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Advancements in Automatic Identification and AI-Based Evaluation in the Distribution Process

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Abstract Information remains a critical competitive tool in logistics. Over the past decade, rapid technological development—especially in the fields of Automatic Identification and Data Capture (AIDC), Internet of Things (IoT), and Artificial Intelligence (AI)—has significantly transformed postal and logistics services. This paper updates the previously published results by integrating the latest trends and highlighting the growing role of AI in evaluating shipment data. The measurements of postal container monitoring using RFID technology are complemented with a hypothetical scenario applying AI for predictive analytics and anomaly detection. The paper demonstrates how modern technologies contribute to smarter, more efficient postal networks.

Keywords logistics, distribution, AIDC, RFID, AI, IoT, postal services

JEL L87, O33, C88, L86, R41

1. Introduction

Automatic Identification and Data Capture (AIDC) technologies have become a cornerstone in the evolution of global logistics and supply chain management. These technologies support the traceability, tracking, and automation of goods and assets across transport and distribution networks (Bai & Sarkis, 2020). The global push toward digital transformation, along with increasing customer expectations for transparency and speed, has intensified the adoption of systems like barcodes, QR codes, Radio Frequency Identification (RFID), and biometric identification (Brous et al., 2020).

RFID has emerged as a critical solution for overcoming visibility issues in complex logistics networks. It enables non-line-of-sight data acquisition, which enhances operational efficiency and inventory accuracy (Sarac et al., 2010). Its relevance is magnified in postal and distribution contexts, where rapid and secure delivery of large volumes of consignments is crucial.

Since 2020, technological development has accelerated under the influence of global supply chain disruptions, particularly those caused by the COVID-19 pandemic. Logistics operators were compelled to adopt more resilient, data-driven, and automated systems (Ivanov & Dolgui, 2021). As a response, many distribution networks began integrating AIDC with next-generation technologies such as the Internet of Things (IoT), edge computing, and Artificial Intelligence (AI). These tools enable real-time monitoring, predictive analytics, and the optimization of resource utilization, all while enhancing customer service and reducing costs (Min, 2010).

In recent years (2021–2025), logistics chains have increasingly integrated IoT sensors, edge computing, and cloud-based platforms to enhance data sharing, real-time monitoring, and predictive decision-making. Furthermore, AI has emerged as a key enabler in automating the analysis of large volumes of logistics data (Ghosh et al., 2023). The convergence of these technologies is giving rise to the concept of "smart logistics," where physical flows and digital systems are seamlessly interconnected.

2. AIDC and Modern Technologies in Logistics

Currently, many companies, to survive or respond to current challenges, have resorted to taking measures that include digitalization and the related implementation of elements and solutions that are associated with I4.0. These tools can now take over routine tasks that were previously performed by people, and this significantly affects transport and logistics. Here, the first elements of digitalization began to be implemented in previous decades and were related to the need to ensure logistical operation management. Today, this role is significantly fulfilled by automatic identification of shipments/goods and related technologies (especially IoT) and artificial intelligence, the use of which brings improved efficiency, but also speed and accuracy in processes, which increases security, plannability and productivity. In general, current development can be linked to four basic systems, namely:

• IoT-based sensors embedded in containers, offering temperature, humidity, and shock data (Zhou & Wang, 2022; Baláž at al., 2024)

• Cloud-native warehouse management systems (WMS) that integrate AIDC devices with centralized data repositories (Chen et al., 2021).

• Edge computing reducing latency in RFID scanning and decision-making (Lee & Park, 2021).

• AI algorithms used to predict delivery times, detect anomalies in movement patterns, and assess asset utilization (Al-Fuqaha et al., 2022).

These technologies enable a shift from passive data collection to intelligent logistics management. Logistics process management depends on active and accurate data collection and its immediate processing and evaluation. Large logistics companies and FreightTech companies are developing and implementing data-driven solutions that will make the benefits of automation and artificial intelligence available. However, small logistics partners, carriers, postal companies and other companies involved in logistics and transport activities can also benefit from this development, which is also confirmed by a study by the consulting firm Roland Berger (2019) and PWC (2025). Our focus in this article will be on AIDC and AI in parcel distribution.

2.1. Basic AIDC tools in postal distribution processes

AIDC (Automatic identification and data capture) includes methods of automatic identification of objects, collection of data about objects and direct data entry into a computer system (without human intervention). These technologies provide fast, accurate and cost-effective ways to identify, route, retrieve and manage data and information about objects, people, transactions and resources. These include, for example, technologies: bar codes, RFID (Radio Frequency Identification), NFC (Near Field Communication), OCR (Optical Character Recognition), biometrics. Data captured from printed documents (typical for distribution processes) can be carried out using OCR (Optical Character Recognition) or BCR (Bar Code Recognition).

