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Using Radio Frequency Identification for Aviation Logistics Planning Systems Optimization

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Abstract: Modern aviation logistics faces numerous challenges, including the need for fast processing of large cargo volumes, cost reduction, and ensuring accuracy in monitoring. This study explores the integration of electronic monitoring and planning systems, built on radio frequency identification (RFID) technology, to optimize aviation logistics operations. The proposed system incorporates radio readers, a centralized database, and mathematical optimization models, offering cost-effective and efficient solutions to key logistical issues. By enabling real-time cargo tracking, improving workflow transparency, and reducing errors, the system enhances overall operational efficiency. These benefits contribute to the environmental sustainability of cargo operations and align with green energy transition efforts. This paper provides an in-depth review of the methodology, results from system modeling, and implications for future research and implementation. The findings indicate that the adoption of RFID technology can significantly streamline logistics processes, reduce opera-tional costs, and improve the accuracy of cargo handling. Future research should focus on scaling the technology for broader applications and addressing integra-tion challenges across global aviation networks.

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1 INTRODUCTION

Managing cargo terminals faces significant challenges due to the continuous growth in freight volumes, the demand for rapid processing, and the need for optimal space utilization. Traditional approaches based on static zoning and fixed cargo movement routes often prove inefficient in modern logistics systems. The lack of adaptability in such systems leads to congestion in specific areas, time losses, and increased costs.

The proposed storage zone organization model addresses these issues by implementing a dynamic approach to space and resource management within terminals. This model leverages algorithms that consider variable freight flow parameters, delivery priorities, and forecasted operational changes. Such an approach enables flexible cargo placement, minimizes movement between zones, reduces processing times, and optimizes the use of available space.

Let's explore how storage zones in cargo terminals can be reimagined with a dynamic approach that responds to changing cargo flows and resource availability in real time. This method focuses on reducing processing time and making the most of available space, aligning with the fast-paced nature of today's logistics.

The model is built on a few key principles. Imagine the terminal as a network of N zones, each playing its role in storing and processing cargo. Each cargo i has its own story—its volume V_i, priority P_i, and type T_i, all shaping how it's handled. Time t_{ij}, the duration it takes to move cargo between zones i and j, also plays a crucial role. Meanwhile, the terminal's resources, from loaders to scanners, are finite and must be allocated wisely.

To tackle this, we define two key variables: x_{ik}, which tells us if cargo i is in zone k, and y_{ij}, which shows if cargo moves from zone i to zone j. These variables become the building blocks of a strategy that minimizes total time for movement and processing:

$$Z_{minimized} = \sum_{i=1}^{N}\sum_{j=1}^{N} y_{ij} \cdot t_{ij} + \sum_{i=1}^{N}\sum_{k=1}^{N} x_{ik} \cdot h_k \quad (1)$$

Here, h_k is the time needed to process cargo in zone k.

To keep things running smoothly, there are a few rules to follow. Zones can't take more cargo than they can handle:

$$\sum_{i=1}^{M} x_{ik} \cdot V_i \leq C_k\,,\ \forall k \quad (2)$$

where C_k is a zone capacity. Cargo also has to match the type of the zone:

$$x_{ik} = 0,\ \ if\ T_i \notin T_k \quad (3)$$

And, of course, each piece of cargo can only move to one other zone at a time. This happens while balancing limited resources and keeping movement time under control:

$$\sum_{j=1}^{N} y_{ij} \cdot t_{ij} \leq T_{max}, \forall k \quad (4)$$

This a dynamic plan. By constantly updating the parameters based on what's happening in the terminal, the model adapts in real time. Predictive algorithms using past data can make this even smarter, anticipating problems before they happen.

To bring this to life, the model can be solved with linear programming for smaller cases or heuristic methods like genetic algorithms (Shevchuk, Yakushenko, Steniakin, Shyshka, 2024) for more complex scenarios. This dynamic framework reshapes how cargo terminals work, cutting delays and using resources more efficiently.

The Role of RFID and UHF Tags in Cargo Management. RFID (Radio Frequency Identification) and UHF (Ultra-High Frequency) tags provide a seamless way to monitor and track cargo in real time. Unlike traditional barcode systems that require line-of-sight scanning, these technologies use radio waves to transmit data between a tag and a reader. This enables faster and more reliable identification, even for cargo that is stacked or in motion.

