West Science Interdisciplinary Studies
Vol. 03, No. 03, March and 2025: pp. 455-462

Revolutionizing Supply Chain Management: Internet of Things (IoT) and Machine Learning on Logistics Transparency and Efficiency in the Retail Industry in Indonesia

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ABSTRACT

The integration of Internet of Things (IoT) and Machine Learning (ML) technologies is transforming supply chain management, particularly in the retail industry. This study examines the impact of IoT implementation and ML application on logistics transparency and operational efficiency in Indonesia's retail sector. Using a quantitative research approach, data were collected from 115 professionals and analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS). The findings reveal that IoT and ML significantly enhance logistics transparency, which, in turn, positively influences operational efficiency. This study highlights the mediating role of logistics transparency and underscores the importance of leveraging digital technologies for improving supply chain performance. These findings provide actionable insights for stakeholders aiming to optimize their logistics operations in dynamic and competitive markets.

Keywords: *Internet of Things (IoT), Machine Learning (ML), Logistics Transparency, Operational Efficiency, Retail Supply Chain.*

1. INTRODUCTION

Technology is transforming supply chain management in Indonesia's retail sector to meet consumer demands for speed, availability, and transparency. The integration of IoT and ML enhances operations by enabling real-time tracking, predictive analytics, and improved efficiency. IoT reduces lead times by 23%, improving responsiveness [1], [2]. AI-driven tools increase demand forecasting accuracy by 37%, minimizing stockouts and excess inventory [2], [3]. ML enhances resilience through predictive analytics [3]. Big Data analytics optimize inventory and boost customer retention by 28% [1], [2]. Ethical and sustainable practices strengthen brand trust and corporate responsibility, with green logistics reducing environmental impact [4], [5].

The integration of IoT and machine learning (ML) in supply chain management enhances operational visibility and decision-making. IoT enables real-time monitoring of inventory, transportation, and delivery conditions, ensuring end-to-end visibility [1], [6]. It also optimizes logistics by improving routes, reducing risks, and enhancing asset utilization [6], while predictive maintenance and automated notifications help prevent disruptions [6]. Meanwhile, ML strengthens predictive analytics for demand forecasting, inventory management, and transportation planning [7]. By processing large datasets, ML provides actionable insights for proactive decision-making and operational efficiency [1], [8]. Additionally, AI-driven ML enables autonomous responses to dynamic challenges, reducing downtime and enhancing performance [7].

The adoption of IoT and Machine Learning (ML) in Indonesia's retail industry offers significant potential to address challenges related to geographic diversity, fragmented logistics, and varying consumer demands. These technologies enhance supply chain processes, improving operational efficiency and competitiveness through real-time monitoring, data-driven decision-making, and personalized consumer experiences, which are crucial in Indonesia's complex retail environment. IoT-based logistics systems provide real-time tracking of goods using GPS and sensors to monitor conditions like temperature and humidity, which is especially important for perishable goods [9]. Additionally, by automating logistics processes, IoT reduces manual intervention, speeds up decision-making, and minimizes human error, thereby improving service quality and customer satisfaction [9]. Meanwhile, ML techniques such as Market Basket Analysis, using the Apriori algorithm, help retailers understand consumer purchasing behavior, enabling targeted product bundling and personalized marketing strategies [10]. These insights allow retailers to tailor their offerings to diverse consumer personas, enhancing the shopping experience and potentially increasing sales [10]. Furthermore, integrating logistics networks with IoT and ML helps address infrastructural and regulatory challenges in Indonesia, leading to cost reductions and improved customer satisfaction, although initial implementation costs and technological barriers remain key considerations [11]. However, barriers such as infrastructure limitations, data management challenges, and the need for specialized expertise hinder widespread adoption. This study explores the impact of IoT and ML on logistics transparency and supply chain efficiency in Indonesia's retail sector.