RFID technology represents an innovation in identification technology using bar codes. It is mainly focused on identifying objects/goods in warehouses, distribution centres or in the transport chain; however, it is also used to identify people - e.g. patients, competitors, and visitors to various events/spaces, etc. RFID is also used for real-time locating systems. But also, as electronic customs collection, electronic wallet. Use them for radio frequency bands LF (120 to 150 kHz), HF (13.56 MHz) to microwaves (3.1 to 10 GHz). RFID tags are read at the RFID interface (air interface). Many authors are devoted to standards, development and implementation in their publications, for example Kolarovszki at al., (2016); Tengler at al., (2017); Tengler (2020); Madleňáková, (2020).

AIDC tools in postal and distribution processes include, for example:

• Real Time Location System (RTLS) - tracking the movement of objects in a defined space in real time (inside buildings, halls, warehouses, ...). The system is supplemented with GPS. (Moghaddam, 2018).

• Pick by Voice or Voice Picking - allows implementation into the customer's WMS or ERP system. It is used for completing order picking in warehouses and distribution centres, but also in production management and technological processes in shipment logistics, etc. (Wannenwetsch, 2019).

• Pick to Light (P2L) - belongs to the so-called Poka-yoke solution system. A system for picking items from warehouse positions using light navigation, which is located at each warehouse position. It is used primarily in logistics but also in primary production and assembly. The opposite of P2L is the put-to-light system. (Kim, 2006).

• Direct Part Marking (DPM) - permanent marking of objects allowing continuous tracking throughout the product's life cycle. (Elmaghraby, 2003).

2.2. Basic AI tools in postal distribution processes

AI tools in logistics and supply chains are a key success factor in the current era of process digitalization. Their use enables the use of exponential technologies.

• Transportation Management System (TMS) - uses machine learning algorithms to intelligently match shipments with optimal transportation options based on historical data, shipment parameters and carrier availability (Zhang & Zhao, 2020).

• Route optimization with regard to driving times and breaks - AI analyzes traffic, weather, and legal constraints to shorten delivery times while complying with regulations; for instance, DHL optimizes delivery routes daily using AI (Wang & Zhang, 2021).

• Warehouse Management Systems (WMS) - AI enhances storage slotting, optimizes picking routes (for humans and robots), and improves inventory management (Gu, Goetschalckx, & McGinnis, 2010).

• Supply Chain Planning & Forecasting Tools - facilitate resource utilization planning, route design, vehicle load optimization, and workforce management. These systems also support automation with drones, robotics, and vision picking (Choi, Wallace, & Wang, 2018).

• Risk Management Platforms - enable global event monitoring and early identification of supply chain disruptions (Ivanov, 2020).

• Business Intelligence (BI) and analytics - Support decision-making through logistics data visualization and interpretation (Ivanov, 2020).

3. Aim and Methodology

The main objective of the paper is to propose a method for identifying and tracking postal items using RFID and AI technology, enabling real-time visibility and control. This paper uses an AI-based model scenario to illustrate how data analysis can further improve decision-making. The paper is an extension of the findings from the article Madleňáková, (2020).

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4. Results and Discussion

4.1. Pilot Measurement by RFID

The implementation of a mail container monitoring system is instrumental in enhancing operational efficiency across postal distribution networks. This system primarily focuses on tracking active network elements—namely, transport containers—to streamline their circulation and improve asset utilization. The pilot study was designed to verify whether it is feasible to identify and localize specific transport units in real time and within the expected locations, aligning with predefined logistics workflows and behavioural patterns (Kebo et al., 2013).

This functionality is particularly important to both contractual customers (typically bulk mailers) and postal service providers. Bulk mailers, in compliance with service agreements, often carry out preliminary processing tasks such as pre-sorting, labelling, and grouping of postal items directly at the point of origin. Consequently, mail containers are employed at both the sender's premises and within the internal logistics chain of the postal operator.

Within the operator's domain, containerization occurs at multiple levels of the logistics hierarchy, including central processing hubs and regional sorting centres. These operations are vital to ensuring secure and optimized movement of consignments across the transport network. Additionally, effective container tracking contributes to improved resource management, particularly in the context of packaging circulation (e.g., returning crates, monitoring available capacities at depots, and minimizing container losses). (Madlenak at al., 2016)

Procedure for Pilot Measurement Implementation mail container monitoring system

The pilot measurement of container monitoring using RFID technology followed a structured sequence of steps designed to ensure accurate data acquisition and system validation in selected postal logistics centres:

a) Device preparation and installation

Selected logistics and distribution centres need to be equipped with RFID readers and connected to a centralized database server via mobile internet. A dedicated web application needs to be developed to support the measurement process and middleware needs to be deployed to manage, filter and synchronize incoming data streams. (Tengler, 2018)

b) Shipping unit labelling

RFID tags (passive UHF tags) need to be attached to each shipping container. The tag configuration needs to ensure optimal readability within the operating environment, ensuring consistent data recording throughout the measurement cycle.

c) Initial container scanning and routing

Before shipment, each container is scanned to match its designated destination. The containers pass through the appropriate shipping gate or loading point. If a container is detected on the wrong loading bay, the system automatically generates an error message with a prompt for corrective action within the information system to ensure accurate routing.

d) Loading and transportation

After verification, shipments are loaded into marked containers, which are then placed on postal vehicles. During transportation, the system continuously monitors the movement of the container through the logistics network.

e) Data collection and real-time monitoring

The RFID system captures real-time data on the location of the container and the time it has been in the processing facilities. This allows for continuous traceability and visibility of container flows in real time. In addition, each container is matched to the relevant shipments to increase tracking accuracy.