Each RFID tag carries unique data about the cargo, such as its ID, type, weight, and destination. When cargo enters the terminal, RFID readers automatically log this information into a centralized system. This eliminates the need for manual data entry and significantly reduces the likelihood of human error.

The integration of RFID technology into global aviation logistics demands adherence to international standards, such as ISO 18000-6C for UHF tags, which ensure interoperability across diverse logistical systems. Standardized protocols facilitate seamless communication between various stakeholders, including airports, airlines, and cargo operators, enabling a unified approach to cargo handling and tracking.

RFID has already demonstrated its potential in large international hubs like Heathrow Airport in London and Frankfurt Airport in Germany, where it

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is used to streamline baggage and cargo operations. These implementations have shown significant improvements in operational efficiency, reduced misplacements, and enhanced accuracy in monitoring.

Moreover, global collaboration in implementing RFID systems allows for the creation of centralized databases, promoting transparency and real-time data sharing across the logistics network (Harazha, Shevchuk, 2024). Such systems not only optimize internal operations but also enhance external coordination, providing live updates to shipping companies and regulatory bodies. By aligning RFID technologies with international practices, aviation logistics can move towards a truly interconnected and efficient global network (Ivannikova, Sokolova, Cherednichenko, 2024).

The integration of RFID and UHF tags enhances operational efficiency in several key ways (Fan, Tao, Deng, Li, 2015):

Real-Time Tracking and Visibility. Cargo movement can be tracked in real time across the terminal. RFID readers positioned strategically at checkpoints continuously update the system, allowing operators to monitor the exact location and status of each shipment.

Dynamic Zone Allocation. By combining RFID data with the dynamic mathematical model described earlier, the system can optimize zone assignments on the fly. For example, if a zone nears capacity, the system can reroute incoming cargo to alternative locations without interrupting workflows.

Reduced Processing Time. Automated scanning reduces the time required to register cargo, accelerating the overall processing speed. This is especially critical during peak periods when high cargo volumes must be managed efficiently.

Enhanced Security and Error Reduction. RFID systems minimize the risk of misplaced or misidentified cargo. Alerts can be generated when cargo is moved to the wrong zone or deviates from its intended route.

Environmental Sustainability and Energy Efficiency The deployment of RFID systems not only enhances operational performance but also contributes to environmental sustainability. By reducing idle cargo movements, eliminating redundant inspections, and optimizing terminal operations, the system leads to lower energy consumption and reduced greenhouse gas emissions. Furthermore, integration with dynamic planning algorithms ensures efficient use of electrical handling equipment, minimizing unnecessary energy use.

2 LITERATURE REVIEW

The integration of RFID technology into logistics has been widely explored in recent years, as highlighted by Novitasari et al. (2022), Casella et al. (2022), and Popova et al. (2021). Across courier services, warehouse systems, and transport logistics, RFID systems address critical challenges in tracking, identification, and process efficiency. Early works emphasized how RFID minimizes human error, speeds up item processing, and enhances traceability through passive and active tags, compared to traditional barcode systems. These systems improve inventory accuracy, enable multiple simultaneous readings, and reduce processing time, making them highly applicable to fast-moving logistics sectors such as aviation.

Casella et al. (2022) conducted a systematic review of 129 studies, revealing that most RFID research focuses on applied and technical solutions aimed at improving supply chain visibility and operational flows. They highlight both discrete tracking (tracking at checkpoints) and continuous tracking (real-time monitoring), with aviation logistics leaning heavily on the latter to ensure seamless cargo movements across terminals. The research also underlines key barriers: high implementation costs, collision issues when multiple tags respond simultaneously, and the need for standardization across global systems.

Popova et al. (2021) extend this by analyzing RFID's role in warehouse and transport logistics, stressing its contribution to optimizing scheduling, routing, and inventory management. They show how RFID reduces storage time, improves order processing, and minimizes transportation errors—factors critically important in aviation cargo hubs where time-sensitive handling is essential.

For aviation logistics, integrating RFID into dynamic resource allocation models not only boosts internal process efficiency but aligns with broader green logistics goals. As noted in the analyzed works, this includes reducing energy waste, improving planning accuracy, and supporting the transition to low-carbon operations. Despite the challenges—cybersecurity risks, workforce training needs, and integration with legacy systems—the literature strongly supports RFID as a transformative enabler for modern aviation logistics.

