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IMPROVEMENT OF THE WAREHOUSING USING RFID TECHNOLOGY IN A MANUFACTURING ENTERPRISE – A LITERATURE REVIEW

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Purpose: The purpose of this publication is to present a review of the existing literature regarding the use of RFID technology in warehouse processes in manufacturing enterprises. The publication aims to identify the benefits and challenges associated with RFID implementation, as well as to highlight areas where this technology can improve warehouse processes and inventory management.
Design/methodology/approach: A literature analysis was conducted on the applications of RFID in logistics and warehousing, focusing on research related to the automation of inventory processes, improving inventory accuracy, and reducing waste. The paper also compares results from different industries to identify universal benefits and challenges associated with RFID implementation.
Findings: The literature points to several benefits of implementing RFID technology, such as improved inventory accuracy, reduction of human errors, acceleration of warehouse processes, and better warehouse space management. RFID implementation also allows real-time tracking of goods, leading to better inventory control and faster decision-making. However, the literature also highlights challenges related to initial implementation costs, integration with existing systems, and the need for staff training.
Research limitations/implications: Further research should focus on investigating the long-term impact of RFID on operational costs in warehouses and analyzing the effectiveness of RFID technology across different industries. There is a need for research on integrating RFID with other technologies, such as IoT (Internet of Things) and artificial intelligence, to further improve warehouse processes.
Originality/value: The article provides a comprehensive review of the existing literature on RFID technology in warehouse processes, highlighting its potential for automation and optimization. The publication adds value by analyzing various aspects of RFID technology, its implementation, and the long-term benefits resulting from its use in manufacturing enterprises.
Keywords: RFID, warehouse automation, inventory management, logistics, technology in logistics.
Category of the paper: Literature review.

1. Introduction

Modern manufacturing enterprises operate under conditions of increasing market competition, which requires continuous process optimization, reduction of operational costs, and ensuring high product quality. One of the key factors determining competitive advantage is the implementation of modern information and technological tools that support process management. Among such solutions is RFID (Radio-Frequency Identification) technology, which is based on the use of radio waves for automatic identification and tracking of objects. RFID systems enable real-time recording of the flow of materials, raw materials, and semi-finished products throughout the entire production chain, thereby providing more comprehensive control over operational processes. Consequently, their implementation contributes to enhancing organizational efficiency, reducing material losses, and improving product quality through precise monitoring of individual stages of production.

RFID technology brings numerous benefits, such as the ability to automatically identify and locate raw materials, semi-finished products, and finished goods, which enables precise inventory management. As a result, enterprises can reduce costs associated with maintaining excessive stock levels and minimize the risk of stock shortages. Moreover, RFID accelerates warehousing processes, order picking, and goods dispatch, thereby shortening order fulfillment times and increasing operational efficiency.

In various production sectors, RFID technology has found wide application. It is extensively used in logistics, manufacturing, retail, healthcare, and many other fields, ensuring fast and accurate data collection as well as streamlining operational processes. In the automotive industry, RFID is employed to track car parts along the production line, enabling quality monitoring and assembly speed control. In the food sector, it supports supply chain management by tracking products from the moment of production to final delivery to the customer. RFID fosters modern production management by improving efficiency, reducing costs, and enhancing product quality. The benefits of its implementation are recognized by enterprises worldwide.

The application of RFID technology reduces the time required to locate components and tools, automates information flows, and eliminates errors resulting from manual data entry, thereby ensuring real-time updates of inventory levels (Zhang, 2011; Gładysz, Grabia, Santarek, 2017; Weiland, 2025; Jankowska-Mihułowicz, Kłos, Grzechca, 2016; Wójtowicz-Kowalska, Rebech, 2013). This solution also enables warehouse space optimization, reduces operational costs, and improves control over material flows. When integrated with ERP-class systems (e.g., SAP), RFID contributes to the full automation of logistics and production processes, enhancing data security and shortening the execution time of warehouse tasks. Consequently, the use of RFID reduces warehouse losses and improves customer service quality through faster and more reliable order fulfillment. The findings indicate that RFID constitutes an effective tool supporting process management and a source of competitive advantage for enterprises (Kisperska-Maroń, 2009; Ciesielski, 2009; Sharma, 2014; Matulewski, 2018; Wicki, 2021; Gładysz, 2014; Zakrzewski, 2023; Jones, Chung, 2017; Godfryd, 2006; Finkenzeller, Gebhart, 2012; Albrecht, 2006).

