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Digitization of the Production Process: An Example of The Use of RFID Technologies For Modern Enterprises

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Abstract

The purpose of the study is to improve the efficiency of the production process of engineering enterprises. The object of study is enterprise engineering. The scientific task is to determine the most optimal RFID technologies to improve the accuracy and efficiency of the production process of engineering enterprises. The technique involves the use of the Saaty method of hierarchies and pairwise comparison. As a result, the most optimal and effective RFID technologies were selected to improve the production process of engineering enterprises through hierarchical ordering of the most significant RFID technologies that affect the production process of engineering enterprises. One limitation of this study is its exclusive focus on RFID technologies, which may not take into account the potential of other technology solutions to improve manufacturing processes. In addition, the use of Saaty's method of hierarchies and even comparison may introduce subjectivity into the selection of optimal technologies, since the results depend on expert assessments. Prospects for further research may include comparison of RFID with other modern technologies that are being implemented in engineering enterprises to ensure greater objectivity and completeness of the analysis. Also, an important aspect of future research could be a detailed analysis of the impact of RFID implementation on the economic efficiency of production and employee workload.

Keywords: *RFID Technologies, Engineering Enterprises, Production Process, Paired Comparison Saaty, Automatization, Economic Efficiency, Innovative Technologies, Hierarchy Method*

INTRODUCTION

Radio frequency identification (RFID) uses electromagnetic fields to automatically identify and track tags attached to objects. These tags contain electronic circuits and an antenna to receive and transmit data over a distance. An RFID system consists of a tag, a reader and an antenna, providing communication between physical objects and digital control systems. Tags can be active, having their own power source, passive, receiving energy from the reader, or semi-passive, combining both approaches.

RFID technologies vary in frequency characteristics and capabilities. For example, low-frequency tags provide short range and low data rates, but are characterized by high permeability to interference. Ultrahigh frequency tags have long range and high transmission speeds, but their effectiveness may be reduced in the presence of liquids and metals.

RFID technology is widely used in engineering enterprises, where it plays a key role in increasing the efficiency of various processes. In such enterprises, where there is a complex production process and a significant number of assets, RFID becomes an essential tool to optimize operations.

In the engineering field, RFID helps automate inventory control and logistics, where tags are attached to tools, components, and heavy equipment. This application of technology allows you to accurately track the location and status of equipment, reducing the risk of equipment loss and facilitating the rapid resumption of production after failures. At the same time, RFID is being integrated into production lines to monitor assembly and product quality, automating the collection of data from intermediate production steps. This helps identify errors and inconsistencies early, improving productivity and reducing scrap costs (Figure 1).

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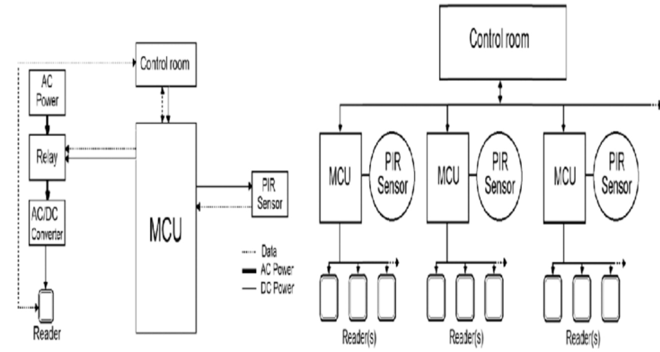

Figure 1. Block diagram of smart RFID-system

RFID also supports asset management in engineering businesses, where it is important to efficiently manage equipment and materials to meet strict project deadlines and budgets. By automatically recording equipment movements within a plant or on project sites, RFID-based systems provide accuracy and transparency in logistics and asset management. This not only optimizes the use of resources, but improves the overall efficiency of the enterprise.

The use of RFID offers significant benefits to manufacturing processes, including the ability to quickly collect large amounts of data, reduce human error, and improve inventory accuracy. The rise of the Internet of Things enhances these benefits by integrating RFID into broader control and analytics systems, helping to optimize logistics and asset management.

The promise of RFID in manufacturing promises even greater integration of digital and physical processes, providing greater insight and control over production cycles. This opens up new opportunities to create more flexible, adaptive and efficient production systems that can respond to changes in market conditions and customer demands. RFID is therefore a key element in modern manufacturing digitalization strategies. processes.