3 METHOD OF MATHEMATICAL INTEGRATION

The inclusion of RFID data into the optimization model ensures that decisions are based on accurate, real-time information. For example, the time parameter tijt_{ij}tij in the objective function can be dynamically adjusted based on RFID readings that capture the current flow of cargo between zones. Similarly, capacity constraints CkC_kCk can be updated instantly as new cargo enters or leaves a zone.

Updated Capacity Constraint:

$$\sum_{i=1}^{M} x_{ik} \cdot Vi + \Delta Vk \leq Ck, \forall k \quad (5)$$

where ΔVk\ represents the volume change recorded by RFID.

Broader Implications. The adoption of RFID and UHF technologies not only optimizes internal terminal operations but also improves external coordination. For instance, shipping companies can access live updates on cargo status, enabling better synchronization of delivery schedules. Furthermore, the data collected through these systems provides valuable insights for long-term planning and predictive analytics.

By integrating these advanced technologies into cargo terminals, we shift from reactive to proactive management, setting a new standard for efficiency and reliability in logistics operations.

Supplier-Level Data and Initial Insights. To evaluate the impact of manual processing, optimization, and RFID integration, operations were modeled for 10 suppliers, each handling between 5 to 20 cargo units. The data captures processing times for correctly handled and misplaced cargo under different scenarios.

For instance:

- **Supplier_1** handled 15 cargo units, with 2 misplaced during manual processing, requiring **35 minutes each**. The remaining 13 units were processed in **15 minutes per unit**, resulting in a total processing time of **205 minutes**.
- Similarly, **Supplier_3**, handling 18 cargo units, experienced 1 misplacement, increasing the processing time from **15 minutes** to **35 minutes** for that unit.

These supplier-level observations provide the foundation for aggregated scenario analysis.

Processing Time by Supplier and Scenario. The chart below compares total processing times across suppliers for the three scenarios:

Manual Processing: High time variability due to frequent misplacements.

Optimized Without RFID: Reduced variability through better zone allocation but with residual misplacements.

Optimized With RFID: Near elimination of misplacements and consistent processing efficiency.

Misplacement Rates. The misplacement rates across scenarios are visualized in the chart below. Manual processing shows **10% misplacement**, optimization without RFID reduces it to **8%**, and RFID nearly eliminates it at **1%**.

Breakdown of Processing Time: Manual Scenario. The following chart illustrates the distribution of processing time in the manual scenario. It highlights how much time is consumed by correcting misplaced cargo compared to correctly handled units:

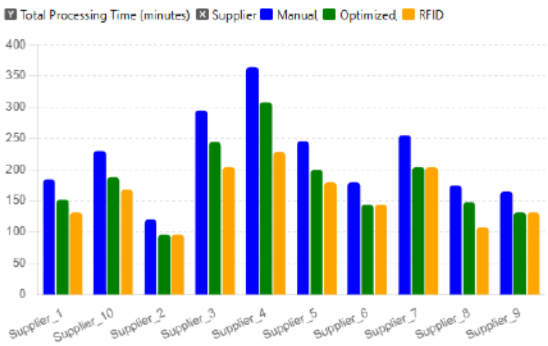

Figure 1: Aggregated Results Across Scenarios. Source: developed by authors.

Table 1: Table captions should be placed above the tables.

Scenario	Total Time (minutes)	Averag e Time per Cargo (minutes)	Time Savings vs. Manual (%)
Manual Processing	1,620	16.2	-
Optimized Without RFID	1,320	13.2	18.5%
Optimized With RFID	1,220	12.2	24.7%

Source: developed by authors

- **Manual Processing:** Inefficient with high time variability and frequent misplacements.
- **Optimization Without RFID:** Reduces processing time and error rates but retains residual inefficiencies.
- **Optimization With RFID:** Achieves consistent performance by eliminating almost all misplacements, resulting in the lowest total and average processing times.

4 DISCUSSION

The structured analysis and visualizations illustrate the progression from raw supplier data to aggregated insights. RFID demonstrates its transformative potential, not by drastically reducing individual processing times, but by eliminating misplacements, ensuring reliability, and delivering overall time savings of nearly 25% compared to manual processing. Also supports green logistics by reducing energy use, CO_2 emissions, and reliance on paper-based documentation through digital and automated tracking.

