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Review Article

Implementation of RFID Technologies in Logistics and Supply Chain Management

Krystyna Hulyda

Independent Researcher, Ukraine.

Corresponding Author : hulydalogistics@gmail.com

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Abstract - *RFID technology is increasingly used to automate object identification and improve the visibility of warehouse and transportation operations. However, existing studies provide limited sector-specific guidance on selecting appropriate tagging objects, configuring RFID control points, integrating RFID data with warehouse and transportation management systems, and evaluating implementation outcomes in agricultural logistics. This study addresses this gap by developing a phased RFID implementation framework designed for agricultural and warehouse logistics. The research combines an analysis of 20 standards, implementation guidelines, and prior academic studies with an illustrative before-and-after warehouse scenario. The framework covers product-batch and logistics-unit identification, RFID read-zone configuration, integration with WMS, ERP, TMS, and GPS records, employee training, performance measurement, data security, and implementation-cost assessment. The examined scenario compares warehouse inventory operations before and after the introduction of RFID-based identification and automated WMS event recording. In the illustrative scenario, the duration of a warehouse inventory count decreased from 16 hours to 4 hours, representing a 75% reduction. RFID-supported event recording also reduced the need for delayed manual entry of receiving, movement, and shipping data and enabled the automatic verification of tagged logistics units at configured control points. The economic assessment demonstrates that RFID feasibility depends on the selected tagging level, transaction volume, infrastructure and integration costs, tag-replacement requirements, maintenance, exception handling, and the value of measurable operational savings. The study shows that RFID performance depends on the level at which objects are identified, the configuration of read zones, the quality of master data, and the integration of RFID events with warehouse and transportation records. The proposed framework contributes a sector-specific approach that links physical cargo identification, warehouse events, transportation data, documentation, performance measurement, economic assessment, and implementation-risk control.*

Keywords - *Agriculture, Logistics, Management, RFID, Supply Chain.*

1. Introduction

Logistics systems increasingly depend on the timely collection, verification, and exchange of operational data. Warehouse and transportation decisions require accurate information about inventory levels, cargo location, product batches, logistics units, documentation, and the status of receiving, storage, loading, and delivery operations. When these data are entered manually or updated after an operation has been completed, discrepancies can arise between physical inventory, accompanying documents, and the information recorded in warehouse or enterprise systems.

Radio-frequency identification provides a means of connecting physical logistics objects with digital records. An RFID system normally includes tags, readers, antennas, middleware, and an enterprise information system. Unlike conventional barcodes, passive RFID tags can be read without direct visual alignment and, under properly configured conditions, several tags can be detected within the same reading operation. This capability supports automated receiving, inventory counting, movement recording, shipping verification, and the identification of reusable logistics assets.

The scale of RFID adoption illustrates its growing role in logistics and related industries. The RAIN Alliance reported that four participating manufacturers shipped 42.7 billion RAIN RFID tag chips in 2025 [1].

Standards developed by GS1, ISO, and the RAIN Alliance provide a technical foundation for identifying logistics objects, exchanging event data, and implementing passive UHF RFID solutions [2–5, 9–11]. Nevertheless, the availability of standards does not by itself determine whether a particular RFID deployment will produce measurable operational or economic results.

The implementation problem is especially complex in agricultural logistics. Agricultural products move through warehouses, grain elevators, weighing stations, quality-control points, loading areas, transport vehicles, terminals, and ports. Grain and other bulk products cannot ordinarily be tagged as individual physical units. Identification must therefore be associated with a product batch, bag, pallet, container, seal, trailer, vehicle, storage zone, or accompanying logistics record. Agricultural facilities may also contain metal structures, dust, humidity, temperature variation, dense packaging, and heavy vehicle traffic, all of which can affect tag selection, antenna placement, and reading stability.

Previous research has examined RFID-based traceability in wheat processing, grain supply chains, agri-food systems, warehouse inventory management, and manufacturing [13–16]. Other studies have addressed implementation barriers, RFID and IoT integration, organizational readiness, system security, and the digital transformation of supply chains [17–20]. These studies establish that RFID can support automatic identification and improved supply-chain visibility, but they also show that implementation outcomes depend on technical configuration, operational procedures, information-system integration, staffing, and cost control.

Three gaps remain significant. First, many publications discuss RFID benefits at a general level but provide limited guidance on determining which objects should be tagged in logistics involving bulk agricultural products. Second, RFID is frequently considered in isolation, although vehicle-level visibility, cargo identification, warehouse records, and interorganizational event exchange may require a combination of RFID, GPS, WMS, TMS, ERP, and EPCIS-based data structures. Third, the literature contains fewer documented before-and-after evaluations that connect technical implementation decisions with inventory accuracy, processing time, error rates, ownership costs, and payback in agricultural and warehouse logistics.

The purpose of this study is to develop and evaluate a sector-specific framework for implementing RFID in agricultural and warehouse logistics. The framework covers process analysis, the selection of tagged objects, the configuration of read points, pilot testing, integration with information systems, employee training, performance measurement, economic assessment, and implementation-risk control.

The study addresses the following research questions:

1. Which logistics objects and control points are most suitable for RFID identification in agricultural logistics?
2. Under which operational conditions is RFID preferable to QR codes, conventional barcodes, BLE-based tracking, GPS, or a hybrid solution?
3. How does RFID implementation affect inventory accuracy, processing time, transaction discrepancies, and manual data-entry requirements?
4. Which technical, organizational, economic, security, and privacy factors determine the effectiveness of RFID implementation?

The contribution of the study lies in combining a sector-specific RFID implementation framework with an empirical warehouse case. The proposed approach links the selection of physical identification objects with event-capture rules, WMS and transportation records, baseline performance indicators, total-cost-of-ownership analysis, and post-implementation evaluation. This makes it possible to assess RFID as an operational-management system rather than solely as a tag-reading technology.

1.1. Research Methodology

This study employed a combined research design consisting of a structured literature review and a single-site before-and-after case analysis. The literature review established the theoretical and technical basis for the research and identified documented RFID applications, implementation barriers, performance indicators, economic-assessment approaches, security risks, and gaps in previous studies. The case analysis examined the implementation of RFID-supported identification and event recording under actual warehouse operating conditions.

1.2. Literature Review Procedure

The literature review covered peer-reviewed publications, international standards, technical guidelines, and institutional materials concerning RFID, warehouse management, agricultural traceability, inventory accuracy, supply-chain digitalization, IoT integration, information security, and implementation economics. Sources published between 2005 and 2026 were identified through searches in Google Scholar, Scopus, Web of Science, and ScienceDirect.

The searches used combinations of the following terms: “RFID,” “agricultural logistics,” “warehouse inventory,” “grain traceability,” “RFID implementation,” “RFID inventory accuracy,” “RFID ROI,” “RFID security,” “RFID IoT integration,” “RFID warehouse case study,” and “RFID supply chain management.” Additional standards and implementation guidelines were identified through the official websites of ISO, GS1, the RAIN Alliance, and other organizations responsible for RFID and supply-chain data standards.

Sources were included when they addressed at least one of the following subjects:

1) RFID application in warehouse, transportation, manufacturing, food, or agricultural logistics;
2) RFID-supported inventory or asset control;
3) product-batch or supply-chain traceability;

4) RFID integration with WMS, ERP, TMS, GPS, or IoT systems;
5) measurable operational or economic results;
6) technical, organizational, security, or privacy barriers;
7) RFID implementation frameworks or pilot-project procedures.

Publications were excluded when they focused exclusively on antenna design, signal-processing theory, consumer marketing, or non-logistics applications without a direct connection to the research questions. Duplicate publications and sources lacking sufficient methodological or technical information were also excluded. Following title, abstract, and full-text screening, 20 sources were retained for the principal analysis. The reviewed materials included international standards and implementation guidelines, empirical case studies, systematic literature reviews, and studies addressing agricultural and food-supply-chain traceability.

The selected sources were analyzed according to their industry context, research method, identification technology, implementation setting, reported benefits, limitations, and performance indicators. The results of this analysis were used to define the research gap and develop the sector-specific RFID implementation framework evaluated in the case study.

1.3. Empirical Case Setting

The empirical component was conducted at Ukrainian Treasures Inc., which operates the SkladUSA warehousing and fulfillment service in Minnesota, United States. The company's logistics operations include inbound receiving, storage placement, inventory control, internal warehouse movement, order picking, outbound processing, carrier coordination, and shipment confirmation.

The case covered RFID-supported warehouse operations conducted during 2025–2026. A before-and-after design was applied to compare operations performed before RFID-enabled event capture with operations performed after the RFID process had been configured and connected with warehouse-management records.

The baseline period represented warehouse operations conducted under the existing identification and recording process before the RFID-supported workflow became operational.

The post-implementation period represented comparable operations conducted after RFID tags, readers, event-recording rules, and WMS-related procedures had been introduced. Comparable operational periods were selected to reduce the effect of material differences in workload, transaction type, and warehouse activity.

The examined processes included:

- Inbound receiving and verification of logistics units;
- Placement of received goods into designated storage locations;
- Inventory counting and reconciliation;
- Internal movement between warehouse zones;
- Order picking;
- Outbound verification and shipment confirmation;
- Control of reusable logistics units;
- Identification and review of operational discrepancies.

1.4. Data Collection

The analysis used operational records generated during the normal performance of warehouse activities. The reviewed data included WMS records, RFID-reader and middleware logs, inventory reports, receiving and shipping records, transaction timestamps, exception records, and employee time records associated with selected logistics operations.

All available records meeting the inclusion requirements for the selected baseline and post-implementation periods were included. A record was included when it contained:

- an identifiable logistics unit, product batch, container, pallet, or other tracked object;
- a recorded operational event;
- a date and time;
- a corresponding warehouse or shipping record;
- sufficient information to determine whether the operation had been completed correctly.

Records were excluded when they contained incomplete timestamps, duplicate technical readings, test scans, cancelled transactions, unidentified logistics objects, or insufficient information to verify the outcome of the operation. Repeated detections of the same RFID tag within a single configured event window were treated as one logistics event rather than as separate transactions.

RFID events were reconciled with the corresponding WMS and operational records. A transaction was classified as correctly recorded when the identified logistics object, event type, location, timestamp, and expected warehouse record corresponded with one another.

Events were classified as discrepancies when the system recorded a missing object, an unexpected identifier, an incorrect location, a duplicate operational event, an incomplete transaction, or a mismatch between physical cargo and the relevant warehouse or shipping record.

The analysis used aggregated operational data. Personal information concerning individual employees, drivers, customers, or warehouse users was not included in the reported results.

1.5. Performance Indicators

RFID effectiveness was evaluated using indicators associated with inventory accuracy, RFID reading performance, transaction discrepancies, and process duration. The same calculation rules were applied to the baseline and post-implementation periods wherever the indicator was available during both periods.

Inventory accuracy was calculated as the percentage of audited inventory records that corresponded with the physical inventory:

$$\text{Inventory Accuracy} = \frac{\text{Correctly Matched Inventory Records}}{\text{Total Audited Inventory Records}} \times 100\%$$

A record was considered correctly matched when the physical logistics unit, product batch, recorded quantity, and assigned warehouse location corresponded with the relevant WMS record.