Digitalization of the production of engineering products is changing traditional approaches to doing business, introducing significant innovations in the management and monitoring of production processes. In this context, RFID technologies play an important role by allowing businesses to integrate high levels of automation and precision in the identification and tracking of components and finished products. With RFID, accurate tracking capabilities extend from raw materials to the final product, which businesses can use to optimize supply chains and improve overall production efficiency. These tags help reduce order processing time and improve inventory accuracy, which is critical to ensuring rapid response to changes in demand and supply.

One of the key aspects of RFID adoption is its synergy with other digital systems such as ERP (Enterprise Resource Planning) and MES (Manufacturing Execution Systems). The integration of these systems ensures the creation of a unified digital infrastructure that facilitates more efficient data exchange and, as a result, greater transparency and controllability of processes at all stages of production.

The use of RFID also helps improve product quality. By implementing strict control over processes and materials at every stage of production, the likelihood of errors or defects in the finished product can be significantly reduced. This is made possible by continuous monitoring and analysis of the data collected by RFID systems.

In addition to technical benefits, RFID technology also provides strategic benefits. They allow engineering companies to be more flexible in production management and quickly adapt to changing market conditions. This is especially important in modern conditions of globalization and high competition. Also, the introduction of RFID contributes to the sustainable development of enterprises. By reducing waste, optimizing resource use and reducing energy consumption, engineering businesses can significantly reduce their environmental footprint.

However, the challenges that accompany the implementation of RFID must also be taken into account. This includes the need for significant upfront investment, the need to ensure data security, and the technical challenges associated with integrating the technology into existing production processes.

Finally, the digitalization of manufacturing through RFID technology opens up new horizons for engineering businesses, offering them the tools to achieve more efficient and adaptive production, which is integral to their success in today's economic landscape.

The purpose of the study is to improve the efficiency of the production process of engineering enterprises. The object of study is enterprise engineering.

LITERATURE REVIEW

Researching relevant sources is a key aspect of scientific research as it provides insight into the current state of knowledge in a particular field and identifies gaps that require further study. In the context of analyzing the implementation and effectiveness of RFID technologies in engineering enterprises, a literature review becomes particularly important. It not only confirms the significance of the study, but provides a fundamental basis for defining scientific objectives and methodology. In addition, a systematic review of the available literature helps to establish connections between theoretical concepts and practical applications of RFID, which is integral to the development of evidence-based recommendations and strategies for improving production processes in engineering plants.

In a study by Ejsmont et al. (2020) authors analyze how the integration of Industry 4.0 technologies, including RFID, can contribute to lean manufacturing, thereby increasing productivity and reducing resource waste in engineering plants. They consider the potential of these technologies to create more flexible and responsible manufacturing systems, which is especially relevant for your research focused on improving manufacturing processes.

The work of Gotmare et al. (2019) conducts a systematic review of RFID applications in the manufacturing and supply chain management sectors, examining in detail the effectiveness of the technology in different scenarios. They are finding that RFID can significantly improve data accuracy and reduce information processing time, which helps streamline operations and reduce overall costs, allowing for greater efficiency in logistics and manufacturing processes.

Öztemel and Gursev (2020) provide a comprehensive review of the Industry 4.0 literature, particularly focusing on technologies such as RFID. They look at various aspects of the digitalization of manufacturing and its impact on industry, pointing to the importance of technologies to increase automation and link the physical and digital components of production processes. Chanchaichujit et al. (2020) offer a systematic literature review that focuses on the benefits and motivators of RFID adoption in supply chains and its impact on organizations' competitive advantage. Their research highlights how RFID can serve as a strategic tool to improve operational efficiency and strengthen companies' market position through better asset management and greater transparency in production processes.

The article by Gladysz et al. (2020) discusses a method for assessing the sustainability of RFID technologies, which is a critical aspect when introducing emerging technologies into production processes. They are developing an integrated assessment model to assess the environmental, economic and social impacts of RFID, thereby providing a more complete understanding of the potential and implications of its use.

A study by Oghazi et al. (2018) focuses on the interaction between RFID and ERP systems in the context of supply chain management. The authors analyze how the interaction of these technologies can help improve data integration and optimize production processes, leading to increased efficiency and reduced costs.

