5th African International Conference on Industrial Engineering and Operations Management, Johannesburg/Pretoria, South Africa, April 23 - 25, 2024
Publisher: IEOM Society International, USA
Published: April 23, 2024 DOI: 10.46254/AF05.20240239

RFID-Technologies in Warehousing: State-of-the Art and Future Prospectives

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Abstract

This paper explores various facets of RFID (Radio Frequency Identification) with a focus on current state-of-the-art technologies. Through an in-depth investigation, we aim to shed light on providing valuable insights for companies as well as others interested. The study employs the processing of literature to analyze various other scientific papers as well as other literature uncovering similarities and trends. The findings of this research contribute to the existing state of knowledge in optimizations of the logistics and the supply chain, also offering practical implications. As the paper unfolds, the audience will gain a comprehensive understanding of the current state-of-the-art RFID technology and their significance in the context of logistics. This research serves as a source of information for scholars, practitioners, and anyone interested in new trends in a constantly changing sector.

Keywords
RFID, Radio Frequency Identification, Warehousing, Smart Logistics, Logistics 4.0

1. Introduction
In the ever-changing world of logistics and supply chain management, the focus is on the efficiency and precision of warehousing to meet the constantly growing demands and complexities. In this context, using state-of-the-art RFID (Radio-Frequency Identification) technologies in warehousing is becoming increasingly important. This scientific paper is dedicated to the central question: "How can the use of RFID technologies in Warehousing support logistics and the supply chain in general?". RFID technology has developed rapidly in recent years and now offers a wide range of possibilities for increasing efficiency, accuracy, and transparency in warehousing. The integration of RFID into warehouse management systems enables real-time tracking, inventory management and automated processes that far surpass traditional methods. These developments not only promise to optimize operational processes but also have the potential to revolutionize the entire supply chain and all related processes. The aim of this paper is to examine the latest advances in RFID technology and analyze its concrete applications in the warehouse environment. Examples will be used to illustrate the current situation and where RFID is already being used successfully or in conjunction with other technologies. By identifying best practices and challenges, the aim is to help deepen the understanding of how RFID technologies can serve as a critical building block for the future of logistics and supply chain optimization.

2. Literature Review
RFID stands for Radio Frequency Identification. It is a technology that uses radio waves to automatically identify and track objects. RFID systems consist of two main components:

- Transponder: The transponder is a small device that is attached to or embedded in the object or living thing that is to be identified or tracked. The transponder contains an antenna, a microchip, and a power source.
- Reader: The reader is a device that emits radio waves and receives data from the transponder. The reader decodes the data and sends it to a computer or other device.

When the transponder is within range of the reader, the reader emits radio waves. The radio waves induce a current in the transponder's antenna. This current powers the transponder's microchip, which sends a signal back to the reader. The reader decodes the signal and sends it to a computer or other device. Over the years, the practices and application of RFID technology have proved the feasibility of integrating RFID into logistics processes. The following examples will demonstrate the development and state of art RFID technologies.RFID technology is now evolving its applications at different levels: At the industrial level, it was firstly conceived at the pallet/case level for enhancing productivity and accuracy of logistics processes, while at present the focus is shifting towards item-level tagging applications for also managing in-store processes, including the selling experience. Due to a more technological customer, the spread of e-commerce and the need for omnichannel sales availability, also Fast-Moving Consumer Goods (FMCG) are subject to an evolution of the way of selling, enabled by item-level RFID tagging. Since these technologies are connected to the fourth industrial revolution, this novelty is referred to as Retail 4.0 (Tebaldi et al. 2023).

Furthermore, the use of intelligent packaging with RFID cards, GPS (Global Positioning System) tags, TTI (Time Temperature Indicator) and other chemical and biosensors enable a more precise planning of operations and better visibility of critical elements within the supply chain. This enables a solution closer to optimal inventory management, reduction in time of transport and delivery of products, and improvement in the efficiency of the entire chain (Hansani 2018).

Several cases of successful use of RFID can give us more confidence in solving the problems arising from social development. With the boom of E-commerce in recent years, third-party logistics (3PL) has gained much favour for its large scope of service provided and economy of scale. Meanwhile, in the face of oceans of parcels to deliver, it casts requests on the efficiency of warehousing management to meet the needs of customers. However, most companies conduct warehousing operations still relying on paper for guiding and recording, and information is rarely shared even in the same company. Besides, few big companies are pursuing an automatic system to replace manpower, but in effect, the system is too massive and complicated to be stable and robust in usage (Wu et al. 2020). In this context, the use of RFID in warehousing might support solving this problem, which is what we are going to discuss in this paper.

