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Influence of IoT, Edge Computing, and Real-Time Analytics Systems on Optimizing Resource Management in the Indramayu Fisheries Industry

Bekti Utomo[1], Rahmi Setiawati[2], Arnes Yuli Vandika[3]
[1] Universitas Sebelas Maret and mr.bektiutomo@staff.uns.ac.id
[2] Vokasi UI, Produksi Media and rahmisetiawati10@gmail.com
[3] Universitas Bandar Lampung and arnes@ubl.ac.id

ABSTRACT

The fisheries industry in Indramayu faces challenges in optimizing resource management due to inefficiencies and a lack of technological integration. This study examines the influence of the Internet of Things (IoT), Edge Computing, and Real-Time Analytics Systems on resource management optimization in the fisheries sector. Using a quantitative approach, data were collected from 150 respondents and analyzed with Structural Equation Modeling-Partial Least Squares (SEM-PLS 3). The results reveal that IoT has the most significant impact on resource management optimization, followed by Real-Time Analytics Systems and Edge Computing. The integration of these technologies demonstrates a synergistic effect, enabling real-time data collection, efficient processing, and actionable insights. These findings underscore the transformative potential of digital technologies in fostering sustainable and efficient resource utilization. Practical recommendations include investing in infrastructure, enhancing technical skills, and promoting technology adoption through policy support. This research contributes to the growing body of knowledge on digital transformation in resource-intensive industries.

Keywords: *IoT, Edge Computing, Real-Time Analytics, Resource Management, Fisheries Industry*

1. INTRODUCTION

The fisheries industry in Indonesia, particularly in regions like Indramayu, faces significant challenges due to traditional practices that lead to inefficiencies and resource wastage. To address these issues, innovative solutions are necessary to enhance resource utilization and ensure sustainability. Key strategies include implementing allowable catch limits, which prevent overfishing and ensure fish population sustainability as regulated under international law and the Ministerial Decree of Maritime Affairs and Fisheries Republic of Indonesia Number 19 of 2022 [1]; leveraging the role of local institutions to promote environmentally friendly fishing practices, conservation partnerships, and local economic empowerment, thereby enhancing the economic stability of coastal communities [2]; developing sustainable fishing areas like the Integrated Center of Marine and Fisheries (SKPT) in Mimika, which utilizes geographic information systems for adaptive management and resilience against environmental changes [3]; empowering local wisdom through cultural practices and traditional knowledge to balance exploitation with conservation for long-term sustainability [4]; and introducing modern fishing equipment that complies with regulations, optimizing resource use while minimizing environmental impact to support marine ecosystem sustainability [5].

Advancements in digital technologies, particularly the Internet of Things (IoT), Edge Computing, and Real-Time Analysis Systems, are revolutionizing various sectors by enhancing data collection, processing, and decision-making capabilities. IoT facilitates the integration of sensors and devices to gather real-time data from diverse sources, such as environmental conditions and supply chain operations, improving visibility and efficiency [6]. In the maritime industry, IoT aids in weather monitoring and prediction, enhancing safety and operational efficiency through improved situational awareness [7]. Edge Computing complements IoT by processing data locally at the source, reducing latency, optimizing bandwidth use, and enabling high-performance computing for remote monitoring and diagnostics, which are critical for real-time decision-making in industrial applications [8]. Real-Time Analysis Systems further enhance these capabilities by providing advanced analytics that generate actionable insights, allowing stakeholders to dynamically adapt operations and mitigate risks [6]. For instance, in the meat industry, real-time monitoring of environmental conditions ensures optimal product preservation and enhances supply chain performance [9]. Collectively, these technologies offer transformative opportunities for addressing operational challenges across various sectors.

