and price formation openly, thereby creating trust between sellers and buyers (Saberi et al., 2019).

Next, from the place aspect, the presence of a marketplace integrated with the port can facilitate the direct distribution of products from cold storage to importers without long intermediaries, making the logistics process more efficient and faster (Hendrayati & Pamungkas, 2016). Finally, the promotion aspect can be carried out digitally through various media such as websites, social media, and content-based marketing campaigns that introduce the advantages of Tual City's tuna in the global market. A promotion strategy oriented towards local values and sustainability can also enhance the region's brand image as a producer of high-quality tuna (Chaffey & Ellis-Chadwick, 2019).

By utilizing e-commerce, which can later be combined with the blockchain system in the warehouse/cold storage at the port, the Tual City community can be assisted in finding sources of income. The Blockchain system in the warehouse/cold storage can be directly connected to the e-commerce website, providing real-time data on product conditions. In

the reviewed studies, the use of e-commerce platforms that provide real-time monitoring features can increase importer satisfaction, and with this increased satisfaction, the economy of the Tual City community can be improved (Pratama, 2024).

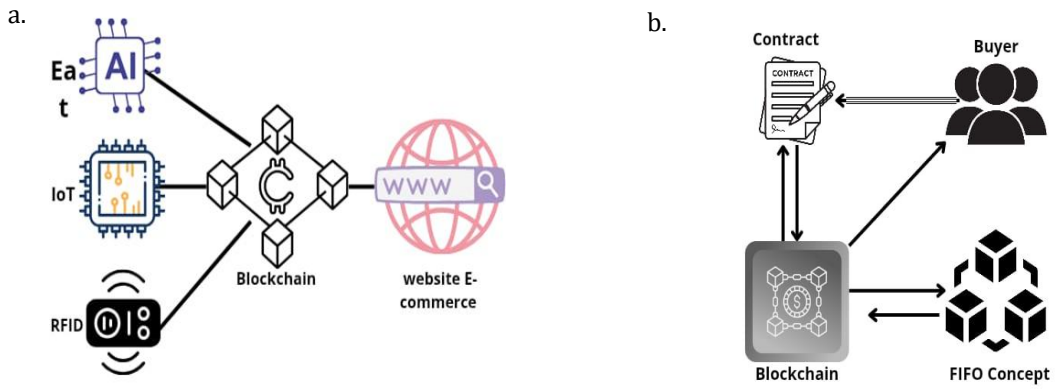


Fig.7. (a) Integration IoT and AI in E-commerce; (b) Application of FIFO Concept

### *3.3 Implementation of TUAL DOCK TECH*

Proposing a technological framework is only the first step; its successful realization depends on a pragmatic implementation strategy, a clear-eyed assessment of its economic and social impacts, and alignment with the prevailing policy landscape. This section moves from the "what" of TUAL DOCK TECH to the "how" and "so what," outlining a phased roadmap for deployment, a framework for evaluating its economic viability, a strategy for managing its social consequences, and a pathway for financing through public-private partnership.

#### *3.3.1 Roadmap of TUAL DOCK TECH*

The implementation of a project of this scale and complexity must be approached strategically through a phased rollout. This allows for iterative learning, risk management, and the demonstration of early successes to maintain stakeholder momentum, a principle vital for large-scale port modernization projects. A proposed three-phase roadmap is presented in Table 3. This phased approach prioritizes establishing a solid foundation (Phase 1) before scaling, ensuring that technology is integrated and the workforce is prepared (Phase 2) ahead of a full commercial launch (Phase 3). This mitigates the risk of operational disruptions and ensures a smoother transition towards a fully smart port ecosystem.