Kineber et al. (2023) explore the critical applications of RFID technology in sustainable construction in developing countries using a global case study. The authors analyze how RFID can help improve project management, reduce waste, and increase resource efficiency in the construction industry. This study is important for understanding the potential of RFID in settings where the technology infrastructure is still developing, highlighting the importance of adapting technologies to local conditions.

Wang et al. (2018) describe the use of RFID in manufacturing integrated with cloud-based MES (Manufacturing Execution Systems). Their research shows how RFID can help connect physical and digital processes, enabling true automation and production monitoring in distributed manufacturing environments. This allows for improved process control and increased transparency of production operations.

Guo et al. (2015) developed an RFID-based intelligent decision support system architecture for production monitoring and planning in a distributed manufacturing environment. Their work demonstrates how RFID can play a role in ensuring data accuracy and responsiveness to changes in production, which is important for optimizing logistics flows and reducing equipment downtime.

Dalenogare et al. (2018) assess the expected contribution of Industry 4.0 technologies, including RFID, to improving industrial efficiency. Their research focuses on how digitalization can transform manufacturing enterprises, increasing their productivity and adaptability to changing market conditions, which is critical for integrating innovative technologies into engineering.

Bukova and others. (2023) [study the environmental aspects of using RFID technology in logistics centers. Their work examines how RFID can impact environmental pressures, particularly through optimizing resource use and reducing waste. This aspect of the study highlights the importance of considering ongoing practices when introducing new technologies into production processes.

Despite the significant amount of existing research on the application of RFID technologies in engineering enterprises, there are still important gaps and shortcomings in the literature. This demonstrates that the RFID industry is dynamic and rapidly evolving, constantly generating new questions and challenges that require deeper study. In particular, the pace of technological innovation and changes in industry operational needs may outpace current scientific understanding of their impact on production processes. This creates a need for continued research aimed at assessing the long-term effects of RFID integration and developing new methods to improve their effectiveness in various manufacturing environments. This approach will not only solve existing challenges but also maximize the potential of RFID technologies for the innovative development of engineering enterprises. (Table 1).

Table 1. Key scientific gaps and shortcomings of the researched topic

Scientific gaps and shortcomings	Essence
Impact on economic efficiency	Many studies focus on the technical aspects of RFID technologies, but not enough attention is paid to analyzing their impact on the overall economic efficiency of production. This includes estimating the cost of RFID implementation, return on investment and change in operational costs, which is important to understand its real benefits and practicality of application in enterprises.
Integration with other technologies	Despite the significant potential for RFID synergies with other digital technologies, such as Internet of Things (IoT) or artificial intelligence systems, research exploring this integration in detail remains limited.
Long-Term Impacts and Technology Adoption	There is a paucity of data on the long-term impacts of RFID adoption on manufacturing processes and how workers and management adapt to the innovation.

The scientific task is to determine the most optimal RFID technologies to improve the accuracy and efficiency of the production process of engineering enterprises.

METHODOLOGY

In the context of our study, two key methods were selected: Saaty's method of hierarchies and pairwise comparison as the main tools for determining the optimal use of RFID technologies in engineering enterprises. These methods were chosen because of their ability to allow complex, multi-level assessment of factors influencing process performance. They help you break down complex technology choices into simpler, more manageable solutions. This approach allows for an objective evaluation of the interdependence between various characteristics and impacts, ensuring high reliability and accuracy in the selection of the most effective technologies.

The hierarchy method helps to systematize selection criteria, distributing them into different levels of importance and interaction. This contributes to a more in-depth analysis and provides an integrated approach to solving the research problem. The pairwise comparison implemented within the Saaty method provides a quantitative assessment of each criterion's relative importance, which helps avoid subjectivity in choosing the best alternative.

The method of hierarchies and paired comparisons, developed by Thomas Saaty, is a recognized tool for making decisions in complex environments where many factors and criteria must be taken into account. This methodology is ideal for use in solving problems in engineering enterprises, where the choice of optimal technologies affects all aspects of production processes. The essence of the method is to break down a complex decision into a hierarchical structure of goals, criteria, subcriteria and alternatives, which simplifies analysis and selection. This method allows the subjective judgments of experts to be expressed in quantitative assessments that are easy to compare and analyze.