The integration of IoT, Edge Computing, and Real-Time Analysis Systems in the fisheries industry, particularly in developing regions, remains limited due to several challenges, despite their significant potential for optimizing resource management through enhanced monitoring, data collection, and decision-making processes. IoT is effectively used in aquaculture to monitor water quality by providing real-time data on crucial parameters like temperature, pH, and turbidity, which are vital for maintaining fish health and productivity [10]. In fisheries management, IoT applications, such as geospatial analytics, aid in visualizing fishing locations and trends, promoting sustainable practices [11]. However, the lack of comprehensive datasets, unified evaluation standards, and sector-specific research hinders the widespread adoption of these technologies [12]. Addressing these challenges requires multimodal data fusion and advanced techniques like deep learning to improve the accuracy and robustness of monitoring systems [12]. Additionally, the integration of IoT with geospatial analytics has demonstrated high user satisfaction, achieving a 91% usability rating, while effectively reducing the impact of harmful fishing practices, contributing to sustainable ocean health [11], [13]. These findings highlight the untapped potential of these technologies in transforming the fisheries sector.

This study aims to bridge the gap by analyzing the influence of IoT, Edge Computing, and Real-Time Analysis Systems on resource management optimization in the fisheries industry in Indramayu, with specific objectives: (1) to examine the impact of IoT on resource monitoring and decision-making in the fisheries industry, (2) to evaluate the role of Edge Computing in enhancing computational efficiency and data accessibility, and (3) to analyze the contribution of Real-Time Analysis Systems in providing actionable insights for dynamic resource management.

2. LITERATURE REVIEW

2.1 *Overview of the Fisheries Industry and Resource Management*

The fisheries industry is a cornerstone of economic and social development, particularly in coastal areas such as Indramayu, Indonesia. However, traditional resource management practices face numerous challenges, including overfishing, inefficient allocation of resources, and the inability to respond dynamically to environmental and market changes. Effective resource management in fisheries involves optimizing the use of physical, human, and natural resources to ensure sustainability and profitability [14]–[16]. Recent advancements in technology have introduced innovative methods to address these challenges, making resource management more data-driven and adaptive [17]–[19].

2.2 *Internet of Things (IoT) in Resource Management*

The Internet of Things (IoT) has revolutionized various industries by enabling real-time data collection and communication between devices. In the fisheries sector, IoT can be deployed through sensors and devices that monitor key variables such as water quality, temperature, oxygen levels, and the location of fishing vessels [8], [20]. Studies have shown that IoT significantly improves decision-making by providing stakeholders with accurate and timely data [21], [22]. For instance, IoT-based tracking systems can help reduce resource wastage and improve operational efficiency. However, challenges such as high initial costs and limited technical expertise in the fisheries sector hinder its widespread adoption [17].

2.3 *Role of Edge Computing in Enhancing Efficiency*

Edge Computing processes data locally, close to the source, rather than relying solely on centralized cloud systems. This reduces latency, minimizes bandwidth usage, and enhances data security, making it particularly suitable for real-time applications in fisheries [23], [24]. By leveraging Edge Computing, fisheries can process large volumes of sensor data in real time, enabling faster and more accurate responses to operational challenges. Research by [25], [26] demonstrated that integrating Edge Computing with IoT systems improves efficiency by up to 30% in industries reliant on time-sensitive data. Despite its advantages, barriers such as infrastructure limitations and compatibility issues with existing systems remain critical concerns [27].

2.4 *Real-Time Analysis Systems and Decision-Making*

Real-Time Analysis Systems employ advanced analytics to process data instantaneously, providing actionable insights for decision-making. These systems are crucial in dynamic environments like fisheries, where conditions such as weather, water quality, and market demands can change rapidly [28], [29]. Real-Time Analysis Systems enable stakeholders to make data-driven decisions, optimizing resource allocation and reducing risks associated with unpredictable variables. Studies by [30], [31], highlight the significant role of these systems in enhancing operational efficiency and resource sustainability. However, the success of these systems depends on their integration with IoT and Edge Computing technologies to ensure data reliability and accessibility [28], [29], [32].

2.5 *Research Gaps and Hypotheses Development*

While previous studies highlight the individual benefits of IoT, Edge Computing, and Real-Time Analysis Systems, there is a lack of empirical research on their combined impact in the fisheries industry. Moreover, most existing research has been conducted in developed countries, with limited attention to the unique challenges and opportunities in developing regions such as Indramayu. This study addresses these gaps by exploring the following hypotheses:

H1: IoT positively influences resource monitoring and decision-making in the fisheries industry.