Table 3. Roadmap of Implementation of TUAL DOCK TECH

| Phase | Timeframe | Key Activities | Key Stakeholders | Estimated Budget (Order of Magnitude) |
|---|---|---|---|---|
| Phase 1: Foundational Infrastructure & Pilot Programs | Years 1-2 | a) Conduct detailed feasibility studies and engineering designs.<br>b) Secure financing through a Public-Private Partnership (PPP) agreement. Undertake necessary civil works: quay reinforcement, yard paving, fiber optic network installation. Procure and install a pilot | Tual City Government, Port Authority, Ministry of Investment (BKPM), Private Sector Consortium (Investors, Tech Providers), | High (Primarily CAPEX) |

| | | | | |
|---|---|---|---|---|
| | | set of 2-3 Smart Quay Cranes (SQCs) and a small fleet of 10-15 AGVs in a designated terminal zone.<br>c) Retrofit one existing warehouse with the full IoT Cold Storage System for pilot testing.<br>Develop and launch the initial phase of the workforce reskilling program. | Ministry of Fisheries and Marine Resources (KKP). | |
| Phase 2: System Integration & Capacity Building | Years 3-4 | a) Expand SQC and AGV deployment across the entire container terminal.<br>b) Build and launch the blockchain traceability platform.<br>c) Integrate data streams from port operations (SQC/AGV), cold storage (IoT), and initial fishing vessel pilots (GPS/Sonar).<br>d) Scale up the workforce training program for all port staff and begin digital literacy outreach to fishing cooperatives.<br>Establish a local technical support and maintenance center. | Port Authority, Private Consortium, KKP, Local Educational Institutions, Fishing Cooperatives. | Medium (CAPEX & OPEX) |
| Phase 3: Full-Scale Operation & Ecosystem Expansion | Years 5+ | a) Achieve full operational capacity of all automated port systems. - Launch the international B2B e-commerce platform, fully integrated with the blockchain ledger.<br>b) Expand the sonar technology program to a wider fleet of local fishing vessels, offering data-sharing incentives.<br>Focus on continuous improvement, data analytics for operational optimization and attracting downstream processing industries to Tual (Hendrayati & Pamungkas, 2016). | Port Authority, Private Consortium, Tual City Government, Exporters, and International Buyers. | Medium (Primarily OPEX & Expansion CAPEX) |

### *3.3.2 Economic viability: A preliminary cost-benefit framework*

While a full quantitative Cost-Benefit Analysis (CBA) requires a dedicated feasibility study, it is possible to construct a robust preliminary framework based on established World Bank guidelines and financial models for port infrastructure. This framework,

outlined in Table 4, systematically itemizes the anticipated costs and benefits, demonstrating the project's strong economic rationale.

Table 4. Preliminary Cost-Benefit Framework for TUAL DOCK TECH

| Category | Item | Description/Quantification |
|---|---|---|
| Costs | | |
| Capital Expenditures (CAPEX) | Port automation hardware | Purchase of SQCs, AGVs, and their control systems. High initial investment is a known challenge. |
| | It infrastructure | Servers, fiber optic network, blockchain platform development, IoT sensors, AI cameras. |
| | Civil works | Quay reinforcement, terminal paving, construction of maintenance and charging facilities. |
| Operational Expenditures (OPEX) | Energy | Electricity to power cranes, AGVs, and extensive reefer services. |
| | Maintenance | Regular and predictive maintenance for all automated equipment and IT systems. |
| | Skilled labor | Salaries for a new workforce of technicians, data analysts, and system operators. |
| | Training & development | Ongoing costs for the "Just Transition" workforce development program. |
| Benefits | | |
| Direct Benefits | Increased port revenue | Higher throughput capacity allows for more vessel calls and container moves. New revenue streams from reefer services, data access, etc.. |
| | Operational cost savings | Reduction in manual labor costs, lower accident/damage rates, and optimized energy consumption through automation. |
| Indirect Benefits | Increased Value of Tuna Exports | Higher prices for Grade A, fully traceable tuna on the global market. |
| | Growth of Ancillary Industries | Attraction of new fish processing, packaging, and logistics companies to Tual. |
| | Reduced spoilage | Lower post-harvest losses in the supply chain, increasing the total volume of saleable product. |
| Induced Benefits | Regional economic growth | Circulation of increased income from port and fisheries sectors through the local economy (retail, housing, services). |
| | Employment multiplier | Creation of new, higher-skilled jobs and indirect employment in supporting sectors. |

| | | |
|---|---|---|
| | Increased tax base | Higher revenues for local and national governments from corporate and income taxes. |