The aim of this article is to provide a comprehensive review of the scientific literature concerning the application of RFID technology in warehouse and production processes, with particular emphasis on its role in logistics management and its impact on enterprise competitiveness. By synthesizing prior research, the paper identifies the main areas of RFID implementation, the associated operational and strategic benefits, as well as the technological and organizational challenges reported in the literature.

Based on the conducted review, several future research directions can be identified. In particular, further studies are needed to examine the long-term cost-effectiveness and return on investment (ROI) of RFID implementations, especially in dynamically changing production and warehouse environments. Moreover, deeper investigation of RFID integration with IoT and artificial intelligence solutions is recommended in order to support predictive analytics and the development of autonomous warehousing systems. Future research should also address cybersecurity and data protection issues, including regulatory compliance requirements. Additionally, cross-industry comparative studies would contribute to validating the generalizability of existing findings.

From a practical perspective, the results of this review provide guidance for practitioners planning RFID implementation. The findings may support decision-makers in selecting priority warehouse processes for RFID deployment, planning effective ERP/WMS integration (including data flow architecture and middleware solutions), identifying key cost categories and implementation risks, and designing employee training and change-management strategies to reduce adoption barriers and increase organizational readiness.

2. RFID Technologies in Warehouse Logistics

RFID systems consist of three fundamental components: tags, readers (scanners), and a data management system. RFID tags are small electronic devices containing a microchip and an antenna (Figure 1). The microchip stores unique identification data, while the antenna enables communication with the reader through radio waves. Tags can be either active (with their own power source) or passive (powered by the radio waves emitted by the reader) (Długosz, 2017; Bidermann, 2014).

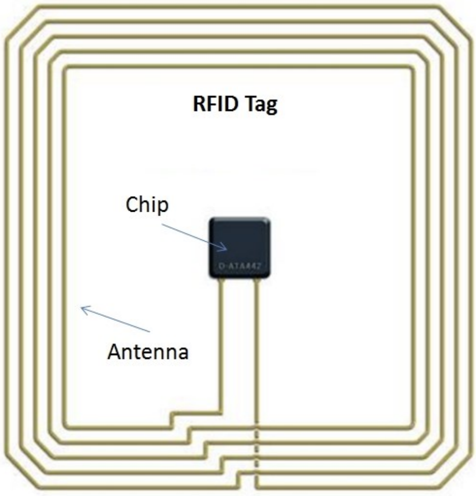

Figure 1. RFID handheld reader (data collector).

Source: Długosz et al., 2017.

RFID readers are devices that transmit radio signals to tags and receive responses containing identification data. The readers are equipped with antennas and data processing modules, which subsequently transfer the information to the management system. The data management system integrates readings from RFID readers with databases and business applications. This enables monitoring and analysis of goods flow, inventory management, and the optimization of logistics and production processes. The operation of RFID systems is based on data exchange between the tag and the reader via radio waves. When a tag enters the reader's range, the reader's antenna sends a signal that activates the tag and enables the transmission of data from the microchip to the reader. The received data are then processed and analyzed within the management system, allowing for automatic identification and real-time tracking of objects (Kiedrowicz, 2013; Munoz-Ausecha, Ruiz-Rosero, Ramirez-Gonzales, 2021; Abugabah, Nizamuddin, Abugabbeh, 2020; Akram, Mian, 2022; Liu, Zhang, Kong, Zhang, 2018; Gao, Zhang, Ma, 2017; Chen, Sun, Chen, Zheng, 2014; Munilla, Hassan, Burmester, 2020; Jones, Wyld, Totten, 2005).

The integration of RFID systems with existing warehouse solutions (such as ERP/WMS systems) involves the implementation of technology that enables automatic data collection, processing, and synchronization in real time, thereby making logistics processes more efficient. (Ciesielski, Długosz et al., 2010).

The key aspects of RFID integration include:

- Data synchronization: RFID integrates data with existing systems such as Warehouse Management Systems (WMS) and Enterprise Resource Planning (ERP), enabling the automation of processes such as inventory control, asset tracking, and order fulfillment. For example, data from RFID tags are transmitted to ERP systems in real time, supporting both operational and strategic decision-making.