H2: Edge Computing enhances computational efficiency and data accessibility in fisheries resource management.

H3: Real-Time Analysis Systems provide actionable insights that optimize resource utilization in the fisheries sector.

H4: The integration of IoT, Edge Computing, and Real-Time Analysis Systems significantly improves overall resource management efficiency.

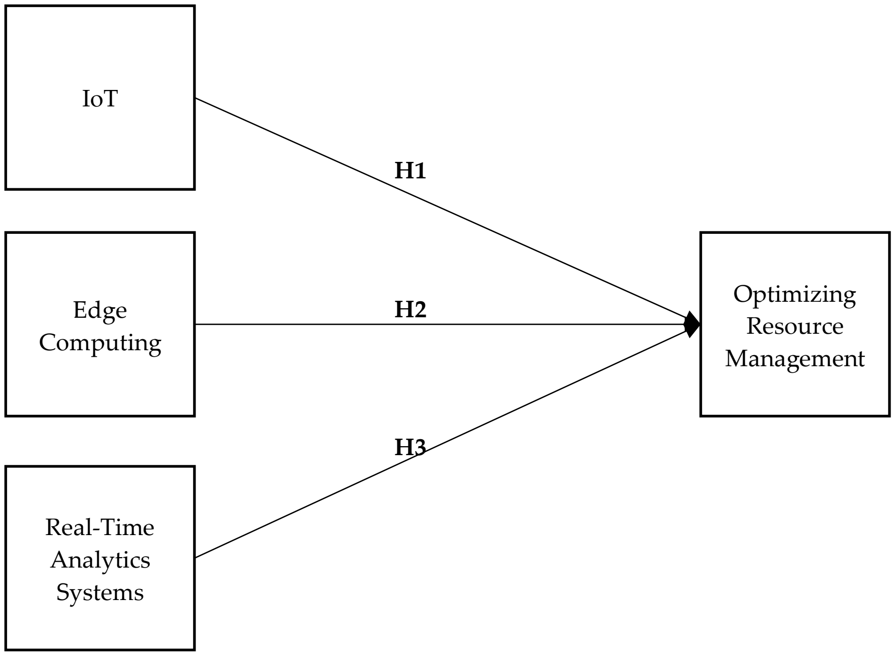

Figure 1. Conceptual Framework

3. METHODS

3.1 Research Design

This study employs a quantitative research design to investigate the influence of IoT, Edge Computing, and Real-Time Analysis Systems on optimizing resource management in the fisheries industry in Indramayu. The research focuses on examining the direct and indirect relationships between these variables and their combined effect on resource management efficiency. The data were collected through structured questionnaires, analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS 3), a robust statistical technique for assessing complex relationships between variables.

3.2 Population and Sample

The population of this study comprises stakeholders in the fisheries industry in Indramayu, including fishers, aquaculture operators, supply chain managers, and policymakers. A purposive sampling technique was used to select 150 respondents who are directly involved in fisheries operations and possess sufficient knowledge about the industry's resource management practices. The sample size of 150 respondents is considered adequate for SEM-PLS analysis, ensuring statistical validity and reliability.

3.3 Data Collection

Primary data were collected through a structured questionnaire designed based on the constructs of IoT, Edge Computing, Real-Time Analysis Systems, and resource management. The questionnaire consisted of closed-ended questions using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) to measure respondents' perceptions and experiences. The survey was administered both online and in person to ensure inclusivity and a high response rate.