The RFID read-success rate was calculated as the percentage of expected RFID events that were successfully recorded by the system:

$$\text{RFID Read Success Rate} = \frac{\text{Successfully Recorded RFID Events}}{\text{Expected RFID Events}} \times 100\%$$

An expected RFID event represented the passage or handling of a tagged logistics object through a process in which RFID recording was required. Unsuccessful events included missing reads, incomplete reads, unidentified tags, and events that could not be associated with the expected WMS transaction.

The transaction-error rate was calculated as follows:

$$\text{Transaction Error Rate} = \frac{\text{Transactions Containing Confirmed Discrepancies}}{\text{Total Transactions Examined}} \times 100\%$$

Confirmed discrepancies included incorrect receiving records, inventory-location mismatches, incomplete internal-movement records, picking discrepancies, incorrect shipment verification, and differences between physical logistics units and the corresponding documents or WMS data.

Process-time reduction was calculated by comparing the average or total duration of the selected operation before and after implementation:

$$\text{Process Time Reduction} = \frac{\text{Baseline Process Time} - \text{Post-implementation Process Time}}{\text{Baseline Process Time}} \times 100\%$$

For inventory counting, process duration was measured from the beginning of the physical count until completion of record reconciliation. For receiving and shipping, duration was measured from the first recorded operational event until confirmation of the completed WMS transaction.

Additional indicators included the number of manual data-entry operations, the number of unresolved RFID exceptions, the rate of loss or late return of reusable logistics units, and the time required to investigate inventory or shipment discrepancies.

1.6. Data Analysis

Descriptive analysis was used to compare baseline and post-implementation performance. The analysis included transaction counts, percentages, average process duration, absolute changes, and percentage changes. Results were presented in before-and-after tables to show how each indicator changed following RFID implementation.

RFID-reader logs were examined together with WMS and operational records to distinguish technical reading problems from warehouse-process discrepancies. Missing or duplicate reads were not automatically classified as inventory errors. Each event was reviewed against the expected process sequence and the corresponding operational record.

The case results were also compared with findings reported in previous RFID studies. This comparison was used to determine whether the observed changes were consistent with prior research and to identify differences arising from the specific conditions of agricultural and warehouse logistics.

1.7. Economic Assessment

The economic assessment was based on the total cost of ownership rather than the purchase price of RFID tags and equipment alone. The assessed costs included RFID tags, readers, antennas, mobile devices, installation, middleware, software configuration, WMS integration, pilot testing, employee training, maintenance, equipment replacement, technical support, and exception-handling labor.

Economic benefits were derived only from operational changes supported by the reviewed records. These included reductions in inventory-count duration, manual data entry, receiving or shipping discrepancies, reusable-asset losses, and the labor required to identify and reconcile warehouse errors.

Total cost of ownership was calculated as:

$$\text{TCO} = \text{Initial Investment} + \text{Integration Costs} + \text{Operating Costs} + \text{Maintenance Costs} + \text{Exception-Handling Costs}$$

Return on investment was calculated as:

$$\text{ROI} = \frac{\text{Cumulative Verified Benefits} - \text{TCO}}{\text{TCO}} \times 100\%$$

The payback period was calculated as:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Average Monthly Net Benefit}}$$

Costs and benefits that could not be verified through company or operational records were excluded from the final economic calculation.

1.8. Reliability and Limitations

The reliability of the case analysis was supported by the use of several data sources, including RFID logs, WMS records, inventory reports, transaction documents, and operational timestamps. Events were considered confirmed only when the relevant physical, RFID, and warehouse records could be reconciled.

The research was limited to one company and one warehouse operating environment. The results may have been affected by facility layout, transaction volume, employee experience, tag type, antenna positioning, cargo composition, and the maturity of the company's information systems. The before-and-after comparison may also reflect operational changes introduced together with RFID, including employee training, master-data correction, and revised warehouse procedures.

The findings, therefore, describe the examined operational setting and should not be generalized to all agricultural or warehouse logistics systems without additional testing. Further research should apply the same indicators and implementation framework to grain elevators, agricultural warehouses, transportation terminals, and facilities with different cargo types and levels of digital maturity.

2. Theoretical Foundations of RFID Technology

2.1. Concept and Nature of RFID

RFID is a radio-frequency identification technology used to automatically detect objects using radio signals. The basic concept is that a product, pallet, container, transport unit, or other logistics object is equipped with a special RFID tag containing a unique code. This code is read by an RFID reader and transmitted to the company's information system.

In practice, RFID makes it possible to link a physical object to digital data about it. In logistics, this could include information about a product batch, storage location, route, shipment status, or loading or shipping date. This is particularly important in grain logistics, as the movement of grain, containers, vehicles, and accompanying documents requires precise monitoring at every stage.

The main difference between RFID and barcoding is that RFID does not always require a direct line of sight between the tag and the reader. Barcodes have to be scanned manually or at close range, whereas RFID tags can be read more quickly, automatically, and in larger numbers at the same time. For this reason, the technology is useful for warehouses, grain elevators, loading areas, transport hubs, and cargo inspection points.

In supply chains, RFID should not be viewed merely as a tagging tool. Its primary value lies in generating accurate data on logistics assets: product batches, packaging, pallets, containers, transport units, or warehouse zones. This data can subsequently be used for accounting, monitoring operations, analyzing variances, and improving the manageability of logistics processes.

GS1 standards view RFID as a tool for identifying objects in supply chains, and one of the most common solutions across many industries is the use of passive UHF tags, also known as RAIN RFID [2]. This is important for logistics because standardization simplifies interactions between manufacturers, warehouses, carriers, distributors, and end recipients.

The RAIN Alliance also defines RAIN RFID as a passive UHF RFID technology based on ISO/IEC 18000-63 and GS1 UHF Gen2 [9]

2.2. Key Components of an RFID System

There are a few key components to an RFID system: RFID tags, a reader, an antenna, software, and the company's information system. Individually, each element serves a technical purpose, but RFID's true effectiveness is only realized when all components work together as a single system.

An RFID tag is a device that stores information about an object. It can be attached to a product, bag, pallet, container, trailer, packaging, or other logistics asset. The tag stores a unique identification code that the system uses to recognize the object and link it to the corresponding data in the company's database.

In the agricultural sector, RFID tags are used to mark grain shipments, warehouse areas, pallets, containers, truck trailers, or reusable containers. For example, during grain loading, the system automatically records which batch was handed over to the carrier, when the loading took place, and to which destination the cargo is to be delivered.

An RFID reader is a device that receives a signal from a tag and transmits the information to software. Readers can be either stationary or mobile. Stationary scanners are typically installed at warehouse gates, in receiving or shipping areas, or at control points. Mobile scanners are used by employees for inventory taking, cargo inspection, or monitoring the movement of goods.

The antenna is responsible for transmitting and receiving radio signals between the reader and the tag. The stability of the reading depends on its proper placement. For example, if the antennas are installed near the warehouse gates, the system can automatically detect when a pallet or transport unit passes through the control point.

The software processes the received data and converts it into actionable insights. It determines what a specific tag scan signifies: goods receipt, movement within the warehouse, shipment, passing a control point, or a deviation from the route.

For logistics, integrating RFID with WMS, ERP, TMS, or other enterprise systems is essential. Without such integration, RFID will remain merely a technical scanning tool. However, when properly configured, the system automatically updates inventory levels, confirms transactions, reduces the need for manual data entry, and minimizes the risk of human error.

2.3. Types of RFID tags

RFID tags differ in terms of power source, read range, cost, and application. In logistics, three main types are most commonly distinguished: passive, active, and semi-passive tags.

Passive RFID tags do not have their own power source. They are activated by a signal from the reader and transmit their identification code to it. These tags are most commonly used in warehouse and transportation logistics because they are less expensive, more compact, and suitable for mass marking of goods, boxes, pallets, and containers.

In grain logistics, passive tags are best used for tracking pallets, bags, containers, warehouse areas, or product batches. Their advantage lies in the ability to use them on a large scale without significantly increasing the cost per logistics unit.

Active RFID tags have their own battery. This allows them to transmit signals over longer distances and be used to monitor large or valuable objects. In logistics, active tags can be used for containers, trailers, vehicles, specialized equipment, or assets that need to be tracked over a large area.

The drawbacks of active tags are their higher cost and the need for battery maintenance. Therefore, they should not be used for every individual object, but rather for assets whose loss or downtime poses significant financial risks.

Semi-passive RFID tags also have a battery, but it is used primarily to support additional features. For example, these tags can monitor temperature, humidity, or other environmental parameters. This can be useful for products that are sensitive to storage and shipping conditions.

The choice of tag type depends on the task at hand. For standard inventory management, passive tags are sufficient. Active solutions may be more effective for monitoring vehicles, containers, or expensive equipment. For shipments that require temperature or humidity control, it is worth considering semi-passive tags with additional sensor capabilities.

Operating conditions should also be taken into account. In agricultural logistics, the system operates in an environment characterized by dust, moisture, metal structures, large quantities of packaging, and heavy vehicle traffic. Therefore, when selecting tags, it is necessary to check their resistance to the specific conditions of the warehouse, grain elevator, or loading area.

2.4. Operating principle and frequency ranges of RFID systems

The principle behind an RFID system is based on the exchange of radio signals between a reader and a tag. The reader generates a radio frequency field, within which the tag is activated and transmits its code. Next, the information is sent to the software, where it is processed and linked to a specific logistics operation.

For example, when a pallet or container passes through an RFID zone in the warehouse, the system automatically records the movement. If the shipment passes through the shipping gate, the RFID confirms that this specific batch has been handed over for transport. This reduces the number of manual checks and minimizes the risk of errors in documentation or inventory levels.

RFID systems operate in various frequency bands. The most common are LF, HF, and UHF.

LF — the low-frequency band, operating below 135 kHz. It is typically used for short-range applications and specialized tasks that require stable reading over short distances. ISO/IEC 18000-2 specifies a radio interface for RFID devices operating below 135 kHz [3].

HF — high-frequency band at 13.56 MHz. It can be used to identify individual objects, documents, cards, or closed-loop accounting systems. ISO/IEC 18000-3 applies to RFID systems for object identification operating at a frequency of 13.56 MHz [4].

UHF refers to the ultra-high-frequency band of 860–960 MHz. It is the most commonly used band in logistics because it offers a greater range and faster read speeds. UHF is ideal for tracking pallets, boxes, containers, and cargo units, as well as for monitoring their passage through warehouse gates and conducting rapid inventory counts. ISO/IEC 18000-63 specifies a radio interface for RFID devices operating in the 860–960 MHz band [5].

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EPC UHF Gen2 is one of the key standards for passive UHF RFID solutions used across various industries and supply chains [11].

For logistics, UHF RFID is the most practical solution, especially when dealing with large volumes of cargo and the need to quickly read a large number of tags. In agricultural supply chains, this technology can be used to track the movement of product shipments between warehouses, grain elevators, transport vehicles, and shipping points.

In short, RFID technology serves as the foundation for automating cargo identification in logistics. It reduces manual operations, improves inventory accuracy, speeds up warehouse processes, and provides greater visibility into the movement of goods. In the agricultural sector, RFID is particularly promising when combined with GPS monitoring, WMS, ERP, and TMS systems, as this integration makes it possible to track not only the vehicles but also specific cargo throughout the entire supply chain.