Advantages of this method include its flexibility and ability to adapt to different research settings. It provides a clear and systematic identification and assessment of factors that contribute to a deep understanding of a decision. This is especially useful in cases where you need to manage complex engineering systems, where every detail can have an important impact on the final result.

The disadvantages of the hierarchy method are its dependence on the subjective assessments of experts, which can lead to bias in decisions. In addition, the difficulty of defining and managing a large number of criteria and alternatives can create difficulties in the analysis process and lead to errors in criterion weights.

Features of using the method in a modern context, especially in the context of engineering enterprises, include its integration with digital tools for data collection and processing. This can significantly improve the accuracy of determining criteria weights and increase the reliability of decisions. Integration with digital platforms expands the ability to assess changes in the production process in real time and quickly adapt solutions to new conditions.

In the context of contemporary engineering enterprise research, the application of the hierarchy method provides a platform for objective comparison of new technologies such as RFID with traditional methods, allowing the identification of the most effective strategies for innovation. This approach helps determine which technologies have the greatest potential for implementation in specific production environments, taking into account both technical characteristics and cost-effectiveness.

RESULTS OF RESEARCH

Digitization of the production process involves incorporating digital technologies into all areas of a business, fundamentally changing how it operates and delivers value to customers. A prime example of such digitization is the use of Radio Frequency Identification (RFID) technologies in modern enterprises. RFID is a form of wireless communication that uses radio waves to identify and track tags attached to objects automatically.

RFID technology consists of three components: an RFID tag, an RFID reader, and an antenna. RFID tags, which can be passive, active, or battery-assisted passive, contain electronically stored information. Passive tags collect energy from a nearby RFID reader's interrogating radio waves, active tags have a local power source such as a battery, and communicate by broadcasting their own signals. This technology enables the tags to be read from several meters away and beyond the line of sight of the reader.

In the context of modern enterprises, RFID technology is employed to enhance the efficiency of production processes. For example, in manufacturing, RFID tags attached to components can be used to track their progress through the assembly line. This real-time tracking helps in reducing errors and optimizing production flow. The data captured via RFID can be used to monitor workflows, manage inventory, schedule maintenance, and ensure that the right components are used at the right time. Another significant advantage of RFID technology in production processes is its ability to improve the quality control. By tracking the history, location, and trajectory of items throughout the production cycle, companies can quickly identify and rectify issues. This traceability is crucial for industries where quality assurance is critical, such as in pharmaceuticals or food and beverage. It helps in ensuring compliance with safety standards and regulations (Fig.2).