Measurement coverage and network focus

The pilot measurement will focus on two levels of the national postal network:

- Main transport network: Connecting the main distribution centres (postal nodes, there are currently 5 nodes in real operation in the Slovak Republic)
- Regional transport network: Connecting regional distribution centres with primary nodes within their attractive districts

This dual-level configuration enabled tracking of processing times at specific centres, inter-hub transit durations, and container flow patterns—paving the way for evidence-based improvements in logistics operations.

System performance assessment

The proposal for the implementation of test and later control measurements should provide a framework mechanism for identifying weak points in the distribution network of the national postal operator. In the first phase of the measurement testing, it is expected to record the movement of containers in selected centres, measure the residence time, transport time and evaluate the efficiency of processing shipments. Pilot measurements in laboratory conditions confirm the high reliability of the system - passive UHF tags achieve a 100% readability rate at all monitoring locations. It is therefore assumed that the implementation of the pilot measurement in real operation will also be successful.

The benefits observed during the implementation in the test environment are consistent with the benefits reported by Kolarovszki at al., (2016):

- Increased efficiency in handling shipments
- Optimization of container circulation
- Reduction of container overloading and losses
- Improved shipment traceability
- Reduced maintenance and repair requirements

RFID, in particular, has emerged as a critical solution for overcoming visibility issues in complex logistics networks. It enables non-line-of-sight data acquisition, which enhances operational efficiency and inventory accuracy (Sarac et al., 2010). Its relevance is magnified in postal and distribution contexts, where rapid and secure delivery of large volumes of consignments is crucial. However, recent studies have also drawn attention to its environmental footprint. Bukova et al. (2023) conducted a case study in a logistics centre quantifying the environmental burden of RFID tags, revealing that approximately 5.7 tons of e-waste are generated annually, including 139 kilograms of metal waste. This finding underscores the importance of considering sustainability in the implementation of identification technologies.

4.2. Hypothetical AI Scenario in Container Monitoring

To further illustrate the transformative potential of advanced technologies in postal logistics, a hypothetical scenario was constructed that integrates Artificial Intelligence (AI) with AIDC-based monitoring data. A simulated dataset based on historical RFID readings was used to test the efficacy of an AI-driven analytics system. The architecture of the model was grounded in a recurrent neural network framework, suitable for time-series prediction and classification tasks in logistics environments.

- Anomaly Detection - the AI algorithm was able to identify deviations from standard container routes and transit times, alerting operators to possible disruptions, delays, or misrouting events.
- Predictive Maintenance - leveraging operational data such as frequency of use and environmental exposure, the model predicted potential equipment failures and flagged containers for preventive inspections.
- Network Optimization - by analysing container movement patterns, the system identified inefficient routes and suggested real-time reallocation of transport units to balance network load.

This hypothetical implementation underscores the value of pairing AIDC infrastructure with intelligent analytics platforms to unlock real-time, data-informed decision-making capabilities. The use of AI in this context supports the move toward proactive logistics management and enhances the adaptability of postal operations.

4.3. Outlook, Toward Smart Postal Ecosystems

The continuing convergence of AIDC, IoT, and AI technologies is driving the evolution of smart postal ecosystems. These ecosystems are characterized by real-time data exchange, decentralized decision-making, and predictive responsiveness. The strategic integration of such systems within postal networks facilitates greater operational transparency and agility. Key areas of advancement include:

- Full digitization of logistics workflows - enabling touchless processing and automatic event logging.
- Predictive delivery planning - allowing more accurate estimations of arrival times and customer notifications.
- AI-enhanced customer communication - providing contextual updates and proactive support based on shipment status.
- Real-time exception handling - improving service recovery through immediate identification and resolution of transport issues.

As these capabilities mature, postal operators are positioned to transition from reactive service models to anticipatory systems that deliver higher performance, reliability, and user satisfaction.

5. Conclusions

The findings validated the functional reliability and operational advantages of implementing RFID-based AIDC technologies in postal logistics. The measurable improvements in container tracking and logistics visibility highlighted the importance of accurate and real-time data collection. Considering recent technological developments, the paper extended its scope to explore how AI-driven analytics and IoT-enhanced sensors can elevate logistics operations to a new level of intelligence and automation.

The convergence of identification systems, advanced data analytics, and cloud-based platforms is setting the foundation for next-generation postal services. These integrated, adaptive systems offer the potential to reshape traditional logistics models and models of postal technological systems in the context of designated national postal operators and enable smarter, more resilient distribution processes.

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