2.5. Literature Review and Research Gap

Prior research identifies three principal areas in which RFID is used in logistics: automatic object identification, inventory and asset management, and supply-chain traceability. The significance of RFID extends beyond the replacement of barcodes. RFID-generated events can connect physical operations with warehouse, production, transportation, and quality-control records, provided that the identification structure and system integration have been configured correctly.

Qian et al. examined a traceability system combining two-dimensional barcodes and RFID in wheat-flour production [13]. The study demonstrated the feasibility of a hybrid architecture in which different data carriers were applied at different stages of the process. Its findings are important for agricultural logistics because they show that RFID does not have to replace every existing identification method. Barcode or QR-based identification can remain appropriate for documents, labels, or manually verified objects, while RFID can be used at control points requiring automatic detection.

Deng et al. proposed a traceability scheme for the grain supply chain that integrated product movement with information exchange across supply-chain stages [14]. Costa et al. reviewed RFID-based traceability in agri-food supply chains and identified cost, technical conditions, and organizational preparedness as continuing implementation barriers [15]. These studies establish the potential of RFID in agricultural systems, but they provide less detailed evidence on before-and-after warehouse performance, integration costs, and the operational rules required to connect RFID events with transportation and warehouse records.

Hellström and Wiberg examined an item-level RFID implementation at an automotive-industry supplier and showed how RFID could reduce sources of inventory inaccuracy [16]. The study also emphasized the importance of analyzing the process through which inventory errors arise, rather than treating inventory accuracy as an automatic result of installing RFID equipment.

However, the physical conditions and identification level in automotive manufacturing differ from agricultural logistics, where bulk products must be represented through batches, bags, pallets, containers, seals, or transport units.

Research on adoption barriers indicates that RFID outcomes depend on the interaction of technological and organizational factors. Initial investment, integration requirements, data privacy, employee acceptance, process redesign, and compatibility with existing systems can influence adoption decisions [17, 19].

Reviews of RFID and IoT integration show that combined systems can improve automated data capture and supply-chain visibility, while also increasing the importance of interoperability, system architecture, and data governance [18].

Security research identifies unauthorized reading, tag cloning, tracking, interception, and data modification as material risks in RFID-based systems [20]. These risks become more significant when RFID events are linked with shipment schedules, routes, inventory levels, drivers, employees, or trading partners. Consequently, security and privacy controls must be incorporated during system design rather than added only after deployment.

The reviewed literature confirms the technical potential of RFID, but it also reveals a gap between general descriptions of the technology and sector-specific implementation decisions.

Limited evidence is available on how agricultural and warehouse operators should jointly determine the tagging level, control points, information-system integration, performance indicators, economic threshold, and security controls.

The present study addresses this gap through a framework that combines technical design, operational implementation, performance measurement, and empirical evaluation.

Table 1. Synthesis of prior RFID research

Study	Context	Research approach	Main contribution	Limitations addressed by this study
Qian et al. [13]	Wheat-flour processing	Development and evaluation of a hybrid traceability system	A combination of 2D barcodes and RFID	Limited warehouse ROI and before-and-after operational analysis
Deng et al. [14]	Grain supply chain	Traceability-model development	Integration of product and information flows	Limited evidence from an implemented warehouse process
Costa et al. [15]	Agri-food supply chains	Literature review	Identification of RFID applications and barriers	No sector-specific implementation and KPI framework
Hellström and Wiberg [16]	Automotive manufacturing	Single empirical case study	Analysis of RFID impact on inventory accuracy	Different industry and item-level identification environment
Michael and McCathie [17]	Supply-chain management	Benefit-risk analysis	Cost, compatibility, and privacy considerations	Limited agricultural implementation detail
Tan and Sidhu [18]	RFID and IoT	Literature review	Integration of RFID with IoT-based systems	Limited before-and-after agricultural warehouse evidence
Zhang et al. [19]	Supply-chain digitalization	Systematic literature review	Technological and organizational determinants	Limited facility-level implementation measurement
El Gaabouri et al. [20]	RFID security	Systematic literature review	Authentication and security risks	Limited connection between security controls and logistics workflows

Source: Compiled by the author based on [13–20]

3. Use of RFID in Logistics and Supply Chains

RFID technology is used in logistics for the automatic identification of cargo, packaging, pallets, containers, transport units, and other objects moving through the supply chain. Its practical significance lies in the fact that the system records not only the fact of movement itself, but also the specific object, its status, location, and connection to the corresponding batch of products.

In the agricultural sector, this is particularly important because the movement of goods often involves several stages: warehouse, grain elevator, weighing, laboratory quality control, loading, transportation, and port or rail terminal. At each of these stages, there is a risk of delays, errors in documentation, loss of packaging, incorrect shipments, or discrepancies between actual and recorded data. RFID helps reduce these risks by automatically recording transactions.

3.1. Use of RFID in Warehouse Logistics

In warehouse logistics, RFID is used to automate the receipt, storage, inventory, picking, and shipping of goods. Unlike manual inventory tracking or barcode scanning, RFID allows for faster reading of information from tags and does not require constant direct contact with the object.

This is particularly relevant for warehouses with a high volume of operations, where delays in receiving or shipping goods affect the subsequent movement of cargo.

During the receiving process, the RFID system automatically records the arrival of a pallet, container, packaging, or other logistics unit. The data from the tag is transmitted to the company's information system and reconciled with the order, delivery note, or delivery schedule. This reduces the need for manual data entry and minimizes errors.

During storage, RFID helps monitor the placement of goods in the warehouse. Tags can be used to identify pallets, containers, warehouse areas, shelving, or reusable containers. This allows employees to locate the desired shipment more quickly, and the system automatically updates its location data.

RFID is particularly valuable for inventory management. Instead of manually checking each object, a company can quickly scan a large number of tags and compare actual stock levels with the data in the system. This improves the accuracy of inventory records and helps identify shortages, misclassifications, or discrepancies more quickly.

In grain logistics, RFID should be used not to tag the grain itself as a bulk product, but to identify batches, bags, pallets, containers, seals, packaging, or transport units. For example, at a grain elevator, RFID records which batch was received, its storage location, the time of shipment, and the carrier to whom it was transferred.

During shipping, RFID makes it possible to verify that the correct batch is being loaded onto a specific vehicle. This reduces the risk of incorrect loading, mis-sorting, and discrepancies between the actual cargo and the accompanying documents.

3.2. RFID in Transportation Logistics and Cargo Tracking

In transportation logistics, RFID is used to track the movement of goods between logistics points: warehouses, grain elevators, manufacturing sites, terminals, ports, or delivery points. The main purpose of the technology is to verify that cargo has passed through control points and to ensure the accurate identification of the logistics unit.

FID is used to mark containers, trailers, pallets, reusable packaging, seals, or individual cargo units. When an object passes through an RFID zone—such as a warehouse gate, a weigh station, or a control point—the system automatically records the event. This provides visibility into when the cargo was loaded, when it left the warehouse, when it arrived at the next destination, and whether its movement aligns with the planned logistics.

In transportation processes, RFID should be combined with GPS tracking. GPS shows the vehicle's location, while RFID confirms exactly which cargo, shipment, or container is being transported. This combination is particularly useful for agricultural transport, as it allows for monitoring not only the vehicle's route but also the cargo's compliance with the documentation, the order, and the delivery schedule.

For example, in grain logistics, GPS can track a truck's route from the grain elevator to the port, while RFID can confirm that the specific batch of grain was loaded onto that vehicle. When cargo passes through an RFID control point at an elevator, weighing station, or terminal, the system creates a continuous digital trail of the shipment's movement.

RFID is also useful for tracking reusable containers, trailers, shipping containers, and seals. It is precisely these objects that are often lost, returned late, or used without proper tracking. Automatic identification improves control over their movement, reduces losses, and increases accountability among those involved in the transportation process.

3.3. RFID in Manufacturing and International Supply Chains

In manufacturing supply chains, RFID is used to track the movement of raw materials, semi-finished products, finished goods, packaging, and equipment. The technology tracks the progress of a specific object: receipt, processing, packaging, storage, shipment, or handover to the carrier.

In the agricultural sector, RFID can be useful during post-harvest processing, batch formation, packaging, storage, and preparation of products for export. In these processes, it is important to maintain a link between the batch, its quality characteristics, storage location, documentation, and subsequent route. RFID helps make this connection more transparent and easier to control.

For agricultural products, traceability is important not only in terms of the route but also in terms of the quality of the shipment. RFID helps link a logistics unit to data on the product's origin, storage conditions, laboratory testing, weighing results, and subsequent shipment.

In food and agricultural supply chains, RFID can support not only inventory management but also product traceability, safety monitoring, and faster response times in the event of a product recall or return [12].

Practical studies in the field of wheat processing show that a combination of RFID and barcoding can be used to track batches in flour milling processes [13].

In the grain supply chain, RFID is also viewed as a tool for establishing a traceability model that integrates product movement and the flow of information across supply chain stages [14].

Scientific reviews on traceability in agri-food supply chains confirm that RFID holds significant potential for the agricultural sector, although its implementation is hampered by cost, technical constraints, and organizational barriers [15].

In international supply chains, cargo passes through a large number of participants: the manufacturer, warehouse, carrier, freight forwarder, customs broker, port, distributor, or end recipient. If the passage through key control points is recorded automatically, the company can identify delays, discrepancies, or route deviations more quickly.

RFID also facilitates data standardization among supply chain participants. This is important for international logistics, where different companies may use different accounting and transportation systems. A unified identification system simplifies information sharing, reduces the need for manual reconciliation, and builds trust among partners [6].

In international shipping, RFID is used to track containers, pallets, shipping containers, seals, and cargo units. This helps verify that cargo has passed through logistics points, improves traceability, and reduces the risk of loss.

In short, RFID in logistics facilitates the transition from manual or piecemeal tracking to systematic management of the movement of goods. In warehouses, it improves inventory accuracy and speeds up operations. In transportation logistics, it helps link cargo to routes and control points. In manufacturing and international supply chains, RFID improves traceability, data standardization, and coordination among process participants.

3.4. Critical Comparison of RFID with Alternative Technologies

RFID should not be treated as the preferred identification technology for every logistics process. The appropriate solution depends on the type and value of the object, transaction volume, required level of automation, available infrastructure, operating environment, and required location accuracy.

Conventional barcodes and QR codes remain appropriate where employees can visually access the label, and transaction volumes do not justify automated RFID infrastructure. Their low implementation cost makes them suitable for documents, individual packages, customer-facing information, and low-frequency verification. Their principal limitation is that each label normally has to be visually positioned and scanned.

Passive UHF RFID is more appropriate when a company needs automatic identification at receiving, shipping, inventory, or other defined control points. It can support the detection of several tagged objects within one operational event. Its performance, however, depends on tag orientation, antenna placement, the material to which the tag is attached, and the presence of metal, liquids, dust, or other sources of interference.

Active RFID and BLE-based solutions may be more appropriate for higher-value reusable assets that require repeated location updates across a facility. Their battery-powered operation supports longer-term transmission but increases tag cost, maintenance requirements, and battery-management responsibilities. These technologies are therefore less suitable for inexpensive, high-volume disposable packaging.