The framework highlights that while the initial capital outlay is substantial, the long-term benefits are transformative. The project is not simply a cost center but an economic engine. Direct benefits are generated through enhanced port efficiency, while indirect benefits accrue from capturing more value within the tuna supply chain. Crucially, the induced benefits promise a multiplier effect, where the new wealth generated stimulates broader economic activity across Tual City. Studies on Indonesian tuna fisheries suggest this total economic effect could be up to three times the initial production value, indicating a powerful potential for poverty reduction and sustainable growth.

## 4. Conclusions

TUAL DOCK TECH provides an output in the form of port integration with technology. This is the main target of our innovation, considering that to optimize exports, the systematic operation of port services is the main key to increasing the mobility capacity of export goods to be loaded or unloaded. Not only that, the optimization of tuna through high-value processed products will explicitly make Tual City an independent region, no longer dependent on central fund transfers to meet Tual City's General Allocation Fund/*Dana Alokasi Umum* (DAU). On the other hand, Tual City also plays a role as a frontline promoter of the Blue Economy concept through the utilization of marine resources as its main income, processed sustainably and responsibly.

The development paradox of Tual City, a region of immense marine wealth yet persistent poverty is a solvable problem. The analysis presented in this paper demonstrates that the city's economic stagnation is not a consequence of resource scarcity but of systemic inefficiencies in its port logistics and post-harvest value chain. The proposed TUAL DOCK TECH framework offers a comprehensive, technologically-driven solution designed to break this cycle of underperformance. By integrating port automation, precision harvesting technologies, accelerating port-industries growth, and a digital ecosystem for quality assurance and market access, the framework operationalizes the principles of the Blue Economy. It provides a clear pathway for Tual to transition from a low-margin commodity supplier into a high-value, self-sufficient maritime economic hub.

The successful implementation of this ambitious vision, however, requires more than just technology. It demands a strategic, phased approach, a viable financing model, and an unwavering commitment to developing local human capital. The analysis confirms that a Public-Private Partnership model is the most suitable pathway, aligning the project's capital needs with Indonesia's favorable regulatory environment for foreign investment. Furthermore, the integration of a "Just Transition" workforce development program is identified as a non-negotiable component, essential for ensuring social equity, securing community support, and building the long-term local capacity needed to sustain the transformation. TUAL DOCK TECH is thus presented not as a simple infrastructure project, but as a holistic socio-technical and economic development strategy.

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## Author Contribution
The authors was equally involved in all stages of this review, including its conceptualization, methodology, data analysis, and writing. All authors jointly reviewed and approved the final manuscript for submission.

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## References
Ahmed, E., El-Abbasy, M. S., Zayed, T., Alfalah, G., & Alkass, S. (2021). Synchronized scheduling model for container terminals using simulated double-cycling strategy. *Computers & Industrial Engineering*, *154*, 107118. https://doi.org/10.1016/j.cie.2021.107118

Algharabat, R., Rana, N. P., Dwivedi, Y. K., Alalwan, A. A., & Qasem, Z. (2018). The effect of telepresence, social presence and involvement on consumer brand engagement: An empirical study of non-profit organizations. *Journal of Retailing and Consumer Services*, *40*, 139-149. https://doi.org/10.1016/j.jretconser.2017.09.011

Azzahra, M., Faturohman, M. I., & Rachmawaty, D. (2025). Analisis Pengendalian Kualitas Produk Frozen Tuna Di PT. Cemerlang Laut Ambon Menggunakan Metode Statistical Process Control. *Journal of Industrial and Mechanical Engineering*, *3*(1), 24-31. https://doi.org/10.20884/1.jimien.2025.3.1.16233