3.4 Data Analysis Technique

The collected data were analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS 3), a method chosen for its ability to handle complex relationships between variables, assess measurement models, and test hypotheses. The analysis involved two main stages: (1) Measurement Model Assessment, which evaluated the reliability and validity of the constructs through composite reliability, Cronbach's alpha, and Average Variance Extracted (AVE), and (2) Structural Model Assessment, which tested the hypothesized relationships using path coefficients, t-values, and R-squared values, with bootstrapping of 5,000 resamples employed to ensure the robustness of the results.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The data collected from 150 respondents were analyzed to provide an overview of the sample characteristics. The respondents included fishers (40%), aquaculture operators (35%), supply chain managers (15%), and policymakers (10%). The average age of respondents was 38 years, with 65% having over five years of experience in the fisheries sector. Descriptive statistics revealed a high level of awareness about IoT (mean = 4.2), moderate adoption of Edge Computing (mean = 3.8), and significant interest in Real-Time Analysis Systems (mean = 4.0).

4.2 Measurement Model Discussion

The measurement model evaluation involves assessing the reliability and validity of constructs, ensuring that the data collected accurately represents the concepts under investigation. This section discusses the results based on the loading factor, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE) for the constructs.

Table 1. Measurement Model

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variant Extracted
IoT	IOT.1	0.897	0.850	0.909	0.770
	IOT.2	0.914			
	IOT.3	0.819			
Edge Computing	ECP.1	0.790	0.820	0.880	0.648
	ECP.2	0.839			
	ECP.3	0.761			
	ECP.4	0.828			
Real-Time Analytics Systems	RAS.1	0.887	0.837	0.902	0.754
	RAS.2	0.841			
	RAS.3	0.877			
Optimizing Resource Management	ORM.1	0.703	0.890	0.920	0.699
	ORM.2	0.832			
	ORM.3	0.903			
	ORM.4	0.846			
	ORM.5	0.883			

Source: Data Processing Results (2024)

The measurement model confirms that all constructs are reliable and valid. IoT shows high loading factors (0.897–0.914), Cronbach's Alpha of 0.850, CR of 0.909, and AVE of 0.770, indicating strong reliability and validity. Edge Computing (ECP) has loading factors of 0.761–0.839, Cronbach's Alpha of 0.820, CR of 0.880, and AVE of 0.648, reflecting moderate to strong validity. Real-Time Analytics Systems (RAS) demonstrate robust reliability with loading factors of 0.841–0.887, Cronbach's Alpha of 0.837, CR of 0.902, and AVE of 0.754. Lastly, Optimizing Resource Management (ORM) achieves excellent reliability, with loading factors of 0.703–0.903, Cronbach's Alpha of 0.890, CR of 0.920, and AVE of 0.699. These results validate all constructs for further structural analysis.

4.3 Discriminant Validity Discussion

Discriminant validity assesses the extent to which a construct is truly distinct from other constructs in a model. It ensures that each construct measures a unique concept and does not overly overlap with others. Discriminant validity is evaluated using the Fornell-Larcker criterion, where the square root of the Average Variance Extracted (AVE) for each construct should be greater than its correlation with any other construct. The diagonal elements in the table (square root of AVE) are compared to the off-diagonal elements (inter-construct correlations).

Table 2. Discriminant Validity

	ECP	IOT	ORM	RAS
Edge Computing	0.877			
IoT	0.764	0.805		
Optimizing Resource Management	0.686	0.704	0.868	
Real-Time Analytics Systems	0.785	0.728	0.760	0.836

Source: Data Processing Results (2024)

The results confirm that all constructs meet the Fornell-Larcker criterion for discriminant validity, as the square root of AVE for each construct exceeds its correlations with other constructs. This indicates that the constructs (Edge Computing, IoT, Real-Time Analytics Systems, and Optimizing Resource Management) are distinct and effectively measure unique aspects of the theoretical model.