GPS provides vehicle-level or outdoor geographic visibility but does not independently confirm which product batch, pallet, container, or seal is carried by a specific vehicle. RFID and GPS, therefore, perform different functions. GPS records the position of the transport unit, while RFID links the transport unit to identified cargo and records its passage through configured logistics points.

For agricultural logistics, a hybrid architecture is often preferable. QR or barcode identifiers may be retained for documents and manually inspected packages; passive RFID may identify batches, bags, pallets, seals, containers, and warehouse movements; GPS may monitor vehicles and routes; and WMS, ERP, TMS, or EPCIS-compatible systems may combine these events into a single operational record.

Table 2. Comparison of identification and tracking technologies

Technology	Principal function	Main advantage	Main limitation	Appropriate application
Barcode/QR code	Manual object or document identification	Low implementation cost and broad compatibility	Requires individual visual scanning	Documents, labels, low-volume operations
Passive UHF RFID	Automatic identification at configured read points	Multi-object reading without direct visual alignment	Sensitive to tag placement and operating environment	Receiving, shipping, inventory, pallet and container identification
Active RFID/BLE	Repeated identification or zone-level asset tracking	Longer operating range and periodic transmission	Battery and maintenance costs	High-value equipment and reusable assets

GPS	Geographic tracking	Outdoor vehicle and route visibility	Does not independently identify cargo inside the vehicle	Fleet and route monitoring
RFID + GPS/WMS	Combined cargo, vehicle, and process visibility	Connects physical cargo with route and warehouse events	Requires integration and consistent master data	Agricultural and multi-stage logistics

Source: Compiled by the author based on [2, 8, 13, 18, 19]

The comparison shows that RFID is justified where automation, transaction volume, or the risk of identification errors creates sufficient operational value. Where these conditions are absent, barcodes or QR codes may remain more economical. The implementation decision should therefore be based on process requirements rather than on the assumption that a newer technology is necessarily the better solution.

4. Benefits, Risk Factors, and Limitations of implementing RFID Systems

The implementation of RFID systems in logistics enables companies to automate cargo identification, reduce the number of manual operations, and improve the manageability of warehouse and transportation processes.

However, the effectiveness of this technology depends not only on the availability of tags and readers. It is important to select the right objects for marking, ensure high-quality technical configuration, integrate with information systems, and ensure the company is prepared to change its operational procedures.

In the agricultural sector, RFID is most effective when it is not used in isolation but as part of an integrated monitoring system: in conjunction with GPS tracking, inventory management, transportation planning, and digital document management. In this format, the technology not only helps read data more quickly but also generates reliable information for managing product batches, packaging, transport units, and delivery control points.

4.1. Main Advantages of RFID

One of the main advantages of RFID is improved tracking accuracy. In traditional logistics processes, a significant portion of errors arises from manual data entry, delayed updates, incorrect scanning, or discrepancies between the actual cargo and the documentation. RFID reduces these risks by automatically recording transactions and transmitting information to the management system more quickly.

The second advantage is a reduction in the time required to complete operations. During receiving, inventory, or shipping, employees do not need to check each product unit manually. The RFID reader can detect multiple tags simultaneously, which is particularly useful for warehouses, grain elevators, loading areas, and transport yards with high cargo traffic.

RFID also reduces the risk of mis-sorting, incorrect loading, and loss of logistics units. If a pallet, container, packaging, or seal is equipped with an RFID tag, the system can automatically verify that it corresponds to a specific batch, order, or route. In grain logistics, this is important when assembling shipments, handing over cargo to the carrier, and monitoring its arrival at the next destination.

Another key benefit is improved traceability. RFID enables tracking of the entire sequence of operations involving cargo: receipt, storage, movement, shipment, passage through a control point, or return of packaging. This digital trail helps identify the source of delays, losses, or discrepancies more quickly.

A key advantage of RFID is that it enhances accountability among participants in the logistics process. When the transfer of packaging, seals, containers, or shipments is recorded automatically, the company gains a clearer chain of accountability: who received the object, when it was transferred, where a delay occurred, or at which stage a discrepancy arose. This is important for logistics systems in which a single shipment passes through several departments or external partners.

RFID generates high-quality operational data for business management. This data can be used to analyze inventory, plan transportation, evaluate warehouse operations, monitor carriers, and calculate the efficiency of logistics processes. This is one of the key advantages of the technology: it transforms individual warehouse and transportation events into data suitable for management analysis.

4.2. Challenges and Technical Limitations

Despite its advantages, RFID has a number of technical limitations that must be taken into account before implementation.

One of the key factors is the environment in which the system will operate. Metal structures, liquids, dust, humidity, densely packed goods, or improper tag placement can affect read quality.

This is particularly relevant in the agricultural sector, as warehouses, grain elevators, transport yards, and loading areas often have challenging operating conditions. Dust, temperature fluctuations, humidity, metal equipment components, and heavy traffic can compromise system stability. Therefore, tags, antennas, and readers should be selected with the specific environment in mind.

An important consideration is selecting the appropriate tagging level. For bulk products, such as grain, RFID should be applied not to the product itself, but to batches, containers, bags, seals, transport units, storage areas, or associated logistics assets. If the tagging level is chosen incorrectly, the solution may prove to be expensive, difficult to maintain, and insufficiently effective.

Problems can also arise due to improper placement of RFID tags. If a tag is attached in an area where the signal is blocked by metal, damaged during loading, or fails to enter the read range, the system will be unable to reliably track movement. Therefore, before scaling up an RFID solution, testing must be conducted under real-world conditions in a warehouse, grain elevator, or along a transport route.

A key technical challenge is configuring the reading zone. A zone that is too wide may result in unnecessary tags being detected, and one that is too narrow may cause required objects to be missed. For logistics, it is essential that the system clearly distinguish between different types of operations: receiving, movement, shipping, return of containers, or passing through a control point.

Special attention should be paid to the human factor. If staff do not understand how RFID works or continue to keep records according to the old rules, the technology will not deliver the expected results. Therefore, the implementation of RFID must be accompanied by employee training, a review of procedures, and a clear division of responsibilities for working with the new system.

Barriers to RFID implementation in supply chains are often related not only to technology but also to high initial costs, compatibility issues, data privacy, and resistance to change [17].

Recent research on RFID in supply chain management emphasizes that the success of its implementation depends on a combination of technical and socio-organizational factors: strategic decisions, staff readiness, a culture of change, system integration, and cost control [19].

4.3. Issues of Cost, Integration, and Data Security

The cost of implementing RFID is not limited to the price of the tags. Total costs include readers, antennas, software, integration with WMS, ERP, or TMS systems, infrastructure setup, testing, staff training, and technical support. That is why, before launching a project, it is important to assess the overall economics of the solution rather than the cost of the equipment alone.

The best approach is to launch a pilot project. RFID can be tested at a single warehouse, grain elevator, route, product group, or container type. A pilot project allows you to verify read quality, identify technical issues, assess changes in operational speed, and determine whether the solution makes economic sense for future scaling.

Before scaling up, the company must define key performance indicators (KPIs): inventory cycle time, inventory accuracy, number of shipping errors, packaging loss rate, receiving speed, and costs associated with manual operations. Comparing these indicators before and after the pilot project is what allows for an assessment of the actual effectiveness of RFID.

Integration with information systems is critical to the effectiveness of RFID. If data from tags is not transmitted to a WMS, ERP, TMS, or other management system, the company receives only the fact that the tags can be read, rather than a fully functional control tool. The RFID system should automatically update inventory levels, confirm transactions, track movements, generate events, and transmit information to the appropriate staff members.

It is also important to consider the quality of the reference data. An RFID system will only be effective if the company has correctly configured the codes for batches, warehouse zones, transport units, packaging, business partners, and routes.

If the accounting system contains duplicates, outdated records, or an inconsistent structure in its master data, RFID will transmit inaccurate data more quickly. Therefore, before scaling up the project, it is advisable to clean up and standardize the master data.

The complexity of integration often stems from the fact that different participants in the supply chain use different accounting systems. This is particularly common in agricultural and international logistics: producers, warehouses, carriers, freight forwarders, ports, and distributors may all work with different data formats. Therefore, when implementing RFID, it is necessary to establish in advance the rules for information exchange, the coding of objects, and the procedures for updating data.

Data security is also a concern. An RFID system may contain information about shipments, routes, inventory levels, partners, delivery schedules, and logistics operations. Such data has commercial value, and access to it should therefore be restricted based on user roles. It is important to implement authentication, activity logging, system access control, and protection of data transmission channels.

Security concerns regarding RFID systems include the risks of unauthorized reading, tag cloning, data tampering, tag tracking, and communication interception; therefore, security measures must be incorporated as early as the system design phase [20].

A separate risk is the excessive collection of data without a clear business objective. RFID should be implemented for specific purposes: improving inventory accuracy, reducing inventory time, tracking packaging, minimizing shipping errors, or enhancing traceability. If the company has not defined its expected performance metrics, it will be difficult to evaluate the project's results.

In short, the benefits of RFID are most evident when the technology is implemented as part of an overall logistics system. In the agricultural sector, RFID improves inventory accuracy, reduces losses, enhances container management, and strengthens cargo traceability. At the same time, the success of such a solution depends on the right choice of tags, testing in real-world conditions, integration with information systems, staff training, and data protection.

4.4. Data Security, Privacy, and Legal Considerations

RFID implementation creates security requirements at the tag, reader, middleware, application, and database levels. Although a tag may contain only an object identifier, the information associated with that identifier can include inventory status, shipment schedules, routes, customer records, warehouse locations, or the identity of the person responsible for an operation.

Unauthorized reading creates a risk that an external party may obtain information about logistics objects or cargo movements. Tag cloning can result in a false physical object being represented as an authorized logistics unit.

Interception or modification of communications between readers and middleware can create inaccurate warehouse events. Unauthorized access to the management system can expose commercially sensitive information or allow inventory records to be changed.

Security controls should therefore be incorporated into the RFID architecture. Reader access should be restricted, devices should be authenticated, communication channels between readers, middleware, and enterprise systems should be protected, and system activity should be recorded in audit logs.

User access should follow role-based authorization rules. Exceptions such as duplicate identifiers, unexpected read points, impossible event sequences, or repeated failed readings should be detected and reviewed.

Privacy requirements arise where RFID-generated events can be linked directly or indirectly to identifiable individuals. Examples include RFID records associated with a particular driver, employee, access badge, vehicle assignment, or work-performance record. In these circumstances, data minimization, purpose limitation, defined retention periods, privacy-by-design measures, and appropriate security controls should be applied in accordance with the applicable legal framework, including Articles 5, 25, and 32 of the GDPR [21].

RFID data should be retained only for a defined operational, contractual, security, or regulatory purpose. Access to shipment and employee-related data should be separated where possible. Object identifiers should not contain unnecessary personal information, and personal data should not be stored directly on an RFID tag unless a documented operational and legal requirement exists.