2. LITERATURE REVIEW

2.1 Internet of Things (IoT) in Supply Chain Management

The integration of IoT in supply chain management enhances real-time tracking, inventory monitoring, and logistics optimization through sensors and GPS, improving transparency and efficiency. It enables businesses to monitor environmental conditions, ensuring product quality and proactive logistics management. However, challenges such as high implementation costs, data security concerns, and technological limitations, particularly in developing countries, hinder adoption. IoT devices enhance logistics visibility by tracking goods' location and condition [9], [12]. They also optimize routes, reduce risks, and improve efficiency through predictive maintenance and automated notifications, leading to cost savings [6]. Additionally, IoT-generated data supports better decision-making in demand forecasting, inventory optimization, and risk mitigation [1]. Yet, high costs pose barriers, especially for small businesses in regions like Nigeria and Indonesia [13], while data security and infrastructure limitations further challenge implementation [6], [13]

2.2 Machine Learning (ML) and Predictive Analytics

Machine learning (ML) transforms supply chain management by improving decision-making accuracy, reducing risks, and enhancing efficiency. By analyzing large datasets, ML applications such as demand forecasting and fraud detection benefit various sectors, including retail. However, challenges like data quality and the need for skilled personnel must be addressed. ML models, particularly regression and time series algorithms, enhance forecasting accuracy, optimize inventory, and reduce holding costs [14], [15]. These models also provide region-specific demand insights for customized fulfillment and logistics automation [15]. AI and ML techniques, including classifiers, effectively detect fraud by identifying hidden patterns [16], while neural networks and genetic algorithms mitigate risks from demand volatility and supply uncertainties [17]. ML-driven analytics enable proactive decision-making, optimizing resources and improving efficiency [18]. Additionally, integrating AI with optimization solvers enhances real-time conflict resolution, balancing cost reduction with service level maximization [17].

2.3 Logistics Transparency

Logistics transparency is a critical component of modern supply chain management, significantly enhanced by digital technologies such as IoT and machine learning (ML). These technologies facilitate real-time monitoring and data analysis, improving visibility, accountability, and operational efficiency. IoT devices enable real-time tracking of goods, providing stakeholders with up-to-date information on product location and condition throughout the supply chain. Sensors monitor critical variables like tempera [19], [20]ture and humidity, essential for industries such as food and pharmaceuticals [20], while IoT integration helps identify bottlenecks and inefficiencies, allowing for timely interventions and improved transparency [19]. Meanwhile, ML algorithms analyze vast datasets generated by IoT devices, offering predictive insights and prescriptive suggestions to optimize supply chain processes [21]. These algorithms help anticipate demand variations, optimize inventory, and mitigate risks, enhancing supply chain resilience [20]. ML is also instrumental in verifying product authenticity and predicting disruptions, as seen in companies like Walmart and Nestlé [21]. Additionally, blockchain technology ensures supply chain transparency through an immutable, decentralized ledger, enhancing traceability and compliance [20], [22]. The integration of AI and blockchain further strengthens predictive analytics, operational efficiency, and fraud reduction, reinforcing regulatory compliance and stakeholder trust [22].

2.4 Operational Efficiency in Supply Chain Management

The integration of IoT and ML technologies in Indonesia's retail industry enhances operational efficiency by addressing fragmented logistics networks and geographic complexities. IoT facilitates automation, reducing manual interventions, while ML optimizes processes through predictive modeling and algorithms, leading to improved delivery speed, cost savings, and customer satisfaction. IoT enables real-time tracking and monitoring of goods, enhancing transparency and minimizing supply chain delays [23]. Additionally, automation through IoT reduces manual errors, increasing operational speed and cost efficiency [23]. Meanwhile, ML models enhance demand forecasting by analyzing historical data, ensuring optimal inventory levels and reduced holding costs [15]. These models also identify efficient delivery routes, minimizing fuel consumption and delivery times [24]. Case studies show that businesses adopting AI-based solutions, including ML, report a 20% reduction in operational costs and improved decision-making [25]. Furthermore, AI and ML technologies optimize demand planning, inventory management, and logistics, leading to more accurate forecasts and reduced losses [15].

2.5 Theoretical Framework

This study is grounded in the Resource-Based View (RBV) theory, which emphasizes the strategic value of organizational resources, including technological capabilities, in achieving competitive advantage (Barney, 1991). IoT and ML are considered strategic resources that enhance logistics transparency and operational efficiency, thereby driving superior performance. The study also incorporates elements of the Dynamic Capabilities Theory, which focuses on an organization's ability to adapt to rapidly changing environments through technological innovation (Teece et al., 1997).

2.6 Research Gap and Contribution

While existing literature extensively discusses the benefits of IoT and ML in supply chain management, limited studies focus on their application in Indonesia's retail sector. Furthermore, research addressing the combined impact of these technologies on logistics transparency and efficiency remains scarce. This study aims to fill this gap by providing empirical evidence on the role of IoT and ML in transforming supply chain practices in the Indonesian retail industry.

3. METHODS

3.1 Research Design

The study adopts a causal research design to examine the relationships between IoT implementation, ML application, logistics transparency, and operational efficiency. By focusing on these constructs, the study aims to provide empirical evidence on how IoT and ML contribute to the enhancement of supply chain management in the Indonesian retail sector.

3.2 Population and Sample

The target population for this study comprises professionals involved in supply chain management within retail companies in Indonesia. This includes supply chain managers, logistics personnel, and IT professionals.

A purposive sampling technique was employed to ensure that participants possess relevant knowledge and experience with IoT and ML technologies in supply chain operations. A total of 115 respondents were selected to participate in the study. The sample size is considered adequate for Structural Equation Modeling-Partial Least Squares (SEM-PLS) analysis, which requires a minimum of 10 times the number of indicators in the most complex construct (Hair et al., 2017).

3.3 Data Collection

Data were collected through a structured questionnaire distributed electronically to the selected respondents. The questionnaire was designed to capture the respondents' perceptions of IoT implementation, ML application, logistics transparency, and operational efficiency.

Each construct was measured using multiple indicators adapted from validated scales in previous studies. Responses were recorded on a five-point Likert scale, ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The questionnaire was pre-tested with a small group of respondents to ensure clarity and reliability before full distribution.

3.4 Data Analysis

Data analysis was conducted using Structural Equation Modeling-Partial Least Squares (SEM-PLS) with SmartPLS 3, a method suitable for exploratory research with small to medium sample sizes and capable of handling complex models with multiple constructs (Ringle et al., 2015). The analysis followed a two-step approach: first, the measurement model assessment evaluated construct reliability using Cronbach's alpha and composite reliability (CR), while validity was examined through average variance extracted (AVE) and discriminant validity. Second, the structural model assessment tested hypothesized relationships between constructs by analyzing path coefficients, t-statistics, and p-values. A bootstrapping procedure with 5,000 resamples was employed to assess result robustness.

4. RESULTS AND DISCUSSION

4.1 Demographic Sample

The demographic characteristics of the respondents provide critical context for understanding the study's findings. The sample comprised 115 professionals working in supply chain management roles within Indonesia's retail sector. In terms of gender distribution, 70 respondents were male (60.9%), and 45 were female (39.1%), indicating a male-dominated workforce. Age distribution showed that 50 participants (43.5%) were aged 20-30 years, 40 (34.8%) were 31-40 years, 20 (17.4%) were 41-50 years, and 5 (4.3%) were above 50 years, suggesting a relatively young and dynamic workforce. Regarding educational background, 85 respondents (73.9%) held a bachelor's degree, 25 (21.7%) had a master's degree, and 5 (4.3%) possessed a diploma or equivalent, indicating a well-educated workforce equipped to manage advanced technologies like IoT and ML. Job roles were distributed among logistics managers (34.8%), supply chain analysts (30.4%), warehouse supervisors (21.7%), and others, such as IT specialists (13.0%). In terms of experience, 45 respondents (39.1%) had 1-5 years of experience, 40 (34.8%) had 6-10 years, and 30 (26.1%) had more than 10 years, with a majority having over five years of experience (60.9%). Organizational size varied, with 25 respondents (21.7%) from small enterprises (less than 50 employees), 50 (43.5%) from medium enterprises (50-250 employees), and 40 (34.8%) from large enterprises (more than 250 employees), ensuring diverse perspectives on IoT and ML adoption.

4.2 Descriptive Statistics

The sample comprised 115 respondents, predominantly professionals in supply chain and logistics roles within the Indonesian retail sector. The respondents rated their experiences with IoT and ML technologies using a five-point Likert scale. Descriptive statistics indicated a high level of agreement regarding the perceived benefits of IoT and ML in enhancing logistics transparency and operational efficiency, with mean scores for key variables ranging between 3.8 and 4.5.

4.3 Measurement Model Assessment

The measurement model was evaluated for reliability and validity, ensuring robustness in the analysis. Reliability was confirmed as Cronbach's alpha and composite reliability (CR) values exceeded the 0.70 threshold for all constructs, indicating high internal consistency. Convergent validity was established with average variance extracted (AVE) values above the recommended 0.50 threshold, confirming that the indicators adequately represented their respective constructs. Additionally, discriminant validity was verified using the Fornell-Larcker criterion, ensuring that each construct was distinct from the others.

4.4 Structural Model Assessment

The structural model was assessed to test the hypothesized relationships between constructs. Path coefficients, t-statistics, and p-values were calculated, and the results are summarized in Table 1.

Hypothesis	Path Coefficient	t-Statistic	p-Value	Result
IoT → Logistics Transparency	0.424	5.212	<0.001	Supported
ML → Logistics Transparency	0.386	4.786	<0.001	Supported
Logistics Transparency → Operational Efficiency	0.501	6.123	<0.001	Supported

The results indicate that IoT and ML significantly enhance logistics transparency, which, in turn, positively impacts operational efficiency. The hypothesis testing results confirm strong relationships among IoT, machine learning (ML), logistics transparency, and operational efficiency in supply chain management. IoT significantly enhances logistics transparency (path coefficient: 0.424, t-statistic: 5.212, p-value: <0.001) by enabling real-time tracking, automated data collection, and improved visibility. Similarly, ML improves logistics transparency (path coefficient: 0.386, t-statistic: 4.786, p-value: <0.001) by processing data, identifying patterns, and optimizing decision-making. The strongest relationship is between logistics transparency and operational efficiency (path coefficient: 0.501, t-statistic: 6.123, p-value: <0.001), demonstrating that greater transparency reduces delays, optimizes resource allocation, and minimizes risks. These findings reinforce the crucial role of IoT and ML in modern supply chain management.

Discussion

The findings confirm that IoT implementation significantly enhances logistics transparency in the Indonesian retail industry. This aligns with previous studies (Kumar et al., 2020; Shi & Li, 2021), which highlighted IoT's ability to provide real-time tracking, improve data accuracy, and facilitate seamless communication across supply chain nodes. In the context of Indonesia, IoT adoption addresses critical challenges such as fragmented logistics networks and delays, enabling stakeholders to gain greater visibility into supply chain operations.

The positive relationship between ML and logistics transparency underscores the value of predictive analytics and anomaly detection in modern supply chain management. ML's ability to process vast datasets and generate actionable insights helps organizations anticipate disruptions and optimize resource allocation (Tan et al., 2020). For Indonesia's retail sector, where demand fluctuations and infrastructure limitations are common, ML applications are particularly valuable for maintaining transparency and efficiency.

The study highlights the mediating role of logistics transparency in the relationship between IoT, ML, and operational efficiency. Enhanced transparency reduces information asymmetry, fosters collaboration among stakeholders, and minimizes delays, ultimately leading to improved operational outcomes. This finding aligns with Gupta et al. (2021), who emphasized transparency as a critical enabler of supply chain performance.

Operational efficiency, as measured by cost reduction, timely deliveries, and resource utilization, was significantly influenced by logistics transparency. IoT and ML serve as enablers by automating routine tasks, optimizing routes, and improving inventory management. These findings corroborate previous research (Reddy et al., 2020) and demonstrate the transformative potential of digital technologies in addressing inefficiencies in Indonesia's retail supply chains.

Practical and Theoretical Contributions

This study contributes to both theory and practice by providing empirical evidence on the combined impact of IoT and ML on logistics transparency and operational efficiency in a developing country context. The integration of Resource-Based View (RBV) and Dynamic Capabilities theories enriches our understanding of how organizations leverage technological resources to adapt to dynamic market environments and achieve competitive advantage.

Limitations and Future Research

While the study provides valuable insights, certain limitations should be acknowledged. The relatively small sample size may limit the generalizability of the findings, and the reliance on self-reported data introduces the possibility of response bias. Future research could explore the long-term impacts of IoT and ML adoption, incorporate larger sample sizes, and examine additional variables, such as organizational culture and regulatory factors, that influence supply chain performance.

CONCLUSION

This study demonstrates the significant impact of IoT and ML on logistics transparency and operational efficiency in Indonesia's retail industry. The results confirm that IoT enhances logistics transparency by enabling real-time data tracking and seamless communication across supply chain nodes, while ML improves transparency through predictive analytics and anomaly detection, facilitating better decision-making. Logistics transparency acts as a critical mediator, linking IoT and ML to greater operational efficiency, reflected in cost reduction, timely deliveries, and optimal resource utilization. These findings highlight the transformative potential of digital technologies in addressing supply chain challenges, emphasizing that investing in IoT and ML is crucial for stakeholders seeking a competitive advantage in Indonesia's dynamic retail market. Future research could expand on these insights by incorporating additional variables, larger sample sizes, and diverse industry contexts to further validate and extend the findings

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