- Operations automation: The integration of RFID simplifies inbound and outbound goods processes through automatic updates of product status, eliminating the need for manual data entry. This leads to greater operational accuracy and a reduction in human errors.
- Technological adaptation: To ensure smooth integration, technologies such as middleware, APIs, or integration platforms are applied. These are used to connect RFID with the systems already operating in the warehouse.
- Testing and validation: A pilot implementation of RFID makes it possible to verify the system's functionality under real warehouse conditions and to resolve integration issues before full-scale deployment.
- Improved tracking and resource management: RFID technology enables precise real-time tracking of goods, which contributes to the optimization of inventory placement, better utilization of warehouse space, and improved customer service quality.

The implementation of RFID systems involves various costs, including both initial investments and ongoing expenses. Initial expenditures include the purchase of equipment such as RFID tags, readers, and antennas, as well as the costs of installation and integration with existing information systems. Staff training is often required, which generates additional expenses. Ongoing costs of maintaining RFID systems cover hardware maintenance, software updates, and the possible replacement of damaged tags and readers. In addition, companies must take into account the costs associated with system management, such as technical support and data administration.

Despite these expenditures, the benefits resulting from operational efficiency, data accuracy, and the reduction of errors and losses may significantly outweigh the costs of implementing and maintaining RFID systems. In the long term, investment in RFID often leads to savings and an increase in the competitiveness of the enterprise (Gołębska, 2018; Chrobak, 2010).

Despite their numerous advantages, RFID systems pose significant challenges in terms of data security and privacy. Since RFID tags transmit information via radio waves, there is a risk of unauthorized data access by third parties. To counteract such threats, various security techniques are applied, such as data encryption, authentication, and the use of protective shielding for tags.

In addition, there is the issue of user privacy protection. RFID tags may be used to track individuals, which raises concerns related to surveillance. Companies implementing RFID must comply with data protection regulations, such as the GDPR in the European Union, and ensure that RFID systems are used in accordance with privacy principles. Effective management of data security and privacy in RFID systems requires the application of advanced security technologies as well as the establishment of appropriate data protection policies and procedures, in order to minimize the risk of unauthorized access and ensure compliance with legal regulations.

Interoperability and standardization are key aspects for the effective implementation and functioning of RFID systems.

Interoperability refers to the ability of different RFID systems to cooperate and exchange data. For RFID systems to function effectively in global supply chains, they must be compatible with the diverse devices and technologies used by different companies. This requires consistency at the hardware, software, and communication protocol levels. Interoperability enables the seamless integration of RFID systems with existing Warehouse Management Systems (WMS) and Enterprise Resource Planning (ERP) solutions, thereby allowing for more efficient management of logistics and production processes.

Standardization in the context of RFID involves the establishment of common norms and technical specifications that ensure products and services from different providers are compatible and can interoperate. Organizations such as ISO (International Organization for Standardization) and EPCglobal develop and publish standards covering various aspects of RFID technology, including operating frequencies, communication protocols, and data formats. Przykłady standardów RFID to:

- ISO 18000 – a series of standards covering different RFID frequency ranges.
- EPC Gen 2 (ISO 18000-6C) – a standard for UHF RFID, widely used in global supply chains.
- ISO 15693 – a standard for HF RFID, commonly applied in areas such as personal identification and libraries.

Standardization brings benefits such as reduced implementation costs, easier integration of systems from different providers, and increased confidence in the performance and reliability of RFID systems. Thanks to established standards, companies can invest in RFID technologies with greater assurance that their systems will be compatible and sustainable in the future.

Trends and forecasts for the development of RFID technology indicate its intensive integration with solutions based on the Internet of Things (IoT) and Industry 4.0. RFID is increasingly applied in smart factories, where it enables automatic monitoring of production processes, resource management, and quality control (Konecka, Maryniak, 2020). Within the framework of IoT, this technology is used for real-time data management, which contributes to more efficient and automated processes.

Research directions in RFID also include the development of Ultra High Frequency (UHF) technology and anti-collision protocols, which improve system performance in large-scale environments. Moreover, RFID is becoming increasingly compatible with database and data analytics systems, enabling better demand forecasting and supply chain optimization.

In the future, a further decrease in the costs of RFID technology is anticipated, which will allow for wider application in sectors such as healthcare, smart cities, and public transportation. Research has also highlighted the growing importance of RFID in the context of security, both in consumer and industrial applications (Sharma et al., 2014).