Table 3. RFID security and privacy risks

Risk	Possible consequence	Control measure
Unauthorized tag reading	Disclosure of cargo or asset information	Controlled read zones, access restrictions, and appropriate tag settings
Tag cloning	False identification of a logistics object	Identifier validation, authentication, and duplicate-event detection
Communication interception	Disclosure or modification of event data	Protected reader–middleware communication and network controls
Data tampering	Incorrect inventory or shipment records	Audit logs, integrity checks, restricted update permissions
Unauthorized user access	Disclosure or manipulation of logistics data	Role-based access control and activity logging
Tracking of identifiable individuals	Privacy and employment-monitoring risks	Data minimization, purpose limitation, retention controls
Reader or network failure	Loss of operational visibility	Fallback procedures, local buffering, redundancy and recovery testing

Source: Compiled by the author based on [20, 21].

5. Stages of implementing RFID in a Company's Logistics System

The implementation of RFID into a company's logistics system should begin not with the purchase of equipment, but with an analysis of the processes that require automation. The technology will only be effective if it is integrated into the company's actual operational model: receiving, storage, handling, shipping, transportation, and tracking the return of containers or other logistics assets.

In the agricultural sector, RFID should be implemented in phases. Warehouses, grain elevators, loading areas, weighing stations, laboratory testing facilities, and shipping areas each operate according to different procedures; therefore, a universal solution for all these areas typically does not yield the desired results.

The best approach is a gradual one: first identify the problem areas, then test the solution on a limited process, and finally integrate the system with accounting and transportation platforms.

5.1. Analysis of the Company's Needs and Logistics Processes

The first step is to audit the company's logistics processes. At this stage, it is necessary to identify exactly where delays, errors, losses, or duplicate operations occur.

The analysis should cover product receipt, warehouse storage, inventory, order picking, loading, handover to the carrier, and monitoring the arrival of the shipment at the next destination.

In agricultural logistics, it is important to analyze the movement of a shipment of products from the moment it is received at the warehouse or grain elevator until it is loaded onto a vehicle. It is necessary to understand which data is recorded manually, which documents accompany the shipment, where the weighing takes place, how quality control results are communicated, who is responsible for confirming the shipment, and how the actual cargo is verified against the records.

At this stage, it is also necessary to define the objectives of the RFID implementation. These objectives should be specific: reducing inventory counting time, minimizing shipping errors, tracking reusable containers, recording the passage through control points, improving inventory accuracy, or creating a digital trail of the batch's movement. Without clearly defined goals, RFID can turn into a technical project without any measurable business results.

It is also important to record baseline metrics prior to implementation: cargo receipt time, inventory duration, the number of errors during order picking or shipping, packaging losses, and the frequency of discrepancies between documentation and actual data. These indicators will ultimately make it possible to assess the effectiveness of the RFID solution.

5.2. Selecting the type of RFID tags, readers, and tagged items

After analyzing its processes, the company must determine exactly which objects need to be marked. In logistics, these may include pallets, containers, bags, transport packaging, trailers, seals, warehouse areas, or individual cargo units.

For agricultural products, it is important to choose the correct level of tagging: in the case of grain, RFID tags should be attached to the batch, container, seal, transport unit, or storage area, rather than to the bulk product itself.

Table 4. Selection of RFID-tagged objects in agricultural logistics

Object of marking	Applications	What is being controlled?	Practical benefits
Batch of products	warehouse, grain elevator, shipping area	origin, status, quality, route	reducing discrepancies between actual data and documentation
Pallet or bag	warehouse storage, order picking, shipping	quantity, storage location, movement	faster search and more accurate inventory
Reusable containers	warehouse, loading area, return of containers	turnover, transfer between responsible parties, return	Reduced waste and better control over usage
Seal	transportation, control points, terminal	the integrity of the cargo, the fact of its transfer to the carrier	reducing the risk of tampering or unauthorized access
Container or trailer	transport logistics, port, terminal	securing cargo to the transport unit	more precise control of the voyage and compliance with the route
Storage area or gate	receipt, transfer, shipment	proof of passing a control point	automatic tracking of a logistics event

Source: Compiled by the author.

This level of detail helps prevent excessive or incorrect marking. Rather than determining the maximum number of RFID tags, a company should identify the optimal level of marking that ensures monitoring of precisely those operations where the greatest risks of errors, losses, or delays arise.

The choice of tag type depends on the operating conditions. Passive tags are typically suitable for large-scale inventory management. Active solutions may be appropriate for tracking containers, trailers, equipment, or other valuable assets. If the cargo requires monitoring of temperature, humidity, or other environmental parameters, you should consider tags with additional sensor capabilities.

Equally important is the selection of scanners. Stationary scanners should be installed in areas where cargo passes through mandatory control points: warehouse gates, the receiving area, the shipping area, the weighing station, or the access route to the loading area. Mobile scanners can be used for inventory management, batch verification, container tracking, or operations in areas where a fixed infrastructure is impractical.

During the technical design phase, it is necessary to take into account not only the type of equipment but also the parameters of the read zone, regional requirements for UHF/RAIN RFID, tag density, and the flow of goods through the control point [10].

At this stage, you also need to establish guidelines for mark placement. Improper mounting can reduce read quality, especially in environments with dust, humidity, metal structures, or heavy traffic. Therefore, the technical solution must take into account the actual environment of the warehouse, grain elevator, or loading area.

5.3. Pilot Project and Testing of the System

A pilot project is an essential step before the large-scale implementation of RFID. Its purpose is to test how the system performs in real-world conditions at the facility, rather than just in the equipment supplier's technical diagram. For the pilot project, it is advisable to select a limited but representative process: one warehouse, one elevator, one product group, one type of packaging, or one transportation route.

As part of the pilot project, it is necessary to test the quality of tag reading, the reliability of the readers, the accuracy of event logging, and the consistency of the data received with actual transactions. For example, the system must correctly distinguish between receiving, moving, shipping, returning containers, or passing through a control point. If the RFID zone detects additional objects or misses required tags, the settings must be adjusted before scaling up.

In grain logistics, pilot projects should be conducted where operational risks are highest: in the receiving area at the grain elevator, during batch formation, when transferring cargo to the carrier, or when inspecting reusable containers. This helps determine whether RFID actually reduces discrepancies between actual and recorded data.

The results of the pilot should be evaluated based on predefined metrics. These metrics may include receiving speed, inventory count time, the number of shipping errors, packaging loss rates, inventory accuracy, scan stability, and the cost of processing a single logistics operation. If the pilot does not yield measurable results, the solution must be refined before moving on to wider implementation.

5.4. Integration with the Company's Information Systems

RFID should be integrated with the company's information systems; otherwise, it will remain merely a tool for technical data capture. Data from the tags must be fed into the WMS, ERP, TMS, GPS monitoring system, or any other platform used to manage the warehouse, transportation, inventory, and documentation.

During the integration phase, you need to determine which events the RFID system should track. These may include receiving goods, moving goods within the warehouse, transferring goods to storage, loading goods onto vehicles, passing through a control point, returning containers, or detecting discrepancies. For each event, responsible parties, data processing rules, and procedures for responding to errors must be established.

Special attention should be paid to the coding of objects. The company must determine in advance how batches, pallets, containers, seals, transport units, warehouse zones, and other objects will be identified within the system. If the coding is unclear, it will be difficult to use RFID data for inventory management, routing, or delivery tracking.

In grain logistics, RFID data should be combined with information on batch quality, weighing results, documentation, the carrier, and the route. This integration makes it possible to view not just a single tag scan, but the entire logistics process: which batch it is, where it came from, where it was received, what its quality metrics are, to whom it was transferred, and where it is to be delivered [6].

5.5. Staff Training and Solution Scaling

Once the system has been technically configured, staff must be trained to work with the new accounting logic. Employees in the warehouse, grain elevator, transportation department, quality control, and administrative accounting must understand which operations are tracked by RFID, how to handle reading errors, who is responsible for verifying data, and how the system affects their daily work.

Training should include not only technical instructions but also explanations of changes to processes. If employees continue to follow the old manual procedures or do not trust the system's data, the effectiveness of RFID will be reduced. Therefore, the implementation must be accompanied by an update of internal regulations, job descriptions, and rules of responsibility.

RFID solutions should be scaled up gradually. Following a successful pilot, the system can be expanded to other warehouse areas, additional container types, new routes, other grain elevators, or transportation operations. At each stage, it is necessary to verify the quality of data collection, the stability of the integration, the readiness of the staff, and whether the results meet the expected targets.
Separately, provisions should be made for technical support and regular system audits.

RFID tags can become damaged, antennas require proper configuration, and the company's logistics processes may change. Therefore, once implemented, the system must not only function properly but also be continuously maintained, tested, and adapted to new operating conditions.

Process analysis

↓

Identifying problem areas

↓

Selecting objects for marking

↓

Selection of tags, readers, and read zones

↓

Pilot project

↓

Integration with WMS / ERP / TMS / GPS

↓

Staff training

↓

Scaling the solution

↓

KPI assessment and system adjustments

Fig. 1 Logic of RFID implementation within the company's logistics system

This approach avoids a purely technical implementation of RFID. The company first identifies an operational problem, then tests the technical solution in real-world conditions, and only after confirming its effectiveness, implements the system across other warehouses, routes, or types of logistics facilities.

Therefore, the implementation of RFID into a company's logistics system should be phased and carefully managed. First, it is necessary to analyze the processes, identify the objects to be marked, conduct a pilot test, verify technical stability, integrate the system with accounting platforms, train staff, and only then scale the solution. In the agricultural sector, this approach helps avoid merely going through the motions of implementing the technology and turns RFID into a practical tool for monitoring, tracking, and managing the supply chain.

6. Assessment of the Effectiveness and Future Prospects of RFID

The assessment of RFID effectiveness should be based not on the mere fact that tags and readers have been installed, but on how the company's logistics processes have changed following the system's implementation. For logistics, it is necessary to measure whether warehouse operations have become faster, whether the number of errors has decreased, whether inventory control has improved, and whether the level of losses in packaging, cargo, or time spent on operations has been reduced.

In the previous sections, RFID was discussed as a tool for automatic identification, tracking the movement of goods, and increasing supply chain transparency. When assessing its effectiveness, the key question is whether this technology delivers measurable managerial and economic results. That is why, before implementing RFID, a company must establish baseline metrics and, once the system is up and running, compare them with actual results.

6.1. Key performance Indicators for RFID: Inventory Accuracy, Transaction Speed, Loss Rate

The first key performance indicator for RFID is inventory accuracy. In logistics processes, errors often arise due to manual data entry, untimely inventory updates, incorrect documentation, or discrepancies between the actual cargo and the data in the system. Once RFID has been implemented, the company can assess the extent to which such discrepancies have been reduced.

For a warehouse, grain elevator, or transshipment site, an important indicator is that the actual inventory matches the data in the accounting system. Before RFID was implemented, inventory levels were checked manually and updated with a delay; now that the process has been automated, the system can more quickly record the receipt, movement, shipment, or return of containers. GS1 notes that standards-based RFID helps to quickly and accurately collect data on objects, maintain inventory records, and improve supply chain visibility [7].

Practical studies on the impact of RFID on inventory accuracy confirm the value of assessing the technology's effectiveness by measuring the degree to which actual inventory levels match the data in the information system [16].

The second key metric is the speed of operations. RFID reduces the time required for receiving, inventorying, locating cargo, picking, and shipping. Employees do not need to scan each item manually: the scanner can read multiple tags at once if the system is configured correctly. This is particularly useful for warehouses and grain elevators during periods of high seasonal demand.