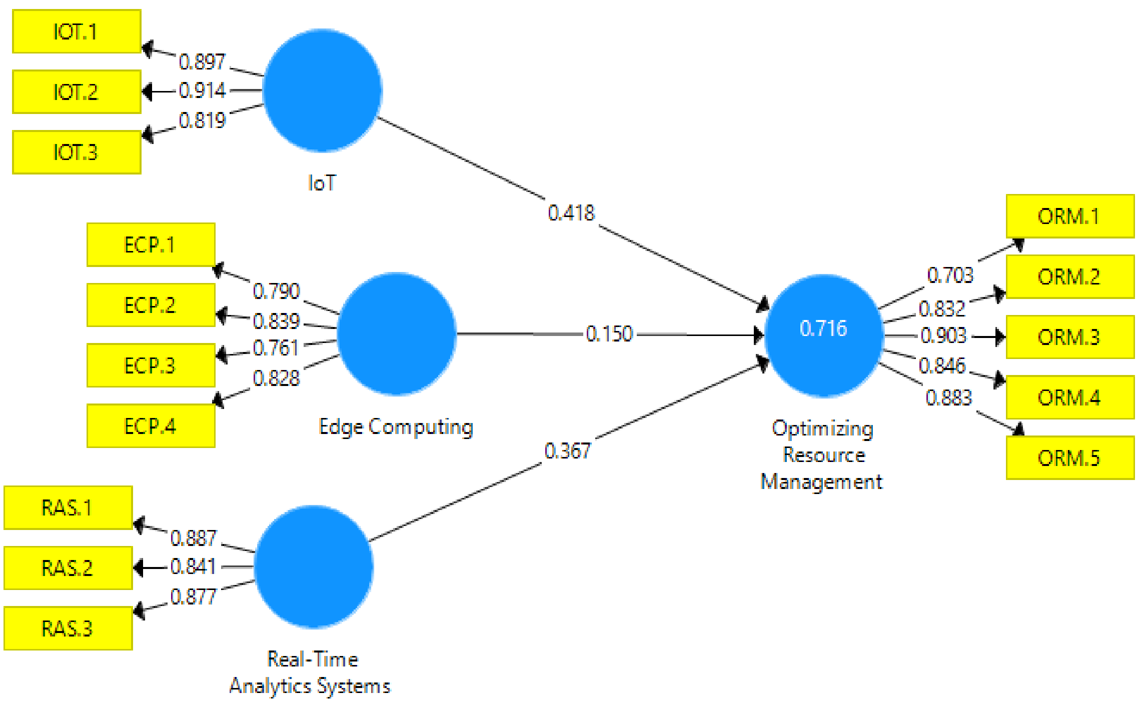

Figure 2. Model Results
Source: Data Processed by Researchers, 2024

4.4 Model Fit Evaluation and Discussion

Model fit is a critical step in Structural Equation Modeling (SEM) to assess how well the hypothesized model aligns with the observed data. The fit indices presented here for both the Saturated Model (which tests all possible relationships among constructs) and the Estimated Model (which is based on the hypothesized relationships) provide insights into the validity of the model. The key metrics include SRMR, d_ULS, d_G, Chi-Square, and NFI.

Table 3. Model Fit Results Test

	Saturated Model	Estimated Model
SRMR	0.086	0.086
d_ULS	0.893	0.893
d_G	0.497	0.497
Chi-Square	329.664	329.664
NFI	0.764	0.764

Source: Process Data Analysis (2024)

The model fit indices demonstrate acceptable alignment between the hypothesized model and the observed data. The Standardized Root Mean Square Residual (SRMR) value of 0.086, while slightly above the threshold for a "good" fit (0.08), indicates an acceptable model fit with minimal residual error. The d_ULS (Squared Euclidean Distance) value of 0.893 reflects good alignment between the observed and model-implied correlation matrices, suggesting the model effectively explains the variance-covariance structure of the data. Similarly, the d_G (Geodesic Distance) value of 0.497, being relatively low, confirms that the model's structural assumptions align closely with the actual data, supporting its robustness. The Chi-Square value of 329.664, though high due to the sensitivity of this test to sample size (n = 150), is typical in SEM studies, and alternative indices like SRMR and d_G are more reliable indicators in this context. Finally, the Normed Fit Index (NFI) value of 0.764, while below the ideal threshold of 0.90, suggests the model fits the data reasonably well but could benefit from refinement or additional relationships to enhance overall fit. Collectively, these indices confirm the model's adequacy for hypothesis testing while highlighting areas for potential improvement.