BPS. (2024). Jubaida Series 2.2. Badan Pusat Statistik. https://tualkota.bps.go.id/id/news/2025/02/21/149/--jubaida-series-2-2-.html

BPS. (2025). *Produk Domestik Regional Bruto Kota Tual menurut Lapangan Usaha 2020-2024*. Badan Pusat Statistik Kota Tual. https://tualkota.bps.go.id/id/publication/2025/04/11/6d9a8fd1fb9581f177f09666/produk-domestik-regional-bruto-kota-tual-menurut-lapangan-usaha-2020-2024.html

Chaffey, D., & Ellis-Chadwick, F. (2019). *Digital Marketing (7th ed.)*. Pearson Education Limited.

Cheng, B. (2020). Promotive effect of port trade on the international economy considering the effect of industrial clusters. *Journal of Coastal Research*, *106*(SI), 221-224. https://doi.org/10.2112/SI106-052.1

Ding, Y., Zhang, Z., Chen, K., Ding, H., Voss, S., Heilig, L., ... & Chen, X. (2023). Real-Time Monitoring and Optimal Resource Allocation for Automated Container Terminals: A Digital Twin Application at the Yangshan Port. *Journal of Advanced Transportation*, *2023*(1), 6909801. https://doi.org/10.1155/2023/6909801

Ely, R. (2025). Pemkot Tual Fasilitasi Ekspor 15 Ton Ikan ke Vietnam. RRI. https://rri.co.id/ambon/daerah/1496366/pemkot-tual-fasilitasi-ekspor-15-ton-ikan-ke-vietnam

Fitri, N. A. (2022). Dampak E-Commerce terhadap Strategi Pemasaran (Studi Kasus Pada Platform Shopee). *PROCURATIO: Jurnal Manajemen & Bisnis*, *1*(2), 67-77. https://doi.org/10.62394/projmb.v1i2.34

Handoyo, R. D., Ibrahim, K. H., Rahmawati, Y., Faadhillah, F., Ogawa, K., Kusumawardani, D., ... & Gulati, R. (2024). Determinants of exports performance: Evidence from Indonesian low-, medium-, and high-technology manufacturing industries. *Plos one*, *19*(1), e0296431. https://doi.org/10.1371/journal.pone.0296431

Hendrayati, H., & Pamungkas, B. (2016). Implementasi Model Hybrid Learning Pada Proses Pembelajaran Mata Kuliah Statistika II Di Prodi Manajemen FPEB UPI. *Jurnal Penelitian Pendidikan*, *13*(2). https://doi.org/10.17509/jpp.v13i2.3430

Indraprakoso, D. (2023). Eksplorasi Potensi Penggunaan Blockchain Dalam Optimalisasi Manajemen Pelabuhan di Indonesia: Tinjauan Literatur. *Sanskara Manajemen Dan Bisnis*, *1*(03), 140-160. https://doi.org/10.58812/smb.v1i03.131

Jumawati, J., Ramli, R., Sukriati, S., Hamran, H., Ahmad, M. I., Imran, M. A., & Saleh, A. R. (2025). Integrasi, Implementasi, dan Evaluasi Pengendalian Mutu dalam Manajemen Modern. *Sulawesi Tenggara Educational Journal*, *5*(1), 225-232. https://doi.org/10.54297/seduj.v5i1.1102

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International journal of information management*, *52*, 101967. https://doi.org/10.1016/j.ijinfomgt.2019.05.023

Kawamoto, T. (2022a). A challenge to estimate global canned tuna demand and its impact on future tuna resource management using the gamma model. *Marine Policy*, *139*, 105016. https://doi.org/10.1016/j.marpol.2022.105016

KKP. (2025). *KKP Siapkan Checker Mutu Ikan Dukung Implementasi PIT di Tual.* Kementerian Kelautan dan Perikanan. https://ppid.kkp.go.id/media/uploads/document_information_public/Profil_PPN_Tual_Update_072024.pdf

Kotler, P., & Keller, K. L. (2016). *Marketing Management (15th ed.).* Pearson Education.