The third indicator is the loss rate. In logistics, losses can involve not only products but also pallets, containers, seals, trailers, reusable packaging, or warehouse equipment. RFID helps track the location of a logistics object, identify to whom it was transferred, and determine at which stage a discrepancy occurred. This is particularly relevant in the agricultural sector, as containers, seals, and transport units often pass through the hands of several parties involved.

Additional KPIs include:
1. time spent on inventory;
2. number of errors during receiving and shipping;
3. frequency of mis-sorting;
4. level of losses or late return of containers;
5. speed of data updates in the system;
6. number of manual operations;
7. transport downtime during loading or unloading;
8. number of discrepancies between documents and actual data.

Agricultural enterprises should also verify that each shipment matches the weighing data, product quality, storage location, route, and accompanying documents. This approach allows RFID to be viewed not merely as a warehouse technology, but as a tool for managing the entire logistics operation.

To make the evaluation reproducible, each KPI should be connected to a defined data source, observation period, unit of measurement, and calculation rule. Inventory accuracy should be calculated from verified matches between physical inventory and WMS records. Inventory-count duration should be measured from the start of the counting operation until the reconciliation of identified discrepancies. The transaction-error rate should include only confirmed receiving, movement, picking, or shipping discrepancies.

Table 5. RFID evaluation indicators

Indicator	Measurement rule	Data source
Inventory accuracy	Correctly matched records / audited records × 100%	Physical count and WMS records
Inventory-count duration	Total time required to count and reconcile inventory	Employee time or WMS logs
RFID read-success rate	Recorded RFID events / expected RFID events × 100%	RFID middleware logs
Receiving time	Time from arrival to confirmed WMS receipt	Gate, RFID and WMS timestamps
Shipping error rate	Confirmed incorrect shipments / total shipments × 100%	Shipping and exception records
Manual data-entry volume	Number of manually entered logistics transactions	WMS or ERP audit logs
Reusable-asset loss rate	Unreturned or unlocated assets / issued assets × 100%	Asset and RFID records
Vehicle processing time	Arrival-to-departure time at the facility	GPS, gate and WMS timestamps

The RFID read success rate should be calculated against the number of RFID events expected under the defined process rules. A low read-success rate may indicate improper tag placement, unsuitable tag type, interference, poor antenna configuration, or incorrect movement through the read zone.

This indicator should therefore be examined together with operational outcomes rather than treated solely as a technical measure.

6.2. Cost-Effectiveness: Costs, Payback Period, and ROI

The economic feasibility of RFID should be assessed on the basis of the complete implementation lifecycle rather than the purchase price of tags and readers.

RFID creates economic value only when the operational benefits produced by automatic identification, event recording, and information-system integration exceed the initial and recurring costs of the solution.

The economic result depends on the level at which logistics objects are tagged, the number of processed transactions, the possibility of reusing tags, the required reading infrastructure, the existing quality of warehouse data, and the extent of integration with WMS, ERP, TMS, GPS, or other enterprise systems.

A technically functional RFID system may still be economically unjustified if it automates a low-volume process or if the cost of the identified operational problem is lower than the cost of implementation.

6.2.1. Structure of RFID Implementation Costs

RFID implementation costs can be divided into initial investment, integration costs, implementation-preparation costs, and recurring operating costs.

Initial investment includes RFID tags, fixed and mobile readers, antennas, mounting equipment, network infrastructure, mobile devices, and other hardware required to operate the system. Equipment costs depend on the number of control points, the type of RFID tags, the required reading distance, the operating environment, and the need to protect hardware from dust, humidity, temperature changes, vibration, or mechanical damage.

Integration costs include middleware, software configuration, database development, WMS or ERP integration, event-processing rules, application programming interfaces, and the synchronization of RFID identifiers with master data. If the company's records contain duplicate product codes, inconsistent warehouse-location identifiers, or outdated information, additional resources may be required to clean and standardize the data before implementation.

Implementation-preparation costs include process analysis, technical surveys, pilot testing, antenna positioning, read-zone configuration, employee training, and the development of operating and exception-handling procedures. Temporary productivity losses during testing and employee adaptation should also be included where they can be documented.

Recurring costs include software licences, technical support, equipment maintenance, replacement of damaged tags or readers, system monitoring, cybersecurity controls, employee retraining, and the manual resolution of incomplete or incorrect RFID events. These expenditures may continue throughout the operational life of the system and should not be excluded from the economic assessment.

The total cost of ownership was calculated as follows:

$$\mathrm{TCO} = \mathrm{C_i} + \mathrm{C_{int}} + \mathrm{C_p} + \mathrm{C_o} + \mathrm{C_m} + \mathrm{C_r} + \mathrm{C_e}$$

where:

- $\mathrm{C_i}$ represents the initial hardware and installation investment;
- $\mathrm{C_{int}}$ represents software and information-system integration costs;
- $\mathrm{C_p}$ represents pilot testing, process preparation, and employee-training costs;
- $\mathrm{C_o}$ represents recurring operating costs;
- $\mathrm{C_m}$ represents maintenance and technical-support costs;
- $\mathrm{C_r}$ represents equipment and tag-replacement costs;
- $\mathrm{C_e}$ represents exception-handling costs.

For an assessment covering several years, recurring costs should be calculated for the complete analysis period:

$$\mathrm{TCO_H} = \mathrm{C_i} + \mathrm{C_{int}} + \mathrm{C_p} + \sum_{t=1}^{H}\left(\mathrm{C_{o,t}} + \mathrm{C_{m,t}} + \mathrm{C_{r,t}} + \mathrm{C_{e,t}}\right)$$

In this formula, H represents the selected assessment period in years, while t represents each individual year within that period.

Measurement of Operational Benefits

RFID benefits should be calculated only from operational changes supported by the warehouse, inventory, RFID, and financial records.

Potential or expected benefits should not be treated as realized savings unless they can be connected to an actual reduction in labor, errors, losses, downtime, or another measurable cost.

The principal benefit categories include:

- reduced inventory-count duration;
- reduced manual data entry;
- fewer receiving, picking, and shipping discrepancies;
- reduced loss or late return of reusable logistics assets;
- shorter processing time at receiving and shipping points;
- faster investigation and reconciliation of warehouse discrepancies;
- increased process capacity without a proportional increase in labor.

The illustrative warehouse scenario examined in this study showed a reduction in inventory-count duration from 16 hours to 4 hours. The percentage reduction was calculated as follows:

$$\text{Inventory Time Reduction} = \frac{16-4}{16} \times 100\% = 75\%$$

The scenario, therefore, demonstrates a time saving of 12 labor hours per inventory count. This operational result does not automatically represent a financial saving. The monetary value depends on the number of inventory counts conducted during the year, the number of participating employees, and the applicable hourly labor cost.

Annual inventory labor savings should be calculated as follows:

$$S_i = (T_b - T_a) \times N_i \times N_e \times C_h$$

where:

- S_i represents annual inventory labor savings;
- T_b represents the duration of one inventory count before implementation;
- T_a represents the duration of one inventory count after implementation;
- N_i represents the number of inventory counts conducted annually;
- N_e represents the number of employees participating in each count;
- C_h represents the average hourly labor cost.

Using the time values from the illustrative scenario, the formula becomes:

$$S_i = (16 - 4) \times N_i \times N_e \times C_h$$

Savings associated with reduced manual data entry should be calculated on the basis of the number of avoided manual transactions, the average time required for each transaction, and the hourly labor cost:

$$S_m = (M_b - M_a) \times \frac{T_m}{60} \times C_h$$

where:

- S_m represents annual manual-entry savings;
- M_b represents the annual number of manual transactions before implementation;
- M_a represents the annual number of manual transactions after implementation;
- T_m represents the average number of minutes required to enter and verify one transaction;
- C_h represents the average hourly labor cost.

Savings resulting from fewer warehouse or shipment discrepancies should be calculated as follows:

$$S_d = (E_b - E_a) \times C_e$$

where:

- S_d represents annual savings from reduced discrepancies;
- E_b represents the annual number of confirmed discrepancies before implementation;
- E_a represents the annual number of confirmed discrepancies after implementation;
- C_e represents the average verified cost of investigating and correcting one discrepancy.

The average cost of a discrepancy may include employee time, document correction, repeated picking or loading, return transportation, additional warehouse handling, customer claims, and other directly attributable expenditures. Estimated reputational effects should not be included unless the company has a documented calculation method.

Savings associated with reduced loss or late return of reusable logistics assets should be calculated as follows:

$$S_a = L_b - L_a$$

where:

- S_a represents annual reusable-asset savings;
- L_b represents the documented annual cost of lost, unreturned, or replaced assets before implementation;
- L_a represents the corresponding annual cost after implementation.

If RFID reduces receiving, loading, or vehicle-processing time, the resulting benefit should be calculated from the difference in processing time, the annual number of operations, and the applicable labor or vehicle-downtime cost:

$$S_p = (P_b - P_a) \times N_p \times C_p$$

where:

- S_p represents annual process-time savings;
- P_b represents the average processing time before implementation;
- P_a represents the average processing time after implementation;
- N_p represents the annual number of completed operations;
- C_p represents the verified cost per unit of processing time.

Total verified annual benefits should be calculated as follows:

$$B_y = S_i + S_m + S_d + S_a + S_p$$

where B_y represents total verified annual benefits.

Other benefit categories may be added only when they are supported by company records and do not duplicate savings already included in the calculation.

6.2.2. Published Evidence on RFID Economics

Previous empirical studies demonstrate that RFID is not economically justified under every implementation model. Véronneau and Roy found that pallet-level tagging did not generate sufficient direct benefits to justify the examined deployment in a cruise-corporation service supply chain.

Their analysis indicated that case-level tagging could become economically feasible under specific operational conditions [21]. This finding shows that the economic result depends on the selected identification level and the value generated at each logistics operation.

Hellström examined the implementation of RFID for managing returnable transport items in two global retail companies [22]. The study showed that implementation costs should be evaluated together with the process changes produced by improved asset control. The findings also indicated that implementation cost was not necessarily the principal barrier when RFID addressed a clearly defined control problem and was incorporated into existing logistics processes.

These studies demonstrate that economic assessment should begin with the operational problem rather than the technology. An RFID project intended to automate a low-volume process may not recover its infrastructure and integration costs. The same technology may be economically justified in a high-volume operation involving repeated inventory counts, costly discrepancies, reusable assets, or significant manual processing.

Average Monthly Net Benefit

The average monthly net benefit should be calculated after recurring operating costs have been deducted from the verified monthly benefits:

$$B_m = \frac{B_y - C_y}{12}$$

where:

- B_m represents the average monthly net benefit;
- B_y represents total verified annual benefits;
- C_y represents annual recurring operating, maintenance, replacement, and exception-handling costs.

This calculation prevents recurring costs from being omitted when estimating the payback period.

Payback Period

The payback period identifies the number of months required for cumulative net benefits to recover the initial investment:

$$\text{Payback Period} = \frac{I_0}{B_m}$$

where:

- I_0 represents the initial investment, including hardware, installation, integration, pilot testing, and initial training;
- B_m represents the average monthly net benefit.

The result of the calculation is expressed in months. A shorter payback period indicates faster recovery of the initial investment, but it does not by itself demonstrate that the project will remain economically effective over its complete operating life.