RFID technology is continuously evolving, and its future appears promising due to numerous potential innovations and improvements. (Schwartz, 2011).

The integration of RFID with artificial intelligence enables more advanced analysis of data collected from RFID tags (Zhu, Li, Xu, Wang, 2013). AI systems can support faster and more accurate pattern recognition as well as forecasting of needs and trends in supply chains, which facilitates more effective inventory management and optimization of logistics processes.

AR and VR can already be used for the visualization of RFID data on-site, enabling warehouse and factory workers to manage resources more quickly and intuitively. With these technologies, operators will be able to locate and identify RFID-tagged items more easily and accurately.

RFID tags with multifunctional features, such as measuring temperature, humidity, or condition, open up new application possibilities. Such tags can be used in more demanding environments, such as pharmaceutical manufacturing or the food industry, where monitoring storage conditions is crucial.

RFID has potential applications in healthcare, such as patient monitoring, hospital asset management, and medication tracking. Through RFID, the precision of patient data management can be improved, and the safety of medical processes can be enhanced.

Innovations in RFID may also include the development of tags with lower energy consumption, which will enhance their durability and environmental sustainability. Energy-efficient RFID tags can be more easily applied in scenarios where long-term operations are required without the need for frequent battery replacement. (Sharma et al., 2014; Zakrzewski et al., 2023).

2.1. Integration of the RFID System with the Existing Production System

Designing the architecture of an RFID system requires careful definition of its components and their interrelationships in order to meet the needs of the enterprise under study. The foundation is an understanding of process flows within the company, such as production, warehousing, and shipping, which makes it possible to identify key points for the installation of RFID devices. The system architecture must take into account the placement of RFID tags on products, RFID readers and antennas in strategic locations, and the management software.

At the physical infrastructure level, RFID tags should be located on products or their packaging in a way that does not interfere with production or transportation processes. Tags should be read at designated points such as production lines, where progress in manufacturing is monitored; warehouse entry and exit gates, which control the flow of products; and loading zones, where shipment completeness is verified. RFID antennas should be arranged to ensure maximum range and reading accuracy, taking into consideration possible physical obstacles such as metal racks or other equipment.

The next step is the configuration of RFID middleware, which acts as an intermediary between the RFID hardware and the SAP system. The middleware receives data from RFID readers, processes them, and transmits them to SAP in the appropriate format. For this purpose, it is necessary to integrate the middleware with SAP modules responsible for warehouse management, such as SAP WM (Warehouse Management) or SAP EWM (Extended Warehouse Management). The integration may use standard SAP interfaces such as IDoc (Intermediate Document), SOAP, or OData. The middleware should also provide functionalities such as data filtering, duplicate elimination, and real-time event reporting.

Integration with the SAP system is a key element of the RFID system architecture. The system must enable real-time data transmission, such as the current location of products, their production status, or warehouse availability. Most commonly, APIs, OData connectors, or standard SAP protocols such as IDoc are used. This makes it possible to automatically update inventory levels, manage orders, and optimize production processes.

At the communication level, the architecture should include a stable and reliable network infrastructure. RFID devices may be connected to the network via Ethernet cables or wirelessly (Wi-Fi), depending on local conditions. The use of Power over Ethernet (PoE) technology can simplify installation by allowing both power supply and data transmission through a single cable.

When designing the RFID system architecture, scalability must also be considered, meaning the ability to easily expand the system in the future, for example, by adding additional readers, antennas, or new software functionalities. Appropriate redundancy should also be provided to minimize the risk of failures and operational downtime (Zakrzewski et al., 2023).

The implementation of an RFID system integrated with SAP for inventory management can be divided into several key stages, encompassing both technical and organizational aspects.

The first step is requirements analysis and system architecture planning. A detailed audit of warehouse and production processes should be carried out to identify the key areas where RFID can deliver the greatest benefits, such as the automation of inventory readings, tracking product flows along production lines, and streamlining shipping processes. Based on this, a process map can be developed, and the locations for RFID readers, antennas, and tags can be designated.

Readers and antennas must be compatible with the tags, providing the appropriate range and reading reliability. Attention should also be paid to supported communication protocols, such as EPC Gen2 or ISO 18000-6C, which allow for seamless integration with middleware and the SAP system.

On the SAP side, appropriate configurations must be prepared to enable the processing of data received from the RFID system. This can be achieved by defining new identification points in warehouses and assigning them suitable roles in logistics processes. SAP configuration must consider business logic, such as real-time inventory updates, automatic recording of material receipts and issues, and the tracking of stock transfers between warehouses.