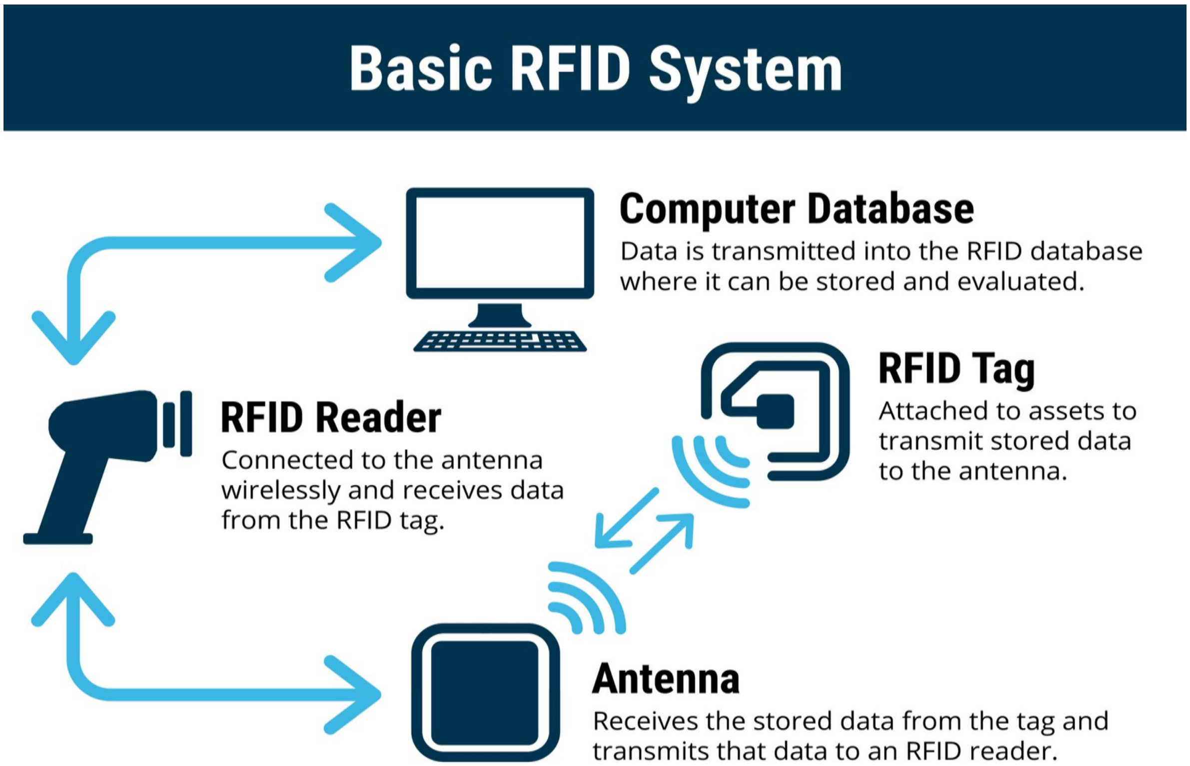

Figure 2. Basic RFID-system

RFID also enhances the scalability of production processes. As enterprises grow, managing increased volumes of products and components becomes challenging. RFID technology provides scalable solutions that can handle vast amounts of data and multiple processes simultaneously. This scalability is particularly beneficial in industries like automotive manufacturing, where hundreds of parts per vehicle need to be tracked and recorded.

Integration of RFID with other digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics can further enhance production processes. For example, data collected from RFID tags can be analyzed to predict equipment failures or optimize resource allocation. These insights can lead to smarter decisions, reduced waste, and increased productivity. However, implementing RFID technologies in production processes is not without challenges. Issues such as data privacy, interference from metal and liquids, and the cost of deploying RFID at scale need to be addressed. Enterprises must carefully plan and execute the integration of RFID to minimize these challenges. Firstly, AI can help in interpreting the vast amounts of data generated by RFID systems. Each tag read can generate multiple data points; when multiplied by the thousands or millions of tags in a production environment, the data becomes incredibly voluminous. AI algorithms can process this data in real-time, identifying patterns, trends, and anomalies that would be impossible for human operators to detect. This capability allows for predictive maintenance, where AI systems predict equipment failures before they occur, reducing downtime and maintenance costs. Moreover, AI enhances the decision-making process in inventory management. By analyzing RFID data, AI can forecast demand more accurately, optimize stock levels, and reduce overstocking or understocking situations. This application is particularly useful in industries with complex supply chains and varying demand patterns, such as retail or automotive manufacturing. AI-driven insights help enterprises to maintain lean inventories and reduce holding costs while ensuring that production lines are not disrupted due to the unavailability of necessary parts.

In quality control, AI combined with RFID creates a powerful tool for ensuring product integrity and compliance. AI algorithms can automatically analyze data from RFID tags to track products throughout the production line and test compliance against quality standards. If a product deviates from the expected path or fails to meet quality benchmarks, the system can trigger alerts for further inspection. This proactive approach minimizes the risk of defective products reaching the consumer, safeguarding the company's reputation and reducing the costs associated with recalls.

AI also contributes to enhancing operational efficiency by optimizing workflows. By analyzing the time-stamped data collected from RFID tags, AI models can identify bottlenecks in the production process and suggest alterations to improve throughput. These optimizations can include changes in the layout of the production floor, adjustments in the scheduling of machine use, or reassignments of workforce resources. Such targeted improvements can lead to significant gains in productivity and cost efficiency (Fig.3).