Return on Investment

ROI should be calculated for a clearly defined assessment period. The selected period must be stated because implementation benefits and recurring costs accumulate over time.

$$ROI_H = \frac{B_H - TCO_H}{TCO_H} \times 100\%$$

where:

- ROI_H represents return on investment over the selected period;
- B_H represents cumulative verified benefits over the same period;
- TCO_H represents the total cost of ownership over that period.

Cumulative verified benefits should be calculated as follows:

$$B_H = \sum_{t=1}^{H} B_t$$

Where B_t represents verified benefits generated during each year of the assessment period.

A positive ROI indicates that cumulative verified benefits exceeded the total cost of ownership. A negative ROI indicates that the project did not recover its costs during the selected period.

Long-Term Economic Assessment

For an assessment covering several years, the timing of costs and benefits may be considered through net present value. This is particularly important where infrastructure expenditure occurs at the beginning of the project while benefits accumulate gradually.

$$NPV = -I_0 + \sum_{t=1}^{H} \frac{B_t - C_t}{(1 + r)^t}$$

where:

- I_0 represents the initial investment;
- B_t represents verified benefits during year ttt;
- C_t represents operating and maintenance costs during year ttt;
- r represents the selected discount rate;
- H represents the assessment period.

A positive NPV indicates that discounted benefits exceeded discounted costs during the selected period.

Sensitivity Analysis

Economic results should be tested under conservative, base, and optimistic scenarios. The conservative scenario should include only directly documented labor savings and avoided costs. The base scenario should use average observed performance and transaction volume. The optimistic scenario may include increased process capacity only where the existing RFID infrastructure can support additional operations without proportional growth in labor or equipment costs.

Sensitivity analysis should examine changes in:

- transaction volume;

- RFID-tag replacement rates;
- read-success rates;
- labor costs;
- software and maintenance expenditure;
- the number and cost of warehouse discrepancies;
- The useful operating life of readers and other equipment.

The economic assessment should distinguish between operational improvement and verified financial benefit. A reduction in process time, for example, creates a financial saving only when the released labor capacity reduces actual expenditure or allows the company to process additional operations without additional staffing. This distinction prevents operational percentages from being presented as financial results without an evidence-based conversion.

6.3. Prospects for the Development of RFID in Logistics

The future development of RFID in logistics is associated with its integration into broader information and decision-support systems. RFID provides automatic identification and event capture, while WMS, ERP, TMS, GPS, IoT, and analytics platforms provide the operational context required to interpret these events.

The principal development direction is therefore the creation of connected architectures in which RFID information is combined with inventory, transportation, quality-control, documentation, and planning data.

6.3.1. Integration with WMS, ERP, TMS, and GPS

RFID integration with warehouse and enterprise systems enables a tag read to produce an operational event rather than an isolated technical record. A detected tag may confirm receipt, storage placement, internal movement, order picking, shipment, or the return of a reusable logistics asset.

The information system must determine which object was identified, where the event occurred, which operation was expected, and whether the event corresponds with the relevant order or warehouse record.

Integration with GPS and transportation-management systems can connect cargo identification with vehicle and route data. GPS shows the geographic position of a vehicle, while RFID identifies the associated pallet, container, seal, product batch, or other logistics unit. This combination creates a more complete record of cargo movement between the warehouse, carrier, terminal, and recipient.

For agricultural logistics, the combined record may include the product batch, origin, weighing result, quality-control data, storage location, assigned vehicle, carrier, route, shipping documents, and delivery status. This allows the company to verify both the movement of the vehicle and the identity of the cargo associated with it.

EPCIS-Based Event Exchange

The development of RFID-based supply chains will also depend on interoperability between independent organizations. Producers, warehouses, grain elevators, carriers, freight forwarders, ports, distributors, and recipients may use different information systems. A common event structure is required if RFID data are to be exchanged without extensive manual reconciliation.

GS1 EPCIS provides a framework for recording and exchanging visibility events by describing what object was involved, when the event occurred, where it occurred, and why it occurred within a business process.

EPCIS-compatible records can connect RFID identifiers with receiving, shipping, transformation, aggregation, transportation, and sensor events.

In agricultural supply chains, this approach may support the exchange of information about the origin of a batch, storage and handling operations, laboratory results, weighing, loading, transportation, and delivery. The use of standardized event structures can reduce the risk that each participant interprets RFID data according to incompatible internal rules.

Integration with IoT Sensors

RFID can be combined with sensor technologies to monitor environmental conditions in addition to object identity. Sensor-enabled tags or associated IoT devices may record temperature, humidity, impact, vibration, or other parameters relevant to cargo quality and equipment condition.

This capability is important for agricultural and food logistics, where product quality may depend on storage and transportation conditions. The system can associate environmental data with a specific batch, container, storage zone, or transport unit. An exception can then be generated when a recorded value exceeds an established threshold.

Sensor deployment should remain connected to a defined operational requirement. Continuous collection of environmental data creates additional equipment, maintenance, communication, storage, and analysis costs. Sensor data are valuable only when the company has established thresholds, responsibilities, and response procedures.

Artificial Intelligence and Predictive Analytics

RFID and WMS event histories can provide data for artificial-intelligence and predictive analytics applications. Analytical models may identify unusual movement patterns, repeated reading failures, delayed logistics events, unexpected route sequences, inventory discrepancies, and assets with an increased risk of loss or late return.

Predictive analytics may also support warehouse-capacity planning, labor scheduling, carrier-performance assessment, inventory forecasting, and the identification of control points associated with repeated delays. For example, repeated RFID timestamps may reveal that a particular receiving area, loading gate, or warehouse zone consistently creates longer processing times.

The reliability of AI-based analysis depends on the quality of the underlying event data. Missing identifiers, duplicate reads, inconsistent timestamps, and incorrectly configured process rules may cause inaccurate conclusions. Data validation and master data governance must therefore precede the implementation of advanced analytical models.

Digital Twins

RFID data may also support the development of digital twins for warehouses and logistics networks. A digital twin represents physical objects, warehouse zones, equipment, inventory, and process events within a digital environment.

RFID events can update the status and location of logistics objects within this environment. Combined with WMS, sensor, and transportation data, a digital twin may be used to evaluate warehouse loading, identify bottlenecks, test alternative process configurations, and simulate the effect of changes in transaction volume.

In agricultural logistics, a digital representation may connect fields, storage facilities, grain elevators, weighing stations, transport units, and terminals. The value of such a model depends on the timely and accurate transmission of data from physical operations.

Blockchain and Shared Logistics Records

Blockchain-based solutions may be used where several independent participants require access to a shared and verifiable history of logistics events. RFID can provide the physical identification event, while the blockchain records the agreed event history.

Potential applications include verifying cargo handover, recording changes in responsibility, confirming product origin, and maintaining a shared history of quality-control or transportation events. Such an architecture may be appropriate where participants do not rely on a single trusted information-system operator.

Blockchain should not be treated as a necessary component of every RFID deployment. Where one company controls the warehouse, WMS, and operational database, a conventional secured database may provide the required functionality at lower cost and complexity. Blockchain is more likely to add value where several organizations require a tamper-evident shared record and have agreed on common data and governance rules.

Security and Privacy Development

The expansion of RFID and IoT integration increases the importance of cybersecurity and privacy. A connected RFID architecture may contain commercially sensitive information about inventory, shipment schedules, routes, partners, customers, and warehouse capacity.

Future RFID systems will require stronger device authentication, protected reader-to-middleware communication, role-based access, event-integrity controls, anomaly detection, and tested recovery procedures. Privacy controls will also be required where RFID data can be associated with employees, drivers, access credentials, or other identifiable individuals.

Security should be incorporated into system architecture and procurement requirements. Retrofitting security after implementation may be more expensive and may leave historical data or operating procedures exposed to unnecessary risks.

Cross-Sector Benchmarking

Future research should compare RFID performance across agricultural warehouses, grain elevators, manufacturing facilities, fulfillment centers, transport terminals, and port operations. Such comparisons would help determine how cargo type, facility design, transaction volume, tag placement, reader configuration, and information-system maturity affect implementation outcomes.

Cross-sector benchmarking should use consistent indicators, including:

- inventory accuracy;
- RFID read-success rate
- process duration;
- transaction-error rate;
- manual data-entry volume;
- reusable-asset loss rate;
- total cost of ownership;
- payback period;
- ROI.

The use of comparable indicators would make it possible to distinguish results produced by RFID technology from results produced by process redesign, employee training, data correction, or other changes introduced during implementation.

Future Role of RFID in Agricultural Logistics

In agricultural logistics, RFID is likely to develop as part of a hybrid identification and monitoring architecture. Passive RFID can identify product batches, pallets, bags, seals, containers, and transport units at defined control points. GPS can provide vehicle and route visibility. Sensors can record storage and transportation conditions. WMS, ERP, and TMS platforms can connect this data with inventory, documentation, and operational planning.

The strongest potential lies in the creation of a continuous and verifiable event history covering receipt, storage, weighing, quality control, loading, transportation, terminal processing, and delivery. This model can improve the ability to identify where delays, discrepancies, losses, or quality deviations occurred.

RFID will therefore continue to develop from a stand-alone identification technology into a source of structured operational data. Its future value will depend on interoperability, master data quality, information security, measurable economic outcomes, and the ability of organizations to use recorded events for operational and strategic decision-making.

6.4. Hypothetical Case Study of the Impact of RFID on Warehouse Operations before and after Implementation

To assess the practical impact of RFID, consider a hypothetical case study of an agricultural warehouse that handles batches of grain products, reusable containers, and shipments by road.

The following illustrative calculations are provided: If inventory took 16 hours before RFID implementation and 4 hours after implementation, the time reduction is 75%. This makes it possible to reduce labor costs, speed up data updates in the WMS, and improve the efficiency of management decision-making.

Before the implementation of RFID, key operations were performed manually. Employees recorded receipts, transfers, and shipments after the operations had been completed. Some of the data was entered into the accounting system from paper documents with a delay. Taking inventory was time-consuming, and discrepancies sometimes arose during shipping between the actual shipment, the documents, and the data in the system.

The main issues with this warehouse were:
1. time-consuming inventory counts;
2. delays during receiving and shipping;
3. manual data entry;
4. the risk of incorrect loading;
5. difficulty in tracking reusable containers;
6. delays in updating inventory levels.

After implementing RFID, the company tagged pallets, seals, reusable containers, and warehouse zones. RFID readers were installed in the receiving and shipping areas, and mobile devices began to be used for inventory management. Data from the tags was automatically transmitted to the warehouse management system, where key events—such as receipt, transfer, shipment, and return of containers—were recorded.

After the system was launched, the warehouse achieved more efficient inventory tracking. During receiving, RFID technology confirmed the arrival of logistics units and cross-checked them against the delivery schedule. During storage, employees were able to locate the right batch or container more quickly. During shipping, RFID helped verify that the correct batch was being loaded onto the designated vehicle.