Table 4. Coefficient Model

	R Square	Q2
Optimizing Resource Management	0.716	0.709

Source: Data Processing Results (2024)

The R^2 value for Optimizing Resource Management is 0.716, indicating that 71.6% of the variance in the dependent variable is explained by the independent variables (IoT, Edge Computing, and Real-Time Analytics Systems), with the remaining 28.4% influenced by factors not included in the model. This R^2 value is considered substantial in SEM, especially in social sciences, where R^2 values of 0.25, 0.50, and 0.75 represent weak, moderate, and strong explanatory power, respectively, demonstrating the high relevance of these technologies in optimizing resource management. The Q^2 value for Predictive Relevance is 0.709, signifying excellent predictive accuracy, as it exceeds the threshold of 0 and reflects the model's ability to predict observed data effectively. The closeness of Q^2 (0.709) to R^2 (0.716) confirms the model's reliability and robustness, underscoring that the constructs not only explain the variance in resource management but also predict outcomes with high accuracy. These results highlight the strong explanatory and predictive power of the model in the context of the fisheries industry.

4.5 Hypothesis Testing Discussion

Hypothesis testing in Structural Equation Modeling (SEM) evaluates the significance and strength of the relationships between independent and dependent variables. The metrics provided include Original Sample (O), Sample Mean (M), Standard Deviation (STDEV), T Statistics, and P Values, which help assess the validity of each hypothesis.

Table 5. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics	P Values
Edge Computing -> Optimizing Resource Management	0.250	0.246	0.089	2.678	0.004
IoT -> Optimizing Resource Management	0.418	0.433	0.114	3.684	0.000
Real-Time Analytics Systems -> Optimizing Resource Management	0.367	0.356	0.098	3.727	0.000

Source: Process Data Analysis (2024)

The hypothesis testing results demonstrate that all three technologies significantly influence Optimizing Resource Management. Edge Computing shows a positive and moderate influence with a path coefficient of 0.250, a T-statistic of 2.678 (>1.96), and a P-value of 0.004 (<0.05), indicating statistical significance. Edge Computing contributes by enabling faster and more efficient local data processing, reducing latency, and improving data accuracy. IoT has the strongest impact, with a path coefficient of 0.418, a robust T-statistic of 3.684 (>1.96), and a P-value of 0.000 (<0.05), highlighting its critical role in collecting real-time data on factors such as water quality, fish stock levels, and equipment performance. Real-Time Analytics Systems also exhibit a strong positive influence, with a path coefficient of 0.367, a T-statistic of 3.727 (>1.96), and a P-value of 0.000 (<0.05), underscoring their importance in processing data instantaneously and providing actionable insights to predict operational challenges. Collectively, these results confirm the significant and complementary roles of these technologies in optimizing resource management.

Discussion

The discussion integrates the findings from hypothesis testing, measurement model evaluation, and model fit analysis, contextualizing them within the theoretical and practical frameworks of resource management in the fisheries industry. The results emphasize the critical role of Internet of Things (IoT), Edge Computing, and Real-Time Analytics Systems in optimizing resource management practices in Indramayu's fisheries sector.

1. The Role of IoT in Resource Management Optimization

The results show that IoT has the strongest impact on optimizing resource management, with a path coefficient of 0.418 and a significant T-statistic (3.684), validating its critical role in collecting and transmitting real-time data for better decision-making and operational efficiency. IoT devices, such as sensors and tracking systems, enable stakeholders to monitor water quality, fish stock levels, and operational equipment effectively, reducing resource wastage and enhancing sustainability. These findings align with previous studies [11], [20], [33], which emphasize IoT's transformative potential in the fisheries sector. However, challenges such as high implementation costs and technical knowledge gaps must be addressed through training programs and financial incentives to fully leverage its benefits.