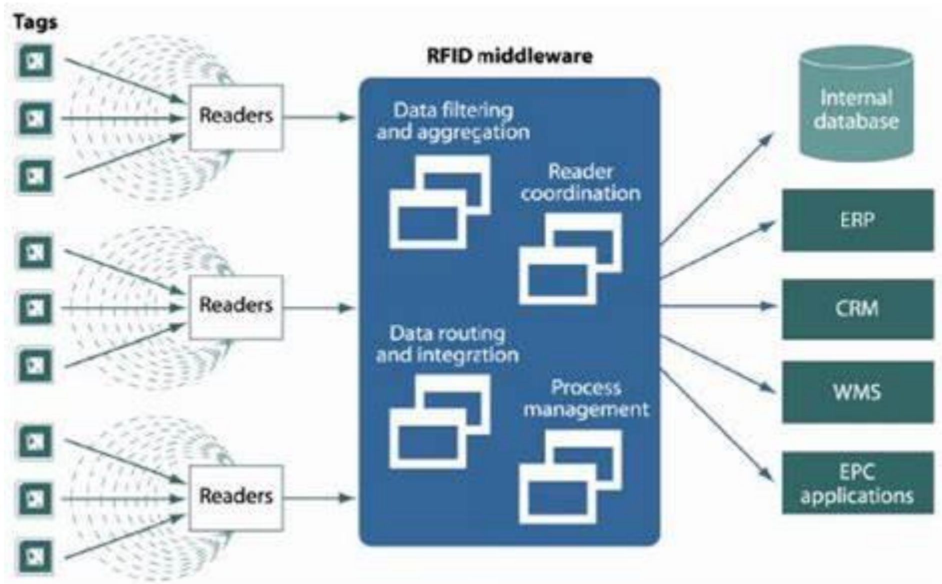

Figure 3. Hierarchieasic RFID-system

The application of AI in RFID systems also extends to improving worker safety. In environments such as manufacturing plants or warehouses, RFID tags can monitor the location of equipment and personnel in real-time. AI systems can analyze movement patterns to predict and prevent potential accidents and ensure that safety protocols are followed. By providing a dynamic oversight of operations, AI not only prevents costly accidents but also helps in creating a safer workplace. Moreover, AI enables the integration of RFID data with other systems within the enterprise, such as customer relationship management (CRM) and enterprise resource planning (ERP) systems. This integration allows for a seamless flow of information across different departments, enhancing cross-functional visibility and collaboration. The holistic view of operations gained through this integration aids in better strategic planning and customer service.

In conclusion, the role of AI in enhancing RFID technologies in production processes is transformative. By enabling the analysis of large datasets, predicting operational failures, optimizing inventory levels, ensuring product quality, improving safety, and facilitating enterprise-wide integration, AI drives significant improvements in efficiency and effectiveness. As both RFID and AI technologies continue to evolve, their combined impact on modern enterprises is expected to grow, leading to smarter, more connected, and more efficient production processes.

In conclusion, the digitization of production processes using RFID technologies offers numerous benefits to modern enterprises. It not only enhances efficiency and scalability but also improves quality control and integrates seamlessly with other digital innovations. As technology advances, the use of RFID in production processes is likely to become more prevalent, driving further improvements in industrial operations.

DISCUSSIONS

In the context of our study, special attention should be paid to the analysis and comparison of the results obtained with data from other relevant studies. This not only confirms the relevance and scientific novelty of our research, but allows us to better understand the context and significance of the contribution of our findings to the overall picture of the development of RFID technologies in the production processes of engineering enterprises. Comparing our results with existing data helps identify convergences and disagreements that may indicate potential directions for further research and improved implementation of technology solutions.

In a study, Ding, Jiang, and Su (2018) consider an RFID-based social production system for inter-enterprise monitoring and dispatch of integrated production and transportation tasks. This research focuses on the application of RFID for cross-enterprise coordination to improve collaboration and supply chain management. In comparison, our research focuses on improving the efficiency of manufacturing processes within a single engineering plant using optimal RFID technologies using Saaty's hierarchies and pairwise comparison method, which provides a more structured approach to technology selection.

In the work of Srinivasa Babu et al. (2022) discusses the use of RFID sensor technology for efficient design of various applications using wireless sensor networks. In comparison, our study focuses on using Saaty's hierarchies and pairwise comparison method to identify the most optimal RFID technologies for improving the efficiency of the production process in engineering plants. Zhang, Tian, and Chang (2022) analyze equilibrium channel structure strategies and RFID technology adoption in a supply chain with manufacturer intrusion. Our research is different in that we focus on selecting the most optimal RFID technologies to improve the production process in engineering plants.

At the same time, Agarwal and Ankolikar (2022) examines the implementation of RFID sensors in the supply chain. In comparison, our research focuses on selecting the most optimal RFID technologies to improve the accuracy and efficiency of the manufacturing process in engineering plants.