Table 6. Changes in warehouse operations before and after the implementation of RFID

Indicator	Before the implementation of RFID	After the implementation of RFID
Warehouse inventory	2 business days	3–4 hours
Updating data in the system	after manual entry	automatically after reading
Shipping errors	occasional discrepancies	significant reduction
Control of reusable containers	manual accounting	automatic motion detection
Search for the desired batch	through an employee or documents	through data systems
Verification of documents against the actual cargo	manually	partially automated
Supervision of responsible personnel	complex to trace the transfer	records the time and place of the operation

The figures provided are for illustrative purposes only to demonstrate the potential benefits of an RFID solution and may vary depending on the size of the warehouse, the type of products, the volume of operations, and the level of integration with the company’s information systems.

Source: Compiled by the author.

The main benefit of RFID in this example is not just faster tag reading. The key change is the shift to real-time and more accurate data. The warehouse is no longer operating on the principle of “first perform the operation, then enter the information,” but rather according to a model in which data is generated almost simultaneously with the movement of logistics objects.

This case study demonstrates that RFID is most effective when implemented to address a specific operational challenge: slow inventory counts, lost packaging, shipping errors, accounting discrepancies, or insufficient batch traceability.

However, if the system is implemented without first analyzing the processes and integrating it with information platforms, its effectiveness will be limited.

Therefore, the effectiveness of RFID should be evaluated based on specific metrics: inventory accuracy, transaction speed, loss rates, data quality, labor costs, and payback period. In agricultural logistics, the greatest value lies not in the scanning of tags, but in the ability to link product batches, packaging, transportation, documents, and control points into a single data system. This integration is what transforms RFID from a technical identification tool into a key component of strategic supply chain management.

6.5. Discussion

The analysis shows that the operational value of RFID is determined by the connection between physical identification, logistics processes, and information-system transactions. A tag read has limited value when it remains an isolated technical record. It becomes operationally significant when the system can identify the logistics object, determine the process in which the reading occurred, connect the event with the corresponding WMS record, and identify whether the transaction follows the expected sequence.

In the warehouse scenario examined in this study, inventory-count duration decreased from 16 hours to 4 hours, representing a 75% reduction. This result illustrates the principal time-saving mechanism associated with RFID-based inventory operations: several tagged logistics objects can be identified without the individual visual alignment required for barcode scanning, while the recorded identifiers can be reconciled with warehouse records automatically. The time reduction also shortens the interval between the physical count and the availability of updated inventory information for management decisions.

The reduction in inventory-count duration should not be interpreted as automatic proof of an equivalent reduction in warehouse expenditure. A financial saving arises only when released employee time reduces actual labor costs, replaces overtime, prevents the engagement of additional staff, or enables the warehouse to process a greater number of operations without a proportional increase in resources. This distinction is important because operational efficiency, cost savings, and return on investment describe different results.

The findings correspond with the observations of Hellström and Wiberg, who examined an item-level RFID implementation at an automotive-industry supplier and connected RFID-supported process control with the reduction of sources of inventory inaccuracy [16]. Their study demonstrated that RFID can improve inventory-record reliability when it is incorporated into the actual production and warehouse process. The present analysis supports the same general principle but applies it to a different logistics environment.

Agricultural and warehouse logistics create identification requirements that differ from item-level manufacturing. Agricultural products may be handled as bulk commodities, product batches, bags, pallets, containers, or mixed logistics units. Grain cannot normally be tagged as individual physical items. The RFID identifier must instead be assigned to a batch, container, seal, transport unit, storage zone, or another object that maintains a verifiable relationship with the product.

The selection of the tagged object, therefore, becomes a central implementation decision. Tagging at an excessively detailed level can increase costs without producing additional control. Tagging at an overly broad level can prevent the system from identifying where a discrepancy occurred. The appropriate level depends on the structure of the logistics process, the value and volume of the goods, the frequency of movement, the cost of existing errors, and the information that must be exchanged among warehouses, carriers, terminals, and recipients.

The findings also support the hybrid traceability approach described by Qian et al. in their study of wheat-flour production [13]. RFID did not eliminate the operational need for barcodes, QR codes, warehouse documents, WMS records, or employee verification. Different identification methods serve different purposes. Barcodes and QR codes remain appropriate where visual verification is practical, and transaction volumes do not justify automated infrastructure. RFID is better suited to high-volume operations and defined control points requiring automatic identification. GPS provides the geographic position of a vehicle but does not independently confirm which batch, pallet, container, or seal is being transported.

The strongest logistics architecture is therefore a hybrid system in which technologies are selected according to their functions. RFID can identify logistics objects and record their passage through warehouse control points. GPS can monitor vehicles and routes. WMS and ERP platforms can maintain inventory and transaction records. TMS can connect cargo with transportation planning, while EPCIS-compatible events can support information exchange among independent supply-chain participants.

The results of the analysis also show that RFID performance depends on master data quality. If product codes, warehouse locations, batches, containers, or transport units are recorded inconsistently, RFID will transmit those inconsistencies more quickly rather than correct them. Master-data preparation, identifier assignment, and event-rule configuration should therefore be completed before the system is scaled beyond the pilot stage.

Read-zone configuration creates an additional operational requirement. A reading zone that is too broad may detect unrelated objects, while a zone that is too narrow may fail to record the required tag. Metal structures, liquids, dust, humidity, tag orientation, vehicle speed, and cargo density can influence reading performance. Technical testing should consequently be conducted under actual operating conditions rather than exclusively in a controlled environment.

Employee participation is equally significant. RFID changes the timing and method by which warehouse events are recorded. Employees must understand which operations are captured automatically, which events require manual confirmation, and how missing, duplicate, or unexpected reads should be processed. Without defined exception-management procedures, employees may establish parallel manual records, reducing the consistency and economic value of the RFID system.

The economic analysis confirms that RFID cannot be evaluated through equipment prices alone. Véronneau and Roy found that pallet-level tagging did not generate sufficient direct gains to justify the examined deployment, while case-level tagging could become feasible under different operating conditions [21]. Their findings demonstrate that the economic outcome depends on transaction volume, tagging level, process structure, and the value of the problem being addressed.

Hellström's analysis of RFID implementation for returnable transport items also showed that costs must be assessed in relation to the asset-control process and the operational benefits produced by the technology [22]. RFID can be economically justified where it reduces the loss of reusable assets, repeated manual searches, processing delays, and reconciliation work. The same investment may remain unjustified where transaction volumes are low, or the existing identification process produces few costly errors.

For this reason, the total cost of ownership, payback period, and ROI should be calculated only from verified company records. The economic analysis should include equipment, integration, pilot testing, training, maintenance, tag replacement, software, cybersecurity, and exception-handling costs. Benefits should include only documented labor savings, avoided losses, reduced discrepancies, shorter processing times, and additional operational capacity that can be converted into measurable financial value.

Security and privacy also influence implementation outcomes. RFID records may reveal information about inventory levels, cargo movements, shipment schedules, warehouse capacity, carriers, and business partners. When the records can be linked with employees or drivers, privacy and access-control requirements also arise. Authentication, protected communication, role-based access, audit logs, data-retention rules, and exception monitoring should form part of the implementation design.

The principal contribution of the study is a sector-specific framework that connects process analysis, tagged-object selection, read-point configuration, information-system integration, employee training, performance indicators, economic assessment, and security controls. This framework extends descriptive accounts of RFID by identifying the technical, organizational, and data-management conditions that determine whether tag readings produce operational results.

The analysis remains subject to several limitations. The quantitative warehouse comparison is limited to an illustrative process scenario and does not establish verified before-and-after changes in inventory accuracy, transaction-error rate, read-success rate, payback period, or ROI. These indicators require operational datasets covering comparable periods before and after implementation.

Additional empirical research should apply the proposed framework to warehouses, grain elevators, transportation terminals, and fulfillment facilities with different layouts, cargo types, transaction volumes, and levels of digital maturity.

7. Conclusion

This study examined RFID implementation in agricultural and warehouse logistics and developed a phased framework connecting physical object identification with warehouse operations, transportation data, documentation, information-system records, performance measurement, economic assessment, and implementation-risk control.

The analysis confirms that RFID should be treated as part of an operational information system rather than as an isolated tag-reading technology. RFID produces management value when each recorded identifier is connected to a defined logistics object, a control point, an expected operational event, and a corresponding WMS, ERP, TMS, or transportation record.

The warehouse scenario demonstrated a reduction in inventory-count duration from 16 hours to 4 hours, corresponding to a 75% decrease. This comparison illustrates how automated identification can reduce the time required to detect logistics objects and reconcile them with warehouse records. The result also demonstrates the importance of measuring operational indicators before and after implementation rather than describing RFID benefits only in general terms.

The analysis does not establish that a 75% reduction in process time produces an equivalent financial saving. The monetary result depends on the number of inventory counts, the number of participating employees, applicable labor costs, and whether the released capacity reduces expenditure or enables additional operations. Operational time, financial benefit, and ROI must therefore be calculated separately.

The selection of the tagged object is particularly important in agricultural logistics. Bulk products such as grain cannot ordinarily be identified through item-level tags. Traceability must instead be established through product batches, bags, pallets, containers, seals, trailers, storage zones, or related logistics records. The selected tagging level must maintain a reliable connection between the physical cargo, warehouse operation, carrier, route, quality information, and documentation.

The findings also show that RFID should not be applied as a universal replacement for other identification and tracking technologies. Barcodes and QR codes remain suitable for low-cost visual verification. GPS remains necessary for geographic vehicle monitoring. BLE and active RFID may be appropriate for higher-value reusable assets requiring more frequent location updates. WMS, ERP, and TMS platforms remain responsible for transaction, inventory, and transportation management.

A hybrid architecture can combine these functions. RFID can identify cargo and record warehouse events; GPS can monitor the associated vehicle and route; WMS can maintain inventory and warehouse transactions; and EPCIS-compatible records can support the exchange of event information among producers, warehouses, carriers, terminals, and recipients.

The effectiveness of RFID depends on several implementation conditions. These include the correct selection of tags and readers, testing under actual operating conditions, configuration of read zones, preparation of master data, integration with enterprise systems, employee training, and the establishment of procedures for missing, duplicate, or unexpected RFID events.

The economic assessment should be based on the total cost of ownership. Equipment cost represents only one component of the investment. Integration, software, testing, training, maintenance, replacement, technical support, cybersecurity, and exception-handling costs should also be included. Economic benefits should be limited to operational improvements that can be verified and converted into documented financial value.

Published sector studies confirm that RFID economics vary by implementation setting and tagging level. RFID may be justified in high-volume processes involving costly errors, repeated inventory operations, reusable assets, or extensive manual data entry. It may remain economically unjustified where process volumes are low or existing identification errors create limited financial consequences.

The proposed framework contributes an integrated approach to RFID implementation in agricultural and warehouse logistics. It connects the technical configuration of the RFID system with process design, data governance, organizational readiness, performance measurement, economic analysis, security, and privacy.

The study is limited by the absence of a complete verified dataset covering inventory accuracy, transaction discrepancies, RFID read-success rates, implementation expenditure, financial benefits, payback period, and ROI. These values should be established from comparable WMS, RFID, inventory, shipment, and financial records before the article presents them as achieved implementation results.

Future research should test the framework in grain elevators, agricultural warehouses, fulfillment centers, transportation terminals, and multi-party supply chains. Further investigation should also address RFID integration with IoT sensors, artificial intelligence, digital twins, EPCIS-based data exchange, and blockchain architectures where independent supply-chain participants require a shared and verifiable event history.

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