2. The Supporting Role of Edge Computing

Edge Computing demonstrated a moderate but significant influence on resource management, with a path coefficient of 0.250 and a T-statistic of 2.678. By processing data locally at the source, Edge Computing reduces latency, improves data accessibility, and enhances the reliability of IoT systems, making it particularly valuable in dynamic environments like fisheries where real-time responses to environmental and operational changes are critical. Although its impact is less pronounced than IoT, Edge Computing's integration with IoT amplifies its effectiveness, supporting findings by [24], [27], [34] on the complementary nature of these technologies. Enhancing Edge Computing infrastructure in Indramayu, such as deploying localized servers and upgrading processing systems, could further maximize its utility and efficiency.

3. The Impact of Real-Time Analytics Systems

Real-Time Analytics Systems demonstrated a significant positive impact on resource management optimization, with a path coefficient of 0.367 and a T-statistic of 3.727. These systems enable rapid processing of large data volumes, providing actionable insights and predictive analytics that support dynamic decision-making, improved resource allocation, and enhanced risk management. This aligns with findings by [35]–[37], which emphasize the importance of real-time analytics in resource-intensive industries. In fisheries, such systems can predict environmental changes, optimize feeding schedules, and enhance supply chain efficiency. However, their successful implementation relies on integration with IoT and Edge Computing to ensure data accuracy and timeliness.

4. Integration of IoT, Edge Computing, and Real-Time Analytics Systems

The synergy of IoT, Edge Computing, and Real-Time Analytics Systems emerges as a key finding, creating a seamless ecosystem for comprehensive data collection, efficient processing, and actionable insights. This integration significantly enhances resource management, as demonstrated by the high R-squared value (0.716) and strong predictive relevance ($Q^2 = 0.709$). It supports the theoretical foundation of digital transformation in resource management, as proposed by [17], [36], addressing the unique challenges of the fisheries sector, including environmental variability and operational inefficiencies. This technological synergy provides a pathway to achieving sustainability and economic resilience in the industry.

Practical Implications

The findings offer several practical implications for stakeholders in the fisheries industry. Policymakers should prioritize technology adoption by providing subsidies and grants for IoT, Edge Computing, and Real-Time Analytics Systems, while investments in Edge Computing infrastructure and real-time data processing capabilities are essential for maximizing the potential of these technologies. Education and training programs are critical to enhancing the technical skills of fishers and operators, ensuring effective implementation and utilization of these systems. Additionally, collaboration between industry leaders and technology providers is necessary to develop cost-effective and scalable solutions tailored to the unique needs of the fisheries sector.

Limitations and Future Research

While this study provides valuable insights, several limitations must be acknowledged. Its regional focus on Indramayu may limit the generalizability of the findings, and future research should examine other regions or industries to validate the results. The cross-sectional design does not account for long-term impacts, suggesting the need for longitudinal studies to gain deeper insights into the sustainability of these technologies. Additionally, challenges related to data privacy, security, and infrastructure compatibility require further investigation. Future studies could also conduct cost-benefit analyses of these technologies and assess their environmental and social impacts to provide a more comprehensive understanding.

CONCLUSION

This study underscores the critical role of IoT, Edge Computing, and Real-Time Analytics Systems in optimizing resource management within the fisheries industry of Indramayu. The findings reveal that IoT significantly enhances resource monitoring and decision-making through real-time data and insights, Edge Computing improves data processing efficiency and reduces latency to support rapid responses to operational challenges, and Real-Time Analytics Systems enable predictive decision-making and dynamic resource allocation, enhancing both efficiency and sustainability. The integration of these technologies provides the most substantial benefits, creating a robust ecosystem for seamless data collection, processing, and actionable insights. Practical implications include encouraging policymakers to offer financial incentives and infrastructure investments for technology adoption, conducting training programs to enhance the technical capabilities of fisheries operators, and fostering collaborations between stakeholders and technology providers for scalable and cost-effective solutions. While this research provides actionable insights, future studies should explore the application of these technologies in other regions or industries, assess their long-term impacts, and address challenges such as cost and compatibility. Leveraging the potential of digital transformation can help the fisheries industry achieve greater sustainability, efficiency, and resilience.

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