Integration with E-Waybills and Electronic Cargo Tracking Systems. The integration of RFID technology with electronic systems, such as e-waybills (E-TTN) and cargo tracking platforms, marks a transformative shift in logistics operations. These integrations enable seamless communication between terminal systems, external stakeholders, and regulatory bodies, significantly enhancing the speed and accuracy of cargo processing (Liskovych**,** 2021).

E-waybills, or electronic transport documents, provide a digital record of cargo details, including its origin, destination, and contents. When combined with RFID, the system enables:

- **Automated Data Synchronization:** RFID readers automatically scan cargo and synchronize real-time information with e-waybill systems, eliminating manual data entry and reducing errors.
- **Instant Status Updates:** Cargo location, processing status, and estimated arrival times are continuously updated, allowing for greater visibility across the supply chain.
- **Improved Regulatory Compliance:** Automatic updates to e-waybill systems ensure that all required documentation is up-to-date and accurate, reducing the likelihood of fines or delays.

Enhanced Speed of Processing and Inspection. RFID-integrated systems also address bottlenecks at key points, such as cargo truck inspections and customs clearance. These technologies:

- **Accelerate Vehicle Processing:** Trucks equipped with RFID-tagged cargo can be scanned within seconds at checkpoints, significantly reducing queue times.
- **Enable Drive-Through Inspections:** In cases of customs control, RFID eliminates the need for physical unloading and reloading of cargo for verification. The system instantly matches cargo information with electronic records, expediting the process.
- **Streamline Multi-Stop Routes:** By tracking cargo movement in real time, terminals can dynamically adjust schedules and routes, minimizing idle time and optimizing resource allocation.

Traditionally, customs inspections require the unloading of cargo to verify the contents against declarations. RFID integration allows:

- **Verification Without Unloading:** RFID readers identify cargo contents and match them with electronic records, removing the need for time-intensive unloading operations.
- **Error Detection in Real Time:** Any discrepancies between the cargo manifest and actual items are flagged immediately, enabling quick resolution.

For instance, in scenarios involving large freight trucks, this approach can save up to 2–3 hours per vehicle, reducing congestion at terminals and improving overall efficiency. The integration of RFID with e-waybill systems and cargo tracking platforms generates a wealth of operational data. By leveraging these insights, logistics managers can:

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- **Forecast Demand:** Use historical data to predict peak times and allocate resources accordingly.
- **Enhance Security:** Track cargo movements and identify anomalies, such as unauthorized access or route deviations.
- **Improve Accountability:** Maintain a transparent record of cargo handling, reducing disputes and increasing trust between stakeholders.

Analysis of Risks and Challenges. While RFID technology offers transformative potential, its adoption in aviation logistics presents several challenges that must be addressed for successful implementation (Boldyrieva, Ivannikova, Konovalyuk, 2022).

Initial Costs and Infrastructure Upgrades. The high initial investment required for RFID readers, tags, and supporting infrastructure can be a barrier, particularly for small and medium-sized airports. This financial hurdle may slow adoption rates and require strategic funding or phased implementation.

Compatibility with Existing Systems. Integrating RFID systems with legacy logistics platforms is a complex process that requires careful planning. Compatibility issues can lead to delays, increased costs, or data inconsistencies, impacting the overall efficiency of operations.

Cybersecurity Risks. The reliance on centralized databases and real-time data transmission introduces potential vulnerabilities to cyberattacks. Unauthorized access, data breaches, or system disruptions could compromise the integrity of the logistics process, requiring robust security measures to safeguard sensitive information.

Operational and Training Challenges. The shift to RFID-based systems requires training for staff to ensure effective usage and management. Resistance to change or a steep learning curve may lead to temporary inefficiencies during the transition period.

Scalability and Global Integration. Implementing RFID on a global scale involves overcoming variations in technological readiness, regulatory frameworks, and infrastructure across regions. Ensuring consistent standards and practices is essential to achieving seamless integration.

Supports green logistics by reducing energy use, CO_2 emissions, and reliance on paper-based documentation through digital and automated tracking.

To address these challenges, a multifaceted approach is needed. This includes securing funding mechanisms, developing robust interoperability standards, implementing advanced cybersecurity measures, and conducting comprehensive training programs. Additionally, pilot projects in high-volume terminals can serve as testbeds for refining RFID systems before scaling them to larger, interconnected networks. By proactively mitigating these risks, RFID can unlock its full potential as a cornerstone of modern aviation logistics.