The system implementation also involves the physical installation of RFID devices, including readers and antennas, in the locations specified during the architecture design stage. It is crucial to ensure stable power supply and network connectivity for the devices, preferably through Power over Ethernet (PoE) technology. Once the devices are installed, their configuration and testing are carried out under real conditions to verify reading quality and the correctness of data transmission.

A key stage is the integration of the RFID system with SAP, during which the flow of data across the entire IT environment is tested. It must be ensured that RFID tag data are correctly processed by the middleware and properly interpreted by SAP. It is also advisable to perform simulations of business scenarios, such as goods receipt into the warehouse, order picking, or internal warehouse transfers, in order to verify the correct functioning of the system.

After completing system tests, user training sessions are conducted, covering the operation of RFID devices as well as the operational process changes resulting from the adoption of the new technology. Finally, the system is launched in the production environment, and its performance is monitored during a pilot phase to identify and resolve any potential issues.

The first step in preparing an RFID implementation plan is to define the objectives and expected results, such as the automation of warehouse processes, improved accuracy of inventory data, and real-time tracking of material and product flows. A detailed analysis of the company's business processes should be conducted in order to identify the key points where RFID technology will bring the greatest benefits. On this basis, an implementation schedule is developed, covering the stages of system design, installation, testing, integration with SAP, and user training.

An important element of the plan is budgeting, which includes the costs of purchasing tags, readers, antennas, middleware, and installation and integration services. The budget should also account for additional expenses, such as IT infrastructure modernization or employee training.

The implementation plan must also address potential risks, such as electromagnetic interference in warehouses or integration issues with the existing SAP system. A risk management strategy should be developed, which includes testing devices under real conditions and ensuring technical support at each stage of the project (Gladysz et al., 2014).

The implementation begins with the procurement and delivery of hardware and software. RFID readers and antennas are first installed at strategic locations, such as warehouse entry points, production lines, order-picking zones, and shipping points.

Once the devices are physically installed, the RFID middleware is configured to collect, process, and transmit data to the SAP system. The middleware must be adapted to handle different types of tags and readers, and it should provide functions such as data filtering, error elimination, and report generation.

Next, the middleware is integrated with SAP using standard interfaces such as IDoc, OData, or SOAP. Within SAP, the appropriate modules—such as SAP WM (Warehouse Management) or SAP EWM (Extended Warehouse Management)—must be configured to enable automatic inventory updates and real-time product tracking.

The following stage involves functional and performance testing of the RFID system. The tests include verifying the accuracy of tag readings, the stability of network connections, and the smoothness of data flow between RFID devices and the SAP system. At this stage, issues such as incorrect readings under specific conditions or delays in data processing can be identified and resolved.

After testing is completed, training sessions for employees are conducted. These cover the operation of RFID devices, the use of the new software, and the changes in operational procedures. Training is crucial to ensure a smooth transition to the new system and to minimize errors in daily operations.

The final step is the launch of the RFID system in the production environment. During the first weeks of operation, the system is monitored to identify potential issues and to optimize its configuration. After the pilot phase has been completed, the implementation is considered finalized, and the system is fully integrated into the company's business processes (Gładysz et al., 2014).

3. Summary

The implementation of RFID technology in warehouses and production processes brings a multifaceted improvement in enterprise efficiency. The use of this technology reduces the time required to locate components and tools, which translates into increased operational performance both in warehouse management and internal transport. The automation of information flows eliminates errors resulting from manual data entry, ensuring real-time updates of inventory levels. Precise identification and localization of resources enable the optimization of warehouse space utilization, thereby reducing operating costs associated with maintaining excessive stock levels and minimizing production downtime.

RFID technology enhances the control of material flows by enabling accurate tracking of resources and minimizing the risk of material shortages. Automated identification shortens the execution time of warehouse tasks and increases the level of data security through the use of encryption mechanisms. The integration of RFID systems with ERP-class solutions (e.g., SAP) ensures full automation and coordination of logistics and production processes. As a result, the implementation of RFID reduces warehouse losses caused by storage errors or damages and improves customer service quality through faster and more reliable order fulfillment. The findings indicate that RFID technology constitutes an effective tool supporting logistics and production management and significantly contributes to the competitiveness of enterprises.

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