Li, J., Jiang, Y., Guan, W., & Lu, J. (2021). Agglomeration effects or port-related benefits? (Re)Location patterns of basic maritime industries: the case of Dalian City, China. *Maritime Policy & Management,* *49*(5), 685–701. https://doi.org/10.1080/03088839.2021.1919775

Lubis, M. Z., & Anurogo, W. (2017). Identifikasi profil dasar laut menggunakan instrumen side scan sonar dengan metode beam pattern discrete-equi-spaced unshaded line array. *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, *10*(1), 87-96. https://doi.org/10.21107/jk.v10i1.2563

Nugraha, B., & Chodrijah, U. (2010). Komposisi hasil tangkapan dan daerah penangkapan kapal tuna longline di perairan Laut Banda. *Jurnal Penelitian Perikanan Indonesia*, *16*(4), 305-309. http://dx.doi.org/10.15578/jppi.16.4.2010.305-309

Pratama, T. A., & Susanto, B. F. (2024). Pengaruh Kepuasan Pelanggan Terhadap Pendapatan Usaha Fresya Jaya Laundry Di Kelurahan Tembilahan Hulu Kecamatan Tembilahan Hulu. *Jurnal Analisis Manajemen*, *10*(2), 160-172. https://doi.org/10.32520/jam.v10i2.3733

Przywara, R. (2017). Deindustrialization-opportunity or threat?. *Athens journal of business & economics*, *3*(4), 427-462. https://www.athensjournals.gr/business/2017-3-4-4-Przywara.pdf

Raji, I. D., Bender, E. M., Paullada, A., Denton, E., & Hanna, A. (2021). AI and the everything in the whole wide world benchmark. *arXiv preprint arXiv:2111.15366*. https://doi.org/10.48550/arXiv.2111.15366

Roh, J., Tokar, T., Swink, M., & Williams, B. (2022). Supply chain resilience to low-/high-impact disruptions: The influence of absorptive capacity. *The International Journal of Logistics Management*, *33*(1), 214-238. https://doi.org/10.1108/IJLM-12-2020-0497

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International journal of production research*, *57*(7), 2117-2135. https://doi.org/10.1080/00207543.2018.1533261

Stiglitz, J. E. (2017). *The revolution of information economics: The past and the future* (No. w23780). National Bureau of Economic Research.

Tual Archipelago Fisheries Port. (2025). *Produksi dan Nilai Ikan Menurut Jenis di Pelabuhan Perikanan Nusantara Tual Triwulan IV, 2024.* Tual: pelabuhan Perikanan Nusantara Tual. https://ppid.kkp.go.id/media/uploads/document_information_public/Laporan_Kinerja_2024_PPN_Tual_FIX.pdf

Tual City Fisheries Service. (2025). *Nilai Perikanan Menurut Kecamatan dan Subsektor di Kota Tual (ton), 2023 dan 2024.* Dinas Perikanan Kota Tual. https://dinasperikanankotatual.com/

Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management: An International Journal*, *24*(1), 62-84. https://doi.org/10.1108/SCM-03-2018-0148

Yang, Y. (2021). Suzhou's "Growth Machine": Tracking the Driving Force Behind a Fast Growing Chinese Urban Region. In *Chinese Urban Planning and Construction: From Historical Wisdom to Modern Miracles* (pp. 301-323). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-65562-4_14

Yusianto, R. (2010). Implementasi teknologi rfid dalam perencanaan dan pengendalian persediaan sistem distribusi barang. *Techno Science*, *4*(2), 554-560. https://publikasi.dinus.ac.id/semantik/article/view/383

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