5 CONCLUSIONS

The integration of RFID technology into aviation logistics represents a transformative step toward a highly efficient, reliable, and automated logistics ecosystem. This study highlights the multifaceted benefits of RFID, including enhanced operational transparency, significant cost reductions, and improved accuracy in cargo tracking and handling. However, the findings also reveal several broader implications and future directions for implementing this technology on a global scale. From our point of view, RFID implementation will be of particular importance in the post-war development of aviation logistics in Ukraine.

Streamlined Operations and Cost Efficiency.RFID technology enables real-time tracking and dynamic zone allocation, reducing cargo misplacements and streamlining workflows. The resulting operational efficiency not only cuts processing times but also reduces the overall cost of cargo management, making logistics operations more economically viable in high-volume environments.

Improved Accuracy and Security. The capability to capture and process real-time data minimizes human error and enhances security through automated cargo identification and tracking. This creates a more reliable logistics process, ensuring the accuracy of cargo handling and reducing the risks of delays or mismanagement.

Enhanced Decision-Making Through Data. RFID systems generate valuable operational data that can be leveraged for predictive analytics, demand forecasting, and resource optimization. This data-driven approach enables proactive management strategies and supports better alignment with customer and regulatory expectations.

Global Interconnectivity and Collaboration. By adhering to international standards such as ISO 18000-6C, RFID systems facilitate interoperability across diverse logistical networks. This paves the way for seamless collaboration among airports, airlines, and cargo operators, fostering a globally interconnected logistics network.

Challenges and Mitigation Strategies. Despite its potential, RFID implementation faces several challenges, including high initial costs, compatibility with legacy systems, cybersecurity vulnerabilities, and the need for comprehensive training programs. Addressing these challenges requires a combination of strategic investments, robust standardization, and phased rollouts supported by pilot programs.

Scalability and Future Research. Scaling RFID for broader applications necessitates addressing regional disparities in technological readiness and regulatory frameworks. Future research should focus on integrating RFID with emerging technologies like artificial intelligence and blockchain to further enhance system capabilities and security.

Environmental and Social Impacts. The automation and efficiency gains from RFID systems also contribute to reducing the environmental footprint of logistics operations by minimizing unnecessary cargo movements and resource wastage. Moreover, the streamlined processes have the potential to improve working conditions by reducing manual labor and error-prone tasks.

The adoption of RFID technology in aviation logistics is not merely an incremental improvement—it is a paradigm shift toward a smarter, more resilient, and globally integrated logistics framework. By addressing current challenges and leveraging the benefits of advanced technologies, RFID can serve as a cornerstone for the next generation of aviation logistics systems, setting a benchmark for innovation, efficiency, and sustainability. Future advancements in this field will further redefine the boundaries of what is achievable in modern logistics operations.

The integration of RFID technology with artificial intelligence (AI) represents a promising avenue for future research in aviation logistics. AI can enhance the capabilities of RFID systems, enabling more intelligent and adaptive logistics operations. Potential areas of exploration include:

- **Predictive Cargo Flow Analysis**: Utilizing AI algorithms to analyze historical RFID data and forecast cargo volumes, allowing terminals to prepare for peak demand periods more effectively.
- **Real-Time Anomaly Detection**: AI-driven models can continuously monitor RFID data streams to identify irregularities, such as unauthorized cargo movement or misplacements, and alert operators immediately.
- **Dynamic Resource Allocation**: Machine learning algorithms could optimize the allocation of resources such as manpower, equipment, and space based on real-time RFID data, minimizing delays and improving efficiency.
- **Global Data Interoperability**: Future studies could investigate how AI-powered systems can facilitate data sharing across airports and logistics networks, enhancing global coordination and transparency.
- **AI-Enhanced Route Optimization**: Combining RFID with AI could help design more efficient cargo routing strategies, reducing transit times and environmental impact.
- By combining the real-time data capabilities of RFID with the predictive and analytical strengths of AI, researchers and practitioners can unlock new levels of efficiency and reliability in aviation logistics. This integration offers a pathway toward smarter, more resilient, and globally interconnected logistics systems.

Moreover, from an environmental perspective, RFID implementation supports decarbonization efforts in aviation logistics by reducing energy waste, enhancing process efficiency, and enabling data-driven decisions aligned with green logistics strategies. These systems can be powered by renewable energy sources such as solar or wind, further strengthening the contribution of aviation terminals to the green energy transition.

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