3. Methods and Data Collection

To analyze the current state-of-the-art of the use of RFID technology in the warehouse as a tool for security a systematic literature review using the Prisma Method was created. The goal of PRISMA is to provide the user with a minimum of items to create higher-quality reviews and meta-analyses (Prisma 2024). The database which was chosen was “SCOPUS” as it is an established database with over 93 million records (Scopus 2024), the search string was the following: “RFID” AND (“logistics” OR “supply chain management”) AND (“storage” OR “warehouse”) AND (“security”). Only results from “Engineering” and “Business, Management and Accounting” that were published in the last 6 years were considered. These restrictions led to the results of 70 papers that were analyzed. Figure 1 shows the steps of the SLR according to the PRISMA standard (Kaiblinger and Woschank 2022; Miklautsch and Woschank 2022; Pacher et al. 2024; Page et al. 2021, Woschank et al. 2020).

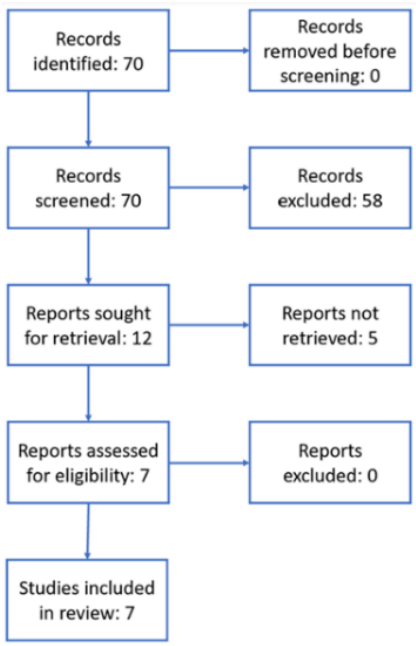

Figure 1. Visualization of the PRISMA process (Page et al. 2021)

The titles and abstracts of the identified publications were screened and rated according to their relevance to the research topic. This was done by four people individually, who rated all publications on a scale of 1-5, 5 being the highest score and 1 being the lowest. The average of the individual scores was calculated and rounded to whole numbers. Only publications with an average result of 4 or 5 were further looked at. Five of the remaining 12 could not be further looked at as they were not open access. The last seven were analyzed more closely in the following chapter.

4. Results and Discussion

Table 1 shows the result of the rating process of the identified records. 58 of them were rated with a score of 1 to 3 and therefore not seen as relevant enough for further analyses. Out of the remaining twelve with a rating of 4 or 5 were seven available to the authors and were looked at further.

Table 1. Distribution of screened records

Relevance	Records	Records [%]
1	19	27%
2	23	33%
3	16	23%
4	8	11%
5	4	6%
Total	70	100%

Figure 2 displays that out of the 70 screened records nine were published in 2018 as well as in 2019, 14 in 2020, 15 in 2022 and 13 in 2023 up to the time of conducting this systematic literature review, showing a constant trend in publications over time.

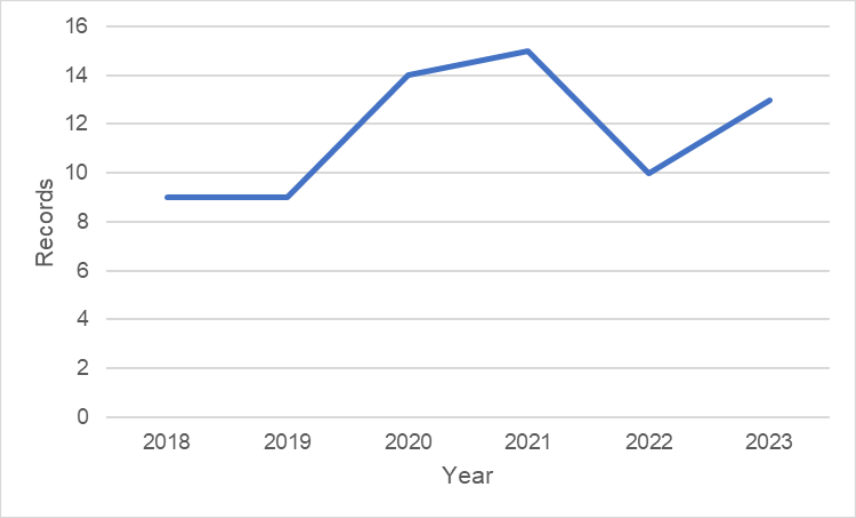

Figure 2. Publication year of the identified records

Before RFID tags were used in warehousing, the most used methods were paper- and barcode-based systems. RFID is mainly used for monitoring/documentation, tracing, inventory, and information storage (Chin Lin and Lun Lin 2018). This is achieved through a reader and writer devise. There are two types of readers/writers: the fixed reader and the handheld version for the employee (Pan and Lui 2021; Du 2021). For example, fixed readers/writers are used after a process to mark this process as finished on its RFID tag. Handheld devices are for example used to check the content of a palette without taking it apart, which makes the time-consuming and maybe even ware-damaging task of checking the inventory a quick and contactless task (Hamadneha et al. 2021; Du 2021). After receiving the signal from the tag, the reader sends it to the database where it is documented. There is no uniform system for RFID management systems now and most solutions are specifically made for each enterprise. Compared to paper and barcodes, RFID offers numerous advantages, with adaptability being a key factor. When using paper, once an order is completed, it cannot be reused (Hehua 2021; Cai and Liu 2023). Barcodes store information in a database, requiring the barcode to be visible within a minimum radius of 1m for effective use and undisturbed by dirt (Yuan 2019).

The information stored on the RFID tag can be customized for each application. For instance, a palette containing a variety of goods can easily checked by referring to the designation, description, and quantity of the items. By incorporating storage requirements and order cycles, the storage organization can be enhanced. Additionally, quality information relevant to subsequent processes can be stored on the RFID tag, contributing to an overall improvement in product quality and process (Hehua 2021).

The significant reductions are in employee utilization, time consumption, errors, and mistakes. This not only saves time and money but also minimizes the need for revision and postproduction efforts. Furthermore, the use of RFID enhances the efficiency of completing orders within a set timeframe and optimizes warehouse storage usage [Hehua 2021; Du 2021; Cai and Liu 2023).

The usage of RFID technology can further be improved by not just implementing it at a local level but also in the supply chain. Normally the warehousing operation starts after the quality check but if the supplier also has an RFID management system, the status of the goods' quality can be written on the tag. Furthermore, the tracking and monitoring of the orders helps the management and the customer because the status of the order is always available (Du 2021). In combination with other devices like WSN (wireless sensor networks) and GPS, the versatility increases. GPS is mainly used in combination with a vehicle. The RFID tags are linked to the GPS, so the tracking of the goods is the tracking of the vehicle (Du 2021). WSN with RFID have many applications like cold chain, environment, and hazardous material monitoring (Pan and Liu 2021). A Simulation with MATLAB was made. With the use of WSN and RFID, where the position location tracking was monitored with a six-axis acceleration sensor and three Nodes. Different Algorithms were used, and the result was that the genetic algorithm with the support vector gave the best results in determining the location (Pan and Liu 2021). Implementing RFID tags needs the necessary hardware and

software, employees who are schooled in the usage of the devices and applications, an environment without electromagnetic indifference, and the necessary funds for investment (Yuan 2019; Hamadneha et al. 2021).

5. Conclusion

From the viewpoint of Industrial Engineering and Management respectively from the interdisciplinary perspective of modern Engineering Education, it can be stated that the introduction of RFID technology in warehousing has brought significant improvements in terms of efficiency, time savings, ergonomics, human integration, and error reduction (Pacher et al. 2022; Pacher et al. 2023; Pacher et al. 2024; Zunk 2018; Zunk et al. 2020). Compared to traditional paper and barcode-based systems, RFID offers a contactless, fast, and accurate method of monitoring, tracking and inventorying goods. The direct storage of information on the RFID tags ensures greater data security compared to paper-based systems, while the line-of-sight independence of RFID readers is a clear advantage over barcode-driven systems.

A decisive factor for the future of RFID technology in warehousing lies in the standardization of RFID management systems. Currently, most solutions are developed on an individual basis for companies, which means that they are incompatible with each other. A standardized system could help to facilitate the integration of RFID in different business contexts and further increase efficiency. A promising approach to optimizing RFID technology in warehousing is to use it not only at the local level but throughout the entire supply chain. By implementing RFID management systems on the supplier side, the quality of goods can be checked and documented before they arrive at the warehouse. This advanced information enables improved inventory management and increases the efficiency of the entire supply chain. These results not only provide an insight into the possibilities of the current technology but also enable future research and application. It would be interesting to continue working on the optimization of algorithms and sensor technologies to make position tracking even more accurate and efficient. In addition, research into the integration of AI (artificial intelligence) technologies into these systems could help to improve automated decision-making processes and reduce the response time to changes in real time. Nevertheless, advances in the integration of RFID with GPS and WSN show that the future of warehousing and logistics will be characterized by innovative technologies. Companies that invest in these advanced systems can increase their operational efficiