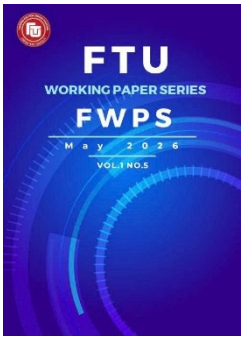

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ỨNG DỤNG CÔNG NGHỆ NHẬN DẠNG BẰNG TẦN SỐ VÔ TUYẾN (RFID) TRONG QUẢN LÝ KHO THÔNG MINH: NGHIÊN CỨU TRƯỜNG HỢP CỦA MẠNG LƯỚI CAINIAO VÀ KHUYẾN NGHỊ CHÍNH SÁCH CHO CÁC DOANH NGHIỆP LOGISTICS TẠI VIỆT NAM

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Tóm tắt

Sự phát triển của thương mại điện tử đã thúc đẩy chuyển đổi từ kho truyền thống sang hệ thống logistics thông minh dựa trên công nghệ số. Trong đó, công nghệ nhận dạng bằng tần số vô tuyến (RFID) cho phép theo dõi tồn kho theo thời gian thực, tự động hóa thu thập dữ liệu và nâng cao độ chính xác vận hành. Tuy đã chứng minh hiệu quả trong các mạng lưới logistics lớn trên thế giới, việc ứng dụng RFID tại Việt Nam vẫn còn hạn cế, đặc biệt với doanh nghiệp nhỏ và vừa (SMEs). Điều này dẫn đến chi phí logistics cao, vận hành kém hiệu quả và thiếu minh bạch chuỗi cung ứng. Nghiên cứu phân tích vai trò của RFID trong quản lý kho thông minh qua trường hợp Mạng lưới Logistics Thông minh Cainiao, đồng thời đánh giá hàm ý cho doanh nghiệp logistics Việt Nam. Kết quả cho thấy việc triển khai RFID theo lộ trình và chi phí hợp lý vẫn có thể nâng

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cao hiệu quả vận hành và năng lực cạnh tranh dài hạn.

Từ khóa: RFID, kho thông minh, logistics, Cainiao, Việt Nam

APPLICATION OF RFID TECHNOLOGY IN SMART WAREHOUSE MANAGEMENT: A CASE STUDY OF CAINIAO NETWORK AND RECOMMENDATIONS FOR VIETNAMESE LOGISTICS ENTERPRISES

Abstract

The rapid growth of e-commerce has accelerated the shift from traditional warehouses to smart logistics systems supported by digital technologies. In this context, Radio Frequency Identification (RFID) plays an important role in enabling real-time inventory visibility, automating data capture, and improving operational accuracy. Although RFID has proven effective in large-scale global logistics networks, its adoption in Vietnam remains limited, particularly among small and medium-sized enterprises (SMEs). This gap leads to operational inefficiencies, high logistics costs, and limited supply chain transparency. This paper analyzes the role of RFID technology in smart warehouse management through a case study of the Cainiao Smart Logistics Network (Cainiao Network) and evaluates its implications for Vietnamese logistics enterprises. The findings suggest that although fully automated models may exceed the financial capacity of many domestic SMEs, adopting RFID through a gradual and cost-effective approach can still significantly improve operational efficiency and strengthen long-term competitiveness.

Keywords: RFID, smart warehouse, logistics, Cainiao, Vietnam

1. Introduction

The rapid growth of e-commerce has significantly reshaped the global supply chain. To meet the increasing demands for fast and accurate order fulfillment, the logistics industry is shifting from manual operations to "smart warehousing." At the center of this digital transformation is Radio Frequency Identification (RFID) technology. Unlike traditional methods, RFID provides real-time inventory visibility, acting as a crucial bridge between physical goods and Information Technology systems to automate warehouse workflows.

Despite this global trend, many logistics enterprises, especially in emerging markets like Vietnam, still rely on conventional barcode systems. These manual tracking methods require line-of-sight scanning, which is time-consuming and prone to human error. As order volumes scale up, these inefficiencies create operational challenges, leading to stock discrepancies, shipping delays,

and increased labor costs. Without real-time data, warehouse managers struggle to optimize storage space and streamline the fulfillment process.

To understand the practical value of RFID, it is highly beneficial to analyze industry leaders who have successfully digitalized their logistics networks. Cainiao Network, the logistics arm of Alibaba Group, serves as a prime example of smart warehouse management. Their model provides a valuable benchmark for operational excellence.

The primary objectives of this paper are:

1. To outline the theoretical framework of RFID technology in smart warehouse management.
2. To analyze the real-world applications and operational benefits of RFID through the Cainiao Network case study.
3. To evaluate the current technological readiness of the logistics sector in Vietnam.
4. To propose actionable recommendations for Vietnamese logistics enterprises to adopt RFID systems and improve their warehouse efficiency.

2. Literature Review and Theoretical Framework

2.1 Literature Review on RFID Technology in Warehousing

2.1.1. Overview and Core Components

Radio Frequency Identification (RFID) is an automatic identification and data capture (AIDC) technology that uses radio waves to wirelessly identify, track, and manage objects (Hu & Yang, 2023). Academic literature broadly recognizes RFID as a vital improvement over conventional, paper-based barcode systems, primarily because it does not require a direct line of sight and can read multiple items simultaneously. An effective RFID system in a warehouse environment is generally comprised of four essential components (Hu & Yang, 2023):

1. **RFID Tags (Transponders):** Attached to goods or pallets, containing a microchip that stores unique identifying data and an antenna to transmit it. These are categorized into passive tags (powered by the reader's signal for item-level tracking) and active tags (used for high-value assets).

2. **RFID Readers (Interrogators):** Devices that emit radio frequency signals to activate the tags and capture their data.
3. **Antennas:** Used by readers to emit radio waves and receive signals back from the tags.
4. **Middleware:** The software interface that filters, processes, and routes the raw data collected by the readers to the central Warehouse Management System (WMS).

2.1.2. Applications in Smart Warehousing

In a warehouse, strategically placed RFID readers (either fixed, wearable or handheld) detect and process inventory as it moves throughout the space. The readers emit radio waves that activate the tags, prompting them to transmit their stored data back. This information is instantly updated on the warehouse management software being used, enabling the warehouse manager to track stock movement and maintain accurate inventory records to the second (Hayes, 2025).

The transition from traditional to "smart" warehousing relies heavily on the integration of the Internet of Things (IoT), with RFID acting as a foundational sensor technology (Zhen & Li, 2021). Research highlights several core applications within warehouse operations:

1. **Inbound and Outbound Logistics:** Automated RFID gates at dock doors can instantly register the receipt or dispatch of entire pallets without manual scanning. This dramatically reduces bottlenecks during loading and unloading.
2. **Real-Time Inventory and Location Tracking:** RFID allows for continuous, real-time visibility of stock levels and exact locations within the facility. This supports dynamic slotting and minimizes the time workers spend searching for misplaced items.
3. **Asset Management:** Beyond tracking inventory, RFID is extensively used to track returnable transport items (RTIs) like pallets and totes, as well as material handling equipment (e.g., forklifts and automated guided vehicles), ensuring optimal asset utilization.

2.1.3. The Role of RFID within the Smart Ecosystem

Within the smart warehouse conceptual framework, RFID technology serves as the critical enabler for the entire IT and logistics ecosystem. While AI provides the analytical intelligence and robotics provides the physical muscle, RFID supplies the raw, accurate, and real-time data necessary for these systems to execute their tasks. By providing continuous and automated visibility of goods flowing in, out, and within the facility, RFID acts as the essential bridge

between the physical inventory and the digital warehouse management system (Anderson et al., 2026).

2.2 Theoretical Framework: TOE Model

The Technology-Organization-Environment (TOE) framework, introduced by Tornatzky and Fleischer, is a widely applied analytical framework for examining the conditions under which organisations adopt new technologies (Tornatzky and Fleischer, 1990). It suggests that successfully upgrading to a smart warehouse depends on three main factors: the technology itself, the organisation's internal structure and resource capacity, and the external competitive and regulatory pressures of the operating environment. Within the analytical scope of this paper, the TOE framework serves to explain the differential adoption trajectories of RFID technology among logistics providers, particularly why some firms successfully modernise their operations while others remain constrained by conventional manual systems.

First, the technological context concerns the relative advantage and compatibility of RFID within existing operational systems. RFID enables rapid, line-of-sight-free batch identification, accelerating receiving and dispatch operations. Real-time visibility supports accurate safety stock management and reduces the risk of lost sales. However, successful adoption depends on system compatibility, as RFID hardware must integrate smoothly with existing Warehouse Management Systems (WMS) and backend databases to avoid data latency or system disruption (Wang et al., 2010).

Second, the organizational context focuses on a firm’s readiness and resources. RFID implementation requires substantial capital expenditure for tags, readers, antennas, and system integration, often costing up to 20% more than traditional barcode systems (International Trade Administration, 2023). Therefore, strong top management support is essential to justify short-term costs for long-term efficiency gains (Almutairi et al., 2022). In addition, workforce capability must be upgraded, as employees transition from manual handling to operating and monitoring automated systems.

Finally, the environmental context reflects competitive and regulatory pressures. Growing e-commerce volumes and rising expectations for fulfillment accuracy and real-time tracking push logistics firms to modernize. Moreover, stricter international traceability requirements increase the need for automated and reliable data systems such as RFID (Ngah et al., 2017).

2.3 Research Gap

While existing literature extensively covers the operational benefits of RFID technology in smart warehousing, the majority of these studies focus on large-scale deployments by global e-commerce giants such as Amazon, Walmart, or Alibaba. There is a significant lack of research addressing how these advanced technologies can be practically implemented in developing logistics markets, particularly in Vietnam.

The Vietnamese logistics sector is currently growing at a rapid pace of 14-16% annually, yet it remains constrained by persistent systemic inefficiencies. Notably, logistics costs in Vietnam account for approximately 16.8% to 20% of the national GDP, which is significantly higher than the global average of 10.6%. According to recent survey data of 273 manufacturing and trading enterprises, logistics operations consume a substantial portion of total production and business costs (Ministry of Industry and Trade, 2023). As illustrated in Figure 2.1, while there are positive trends toward cost optimization, nearly a quarter of businesses (23.07%) still report that logistics account for over 15% of their total expenses, and the largest single segment (32.6%) allocates between 10% and 15% of their budget strictly to logistics operations.

This cost burden is attributable primarily to an overreliance on manual labour, the continued use of outdated tracking systems, and the absence of digital integration across the supply chain. However, current academic models for smart warehouse adoption rarely account for the structural limitations of a developing market where basic infrastructure is still catching up to e-commerce demands.

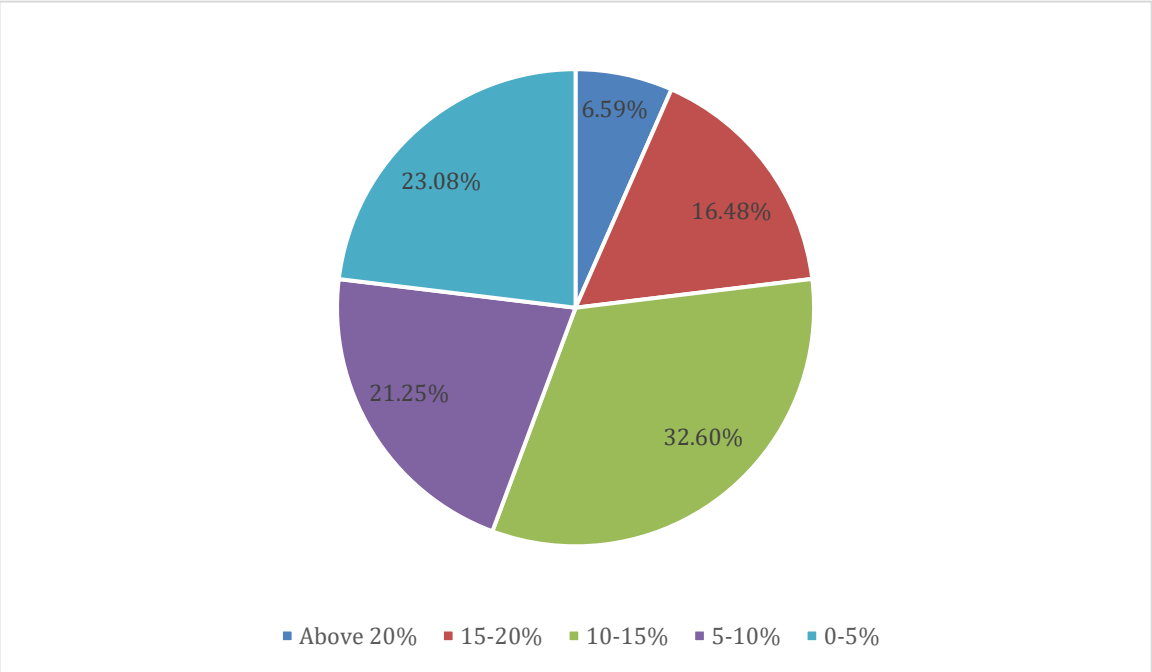

Figure 2.1: Logistics costs as a percentage of total operating costs for manufacturing and trading enterprises

Source: Ministry of Industry and Trade, 2023

Furthermore, there is a distinct gap in the literature regarding cost-effective RFID adoption strategies specifically tailored for Small and Medium Enterprises (SMEs). In Vietnam, the logistics industry is highly fragmented. Approximately 89% of the roughly 3,000 logistics enterprises operating in the country are SMEs, and the vast majority operate with registered capital of less than 10 billion VND (Vietnam Logistics Report, 2022). Existing research on RFID adoption heavily emphasizes full-scale automation, which requires massive initial capital expenditure (CAPEX) for automated sorting lines, comprehensive middleware, and specialized IT personnel. This capital-intensive, comprehensive approach to warehouse digitisation renders full-scale RFID adoption financially unviable for most domestic SMEs, the majority of which continue to rely on basic spreadsheet software for inventory management in the absence of dedicated Warehouse Management Systems (WMS).

3. Case Study: Cainiao Smart Logistics Network

3.1 Overview of Cainiao Network

Cainiao Smart Logistics Network (菜鸟网络科技有限公司) was established on 28 May 2013 as the logistics arm of Alibaba Group, co-founded alongside a consortium of eight major Chinese logistics companies including SF Express, YTO Express, and STO Express (Wikipedia, 2024). Its creation was a direct response to a structural crisis in China's logistics industry: the explosive growth of Alibaba's e-commerce platforms, particularly following the commercialisation of the 11.11 Singles' Day shopping festival in 2009, had generated parcel volumes that far outpaced the capacity of the country's fragmented logistics sector (Rai et al., 2019).

Over the following decade, Cainiao evolved considerably in both scope and scale. By fiscal year 2024, the company was processing more than five million cross-border and international packages daily across more than 200 countries and territories, with annual revenue reaching approximately US$18 billion in 2023 (Alibaba Group, 2024; Supply Chain Digital, 2024). Its stated operational ambition - to fulfil deliveries within 24 hours domestically and within 72 hours to any destination worldwide - has driven sustained investment in technology infrastructure, with

services such as 'Global 5-day Delivery' becoming recognised industry benchmarks (Alibaba Group, 2024). Central to this strategy is the integration of artificial intelligence, IoT, robotics, and RFID technology to automate and optimise warehouse operations at scale (Zhang and Lee, 2023).

3.2 Overview of RFID Adoption at Cainiao

Cainiao's decision to adopt RFID at scale was driven by a fundamental operational challenge: managing real-time visibility across a multi-partner logistics network in which parcels pass through numerous handover points between merchants, warehouses, sorting centres, and couriers. To contextualise the scale of this challenge, Cainiao currently operates over 1,100 warehouses with an aggregate gross floor area of approximately 16.5 million square metres, alongside more than 380 sorting centres worldwide (Cainiao, 2024). Traditional barcode-based systems, which require line-of-sight scanning and manual intervention at each node, were structurally incapable of meeting the data velocity and accuracy demands of Alibaba's e-commerce ecosystem - particularly during peak events such as the 11.11 Singles' Day festival (Zhang and Lee, 2023). RFID's capacity for non-contact batch identification, real-time data transmission, and unique item-level tagging offered a technically compatible solution to these visibility bottlenecks (Lim, Bahr and Leung, 2013). China's 14th Five-Year Plan and 5G Action Plan (2021–2023) further reinforced this strategic direction by explicitly supporting IoT and RFID infrastructure investment across the logistics sector (Cainiao, 2024).

Rather than adopting commercially available hardware, Cainiao invested in self-developed RFID tags, readers, and identification algorithms optimised for high-density logistics environments - particularly addressing signal degradation in scenarios involving metal and liquid items that generic systems cannot reliably overcome (Cainiao, 2024). The operational impact of this proprietary approach has been substantial: inventory checks that previously required up to three days to complete can now be performed in approximately thirty minutes using an RFID handheld device (Cainiao Group, 2023). At a network level, Cainiao has successfully deployed more than 400 intelligent projects across over 20 countries, with plans to expand this to 1,000 projects within the subsequent three years, with RFID serving as a core component in each deployment (IoT EXPO, 2024). In Western Europe specifically, the application of Cainiao's RFID technology has reduced scanning costs by 87% compared to traditional barcode-based methods (IoT EXPO, 2024).

The resulting platform was integrated directly with Cainiao's cloud-based warehouse management system and Alibaba Cloud infrastructure, enabling RFID-captured data to flow in

real time and be processed by AI-driven analytics for demand forecasting, inventory allocation, and anomaly detection (Alibaba Cloud, n.d.). This supported a deliberate transition from labour-intensive to technology-intensive warehouse operations, with RFID functioning not as a discrete upgrade but as the foundational data-capture layer connecting physical operations to digital management systems.

3.3 Application of RFID in Warehouse Operations

3.3.1. Inbound Operations

Cainiao's RFID deployment at this stage replaces line-of-sight manual scanning with automated batch identification at the point of entry. Readers installed at receiving gates automatically capture the identity, quantity, and status of arriving goods without individual item handling, enabling simultaneous reading of multiple tagged items on a single pallet and triggering immediate, automated WMS updates (Cainiao, 2024). RFID-tagged packaging boxes further allow precise pallet-level data binding and automated discrepancy detection before goods move to storage, closing the data gap that commonly arises across multi-partner handover points.

Figure 3.1: Cainiao’s RFID reader

Source: Cainiao

The accuracy improvements are well-documented. The Hong Kong eHub achieves a data accuracy rate of 99.5% from the unloading stage onward, substantially outperforming the manual PDA scanning it replaced (Air Cargo Week, 2024) - consistent with the broader evidence that RFID systems raise inventory accuracy to above 95%, compared to the 60–70% typical of manual approaches (Budiyanto and Muslim, 2024). At the labour level, batch identification has contributed to an approximately 50% reduction in scanning workforce across Cainiao's RFID-enabled facilities, with fewer operators processing substantially higher inbound volumes (Cainiao, 2024). These inbound improvements - faster receiving, higher data accuracy, and reduced labour

dependency - establish the data foundation upon which downstream storage and fulfilment operations depend.

3.3.2. Storage and Inventory Management

In conventional warehouse environments, inventory discrepancies accumulate progressively between physical stock counts as items are moved, misplaced, or recorded incorrectly, translating into fulfilment errors, stock-out risks, and resource-intensive cycle counting (Lim, Bahr and Leung, 2013). Cainiao's RFID infrastructure addresses these challenges by sustaining continuous, automated visibility over stored inventory. Readers deployed throughout the storage area capture real-time location and status data for tagged items, eliminating the need for staff to physically locate and scan products during stock checks. Inventory audits that previously required two to three inspectors over two to three days can now be completed by a single operator in approximately ten minutes with accuracy exceeding 90% (Cainiao, 2024) - reflecting the shift from static, reactive counting to proactive, real-time monitoring that Budiyanto and Muslim (2024) identify as RFID's defining advantage in storage management.

Beyond accuracy, RFID supports dynamic storage allocation by maintaining a continuously updated record of item locations, enabling warehouse management algorithms to optimize slot assignments based on real-time stock levels, order velocity, and available space (Cainiao, 2024). Integration with Cainiao's AI analytics layer further enables predictive restocking and demand-responsive inventory positioning, extending RFID's role into active decision support. These benefits have been externally validated: Xufuji's deployment of Cainiao's RFID platform yielded a 60% improvement in warehousing and inventory management efficiency and a 20% reduction in both product loss and labour costs (Cainiao, 2024).

3.3.3. Outbound and Order Fulfillment

RFID technology fundamentally redefines outbound operations by replacing manual, line-of-sight barcode scanning with automated, continuous identification at every critical transition point in the fulfillment workflow. In Cainiao's facilities, RFID tags attached to parcels, pallets, and containers transmit item data automatically as goods move through warehouse zones, while fixed readers installed at docking bays, conveyor transitions, and storage aisles capture this data in real time without manual intervention (Seiko RFID, 2025). Because RFID reads multiple tags simultaneously and does not require direct line-of-sight contact, the entire outbound sequence - encompassing picking, sorting, and staging - becomes substantially faster and more accurate than conventional scanning methods.

The operational results of this infrastructure are well-documented. At Cainiao's Hong Kong eHub, full RFID deployment improved package processing efficiency by approximately 30% compared to traditional freight centres, while the seamless automated inventory process enables precise location identification within as little as one minute (Seiko RFID, 2025). Through API integration, shippers receive real-time cargo status updates with a data accuracy rate of 99.5%, marking a structural transition from manual intervention to automated smart tracking (Seiko RFID, 2025; Air Cargo Week, 2024). Furthermore, RFID enables rapid freight recognition even before vehicles have fully stopped at unloading docks, eliminating a bottleneck that manual scanning systems are structurally unable to resolve (Seiko RFID, 2025).

The cumulative effect of these outbound efficiencies is reflected in Cainiao's network-level performance. Enabled by its RFID-integrated logistics infrastructure, the company maintains an on-time delivery rate of 98% across its operations (Alibaba Cloud, n.d.). In fiscal year 2023, Cainiao processed a total cross-border parcel volume exceeding 1.5 billion, serving over 100,000 merchants and brands globally (Cainiao, 2023). To further optimise the fulfillment process, Cainiao has also developed AI-driven parcel consolidation algorithms that reduce the number of shipments for the same consumer across multiple merchants, increasing delivery speed without incurring additional costs for either merchants or consumers (Chen et al., 2024). Collectively, these capabilities demonstrate that RFID does not function merely as a tracking tool but as the data foundation upon which Cainiao's broader fulfillment intelligence is built.

3.3.4. Smart Packaging and Sustainability

Beyond operational efficiency, Cainiao deploys RFID technology as an integral component of its green logistics strategy, using it to optimise packaging decisions and enable the lifecycle tracking of reusable assets. Within its smart packaging system, RFID works in conjunction with an AI-powered boxing algorithm that analyses product data - including size, weight, and shipping requirements - to recommend the most appropriate package dimensions for each order. This approach has reduced packing material usage by 15%, eliminating the equivalent of approximately 80 million cartons from circulation annually (Alibaba Cloud, 2023). In fiscal year 2023 alone, Cainiao's packaging optimisation initiatives - spanning original box shipping, reduced packaging volumes, and electronic waybills - contributed to a total reduction in packaging material usage of more than 184,000 tons (Air Cargo Week, 2023). At the network level, cardboard box consumption was reduced by 730 tons in FY2023, and Cainiao warehouse workers sorted, recycled, and reused a total of 47.6 million cardboard boxes in FY2024 (Cainiao ESG, 2024).

RFID also serves as the enabling technology for Cainiao's reusable packaging programme. The company has embedded self-developed RFID chips into approximately 33,000 reusable boxes, each assigned a unique digital identifier that supports tracking across its full use, return, and reuse cycle rather than disposal after a single shipment (Alibaba Cloud, 2023). These boxes were utilised over 130,000 times in the year ending March 2023, with the programme extended to top-tier brands across food, fast-moving consumer goods, and baby care categories, including Pepsi, L'Oréal, and Nestlé (Cainiao ESG, 2024). By providing continuous, automated visibility of packaging throughout its lifecycle, RFID closes the traceability gap that renders conventional single-use packaging systems incompatible with circular logistics models.

The aggregate environmental impact of these initiatives is considerable. According to Cainiao's 2024 ESG Report, the company achieved a total reduction of 458,000 tons of carbon emissions across its operations and value chain in FY2024, with green packaging initiatives accounting for 156,000 tons of that figure (Cainiao ESG, 2024). It is important to note, however, that RFID represents one component within a broader sustainability framework that also encompasses clean energy adoption, electric vehicle deployment for last-mile delivery, and biodegradable packaging materials. Nevertheless, its role as the primary data capture and traceability layer across Cainiao's packaging lifecycle makes it an indispensable enabler of the company's measurable carbon reduction targets.

4. Analysis and Implications for Vietnamese Logistics Enterprises

4.1 Gap Analysis

While Section 2.3 established the macro-economic constraints that make full-scale automation financially unviable for most Vietnamese SMEs, this section focuses on the direct operational disparities on the warehouse floor. By contrasting Cainiao’s highly digitized infrastructure with the standard practices of domestic logistics firms, it is possible to identify the specific technological and human resource barriers that must be addressed prior to achieving smart warehousing.

4.1.1. Level of Automation

Cainiao’s fulfillment centers have achieved a high level of physical automation by replacing line-of-sight manual scanning with automated batch identification. By installing RFID readers at

critical points such as receiving gates and storage aisles, they capture data instantly without manual intervention, entirely replacing manual PDA scanning (Seiko RFID, 2025).

Conversely, traditional Vietnamese warehouses rely heavily on line-of-sight barcode scanning, resulting in slow manual processing and severe bottlenecks during peak seasons. The primary operational gap here is the massive initial capital expenditure (CAPEX) required to install enterprise-grade fixed sorting lines and automated portals. Replicating Cainiao's hardware infrastructure in its entirety presents a prohibitive capital expenditure barrier for typical domestic operators, necessitating a phased, incremental approach to technology adoption rather than direct system replication.

4.1.2. Data Integration Capabilities

At Cainiao, physical automation is powered by seamless digital integration. RFID-captured data flows in real-time to a cloud-based Warehouse Management System (WMS), enabling dynamic storage allocation and achieving inbound data accuracy rates of 99.5% (Air Cargo Week, 2024). Through direct API integration, this system also provides shippers with real-time cargo status updates, shifting from manual intervention to smart tracking.

In contrast, Vietnamese enterprises struggle with low real-time visibility and pervasive data silos. Instead of centralized, automated systems, local facilities frequently manage inventory through disconnected legacy systems or basic spreadsheet software. Even if physical RFID tags were adopted, integrating these raw, continuous data streams into a functional WMS without causing severe system latency remains a profound technical hurdle.

4.1.3. Workforce Skill Structure

The transition to RFID at Cainiao enabled a deliberate, strategic shift from a labor-intensive to a technology-intensive operation. By automating inbound identification, Cainiao reduced its scanning workforce by approximately 50%. Furthermore, routine inventory audits that previously required multiple inspectors over several days are now executed by a single operator in about ten minutes with over 90% accuracy (Cainiao, 2024). This smart environment demands specialized IT personnel and advanced management capabilities rather than manual labor.

For typical Vietnamese logistics enterprises, adopting these systems introduces significant integration complexity that requires specialized IT expertise (Hayes, 2025). Therefore, a successful leapfrog strategy will depend heavily on aggressive workforce upskilling and improving digital data management competencies among local warehouse staff.

4.2 Prerequisites for RFID Adoption in Vietnamese Logistics Enterprises

Cainiao's success with RFID relies heavily on a pre-existing digital foundation that many Vietnamese logistics SMEs currently lack. Approaching RFID as a straightforward hardware upgrade without this foundational preparation frequently results in costly implementation failures rather than the anticipated operational improvements. To mitigate this risk, this section identifies the essential prerequisites local enterprises must meet prior to deployment. These foundational requirements are analyzed through the three dimensions of the Technology-Organization-Environment (TOE) framework established in Section 2.2.

4.2.1. Financial Readiness (Technological & Organizational Context)

The most immediate prerequisite for RFID adoption is financial stability. As noted in Section 2.2, RFID infrastructure can cost up to 20% more than traditional barcode systems (International Trade Administration, 2023). Because enterprise-level deployments require substantial upfront capital expenditure (CAPEX) for hardware, middleware, and system integration, this price difference creates a major barrier for most Vietnamese SMEs, which typically operate with registered capital below 10 billion VND (Vietnam Logistics Report, 2022).

Therefore, financial readiness must be evaluated against two criteria. First, the firm must evaluate the Total Cost of Ownership (TCO) to ensure that the required CAPEX does not compromise its short-term operational liquidity. Academic frameworks established by Tajima (2007) indicate that RFID investment is heavily front-loaded; while hardware (tags and readers) are the most visible expenses, software configuration, middleware integration, and system alignment typically consume 50% to 70% of the initial deployment budget. For Vietnamese SMEs with registered capital below 10 billion VND, leadership must verify that their working capital can absorb this comprehensive TCO, not just the hardware sticker price, without disrupting essential daily operations.

Second, the firm must identify at least one specific product segment where the cost of inventory errors (such as stockouts, mis-shipments, and lost goods) clearly exceeds the cost of the RFID system. Proving a viable return on investment (ROI) within 12 to 18 months in these high-value areas is essential (Lim, Bahr and Leung, 2013). Firms unable to meet these criteria should view RFID as a future goal tied to revenue growth, rather than an immediate operational priority.

4.2.2. Technical Infrastructure Readiness (Technological Context)

A prerequisite frequently underestimated by SMEs is the state of their existing digital infrastructure. RFID technology cannot create operational value on its own; it requires a compatible backend system to process and store the continuous data it collects. As Wang et al. (2010) point out, RFID hardware must integrate smoothly with a functioning Warehouse Management System (WMS) to prevent system crashes and data delays.

This requirement is especially critical in Vietnam, where many logistics firms still manage inventory using basic spreadsheets rather than dedicated WMS platforms (Vietnam Logistics Report, 2022). In fact, recent data shows that around 64% of Vietnamese firms use minimal to no digital tools for freight and inventory management (Nguyen et al., 2023). Without a working WMS, RFID readers will only generate raw, unreadable data streams, making the investment completely ineffective. Consequently, firms must ensure that a functional digital inventory system is fully operational before purchasing any RFID hardware.

4.2.3. Human Capital Readiness (Organizational Context)

As seen in Cainiao's operations, shifting from manual barcode scanning to RFID requires a fundamental change in workforce skills. This transition allowed Cainiao to reduce its manual scanning workforce by roughly 50% while simultaneously demanding more tech-savvy operators (Cainiao, 2024). Before deploying RFID, Vietnamese enterprises must honestly assess whether their current workforce can handle this digital shift.

This readiness assessment involves two key personnel requirements. Technically, the firm needs at least one dedicated IT coordinator, either in-house or outsourced, who can manage middleware setup, reader calibration, and WMS data syncing. Operationally, warehouse floor staff must possess basic digital literacy. Resistance from workers unfamiliar with new technology is a proven risk that directly slows down system adoption. Furthermore, research on Vietnamese logistics firms confirms that employee digital skills and strong management support are vital for successful digital transformation (Nguyen et al., 2025). This underscores that human capital readiness constitutes a fundamental prerequisite for successful RFID deployment, rather than a secondary operational consideration. Enterprises that have not yet developed these personnel capabilities are insufficiently prepared to undertake a system-wide RFID implementation.

4.2.4. Ecosystem and Partner Readiness (Environmental Context)

A unique prerequisite for the Vietnamese market, often overlooked in global RFID studies, is the readiness of the broader supply chain ecosystem. As established by Tajima (2007), the strategic value of RFID is inherently network-dependent; its maximum operational benefits are realized only when data is seamlessly shared across interconnected supply chain nodes, from upstream manufacturers to downstream distributors. If upstream suppliers do not attach RFID tags at the factory, or if downstream couriers cannot scan them, the adopting SME pays the full cost of the technology but only gains a fraction of the network benefits.

Before investing, companies must assess whether their key suppliers and logistics partners already use RFID-compatible systems or are willing to adopt them. This is especially crucial if a firm serves multinational buyers or export-market clients who strictly require real-time traceability data in their contracts.

4.3 Managerial Recommendations

Based on the operational gap analysis, it is evident that the direct replication of Alibaba's fully automated operational model is not immediately feasible for domestic Vietnamese logistics providers. To create an actionable, step-by-step upgrade path, our recommendations are structured around the Technology-Organization-Environment (TOE) framework, addressing the specific constraints facing domestic logistics enterprises.

From an organizational perspective, the primary challenge is that the vast majority of Vietnamese logistics firms are SMEs that lack the high investment capability and the advanced workforce training needed to operate fixed, robotic sorting systems. Rather than pursuing capital-intensive investments in fixed robotic infrastructure, logistics managers are advised to implement a “Hybrid Automation” strategy. This concept involves combining the existing human workforce with mobile or wearable RFID scanners, by equipping warehouse personnel with mobile RFID scanners, local operators can retain the primary operational benefits of the technology - namely, simultaneous multi-item identification without line-of-sight constraints - while avoiding the substantial capital expenditure associated with fixed automated installations (Lim, Bahr and Leung, 2013). This solves the slow manual labor issue while requiring only basic staff training.

However, management should also plan for the specific risks of this hybrid approach. Handheld devices are vulnerable to physical damage on a busy warehouse floor, and introducing new digital tools can cause resistance among less tech-savvy staff. To mitigate these risks,

managers need to invest in industrial-grade hardware and provide hands-on training programs to help staff adjust.

In terms of the environmental context, local warehouses are facing intense pressure from the booming e-commerce market, but adopting an entire warehouse to RFID at once is financially risky. To respond to these market pressures safely, businesses should focus their RFID adoption strictly on high-value and high-margin goods first, such as fashion, retail electronics, and pharmaceuticals. These are the product categories in which inventory errors - including stockouts, mis-shipments, and lost goods - carry the greatest financial consequences for the firm. By using RFID tracking for these premium goods first, companies can quickly see the benefits of the 99.5% data accuracy that Cainiao achieves (Air Cargo Week, 2024). Demonstrating a measurable return on investment within these high-priority segments provides the financial justification required for subsequent, broader technology expansion across additional product lines.

Finally, within the technological dimension, the compatibility of RFID with existing systems is a major hurdle. Connecting continuous RFID data into a working Warehouse Management System (WMS) without causing system crashes requires specialized IT expertise that local SMEs typically do not have . To circumvent this integration barrier, managers should use Software-as-a-Service (SaaS) cloud platforms instead of trying to build their own software systems. Subscription-based WMS platforms enable local enterprises to process RFID data streams without incurring the capital expenditure associated with on-premise server infrastructure. This approach enables domestic logistics providers to deliver comparable real-time shipment visibility to that achieved by Cainiao, at a sustainable and scalable operational cost (Hayes, 2025).

4.4 Sustainability and Regulatory Implications

4.4.1. Enabling Circular Logistics and Waste Reduction

An RFID-enabled smart warehouse supports circular logistics by enabling lifecycle tracking of reusable packaging containers (RPCs). In Cainiao's operations, RFID tags monitor packaging during use, return, and reuse, ensuring traceability across cycles (Wang, 2025). In contrast, traditional domestic logistics relies heavily on single-use cardboard and unmanaged plastic, generating significant fulfillment waste. RFID integration allows firms to control return flows of reusable containers, reducing material loss, procurement costs, and overall waste output.

When integrated with AI-based packaging systems, RFID data on product size and weight enables optimal package selection, minimizing empty space and volumetric weight. For

Vietnamese firms facing high freight costs, this improves transport efficiency, lowers fuel consumption, and reduces carbon emissions (Zghair & Konathala, 2025).

4.4.2. Meeting US/EU Traceability Requirements

The shift from manual barcode scanning to automated RFID systems is increasingly essential for firms targeting international markets. Regulatory frameworks such as the European Union's Green Deal and strict US import traceability requirements demand end-to-end supply chain transparency to verify authenticity and ethical sourcing (Ngah et al., 2014). Manual processes are prone to human error, creating data gaps that risk border rejection. RFID provides continuous, automated visibility and a reliable digital record of goods movement, strengthening compliance with international transparency standards.

4.4.3. Export-Oriented Competitiveness

RFID is therefore not merely operational infrastructure but a strategic capability for export competitiveness. Multinational corporations increasingly prioritize real-time data visibility over low-cost service alone, as RFID enhances supply chain transparency and performance. Empirical research confirms that RFID improves visibility, traceability, and operational efficiency, contributing directly to competitive advantage in global markets (Ullah et al., 2025). Without seamless integration into international tracking systems required by US and EU clients, Vietnamese providers risk losing contracts to foreign-invested competitors. Strategic adoption of smart warehousing thus converts regulatory compliance into a sustained competitive advantage.

5. Conclusion

The transition from traditional, manual-based logistics to smart warehousing is no longer a luxury but a strategic necessity in the global supply chain. This paper has demonstrated that Radio Frequency Identification (RFID) technology serves as the vital digital backbone of this transformation. It acts as the essential bridge between physical goods and Information Technology systems to automate warehouse workflows and ensure data integrity.

Through the case study of Cainiao Network, it is evident that replacing line-of-sight manual scanning with automated batch identification fundamentally redefines operational excellence. The implementation has led to significant improvements in labor efficiency and inventory precision, transforming audits from multi-day tasks into rapid, automated processes. Furthermore, RFID

serves as an enabling component for structural sustainability by optimizing packaging and enabling the lifecycle tracking of reusable assets.

However, the gap analysis for the Vietnamese logistics sector reveals a complex landscape of challenges and opportunities. This transition remains constrained by financial and technical barriers facing domestic SMEs, significant operational disparities between Cainiao's infrastructure and local industry standards, and mounting regulatory and competitive pressures from international markets, particularly those of the United States and the European Union.

In summary, Vietnamese enterprises cannot afford a direct replication of global giants but must adopt a phased, scalable approach to RFID integration. To reduce national logistics costs and secure high-value international contracts, local firms must transition from labor-intensive manual intervention to smart tracking. By aligning technological adoption with global transparency standards, Vietnamese logistics providers can transform regulatory compliance into a powerful competitive advantage in the digital age.

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