A study by Munoz-Ausecha et al. (2021) analyzes the application of RFID technology and the security issues associated with its implementation. In comparison, our research aims to select the most optimal RFID technologies to improve the accuracy and efficiency of the production process in engineering enterprises.

Chan (2016) discusses the use of RFID technology to improve decision-making in apparel supply chains. In comparison, our research focuses on identifying the most optimal RFID technologies for optimizing the production process in engineering plants.

In the work of Benouakta et al. (2022) describes the integration of an RFID UHF temperature sensor into textile yarn. In comparison, our research aims to select the most optimal RFID technologies to improve the efficiency of the production process in engineering enterprises.

Similar to the study by Unnikrishnan et al. (2021) and Litvin (2021), describing a multifunctional chipless RFID tag with identification and touch detection capabilities. In comparison, our research focuses on selecting the most optimal RFID technologies to improve the efficiency of the production process in engineering enterprises.

Duong et al. (2016) examines the application of RFID technology in inventory management of perishable goods. In comparison, our research focuses on identifying the most optimal RFID technologies to improve the efficiency of the production process in engineering plants.

This study makes a significant contribution to the field of manufacturing technology through an innovative approach to analyzing and optimizing the use of RFID technologies in engineering plants. The use of Saaty's method of hierarchies and pairwise comparison to determine the most effective RFID systems is innovative because it allows us to objectify the choice of technological solutions based on a quantitative assessment of their impact on key production parameters. This research not only highlights the potential of RFID to improve the efficiency and accuracy of manufacturing processes, but also opens up new prospects for further innovation in this area, spurring the development of more integrated and intelligent manufacturing systems.

CONCLUSIONS

In the conclusions of the study, we can highlight significant prospects for the use of RFID technologies in the production processes of engineering enterprises. The use of these technologies can significantly increase the level of automation, providing more efficient data collection and analysis, which in turn helps optimize logistics and production processes. By accurately tracking materials and components throughout production, businesses can reduce costs, particularly in warehousing and inventory management. This integration opens up new opportunities to reduce lead times and improve overall product quality.

This study focused on analyzing and identifying the most effective RFID technologies for the manufacturing processes of engineering firms. The use of Saaty's method of hierarchies and pairwise comparisons made it possible to hierarchically arrange available technologies based on their impact on key parameters of production efficiency. The results of the study indicate that the implementation of selected RFID technologies can significantly improve the accuracy of production processes and provide greater transparency in production management.

The analysis showed that RFID technologies not only help improve operational control, but also provide a better understanding of current production needs, which allows enterprises to quickly adapt to changing market conditions. The use of these technologies also helps reduce human errors, particularly during manual data entry, and ensures a high level of repeatability of processes.

The overall results of the study highlight that RFID adoption can serve as a catalyst for changes in the production strategies of engineering firms, allowing them to achieve greater responsiveness and greater competitiveness. The practical implementation of the recommended technologies is already demonstrating positive changes in terms of improving quality and reducing production costs.

In conclusion, it can be noted that the study confirmed the importance and effectiveness of RFID technologies for modern engineering companies. With the help of selected innovative solutions, businesses can not only optimize their processes, but significantly improve the overall quality and speed of production.

The first and most important limitation of this study is its exclusive focus on RFID technologies, which may lead to an underestimation of other technological solutions that could also improve production efficiency. For example, technologies based on artificial intelligence and machine learning may provide additional benefits not covered in this study.

The second significant limitation is the use of the Saaty hierarchy and pairwise comparison method, which includes subjective assessment by experts. This method may introduce bias into the results as they depend on the personal opinions and experience of the evaluators. This methodology may not take into account all external factors that may influence the effectiveness of technologies in the dynamic conditions of a real production environment.

Regarding future research prospects, it is important to consider the integration of RFID with other advanced technologies. For example, combining RFID with artificial intelligence-based systems can lead to smarter and more adaptive manufacturing systems that can predict maintenance needs and optimize supply chains based on dynamic data.

Also a promising direction is to study the impact of RFID implementation on employee workload and overall organizational culture. It is important to determine how the changing technological landscape affects workers' attitudes toward work and their productivity.

In conclusion, expanding the geographic coverage of research may help to understand how different economic and cultural conditions influence the effectiveness of RFID technology adoption in engineering firms in different countries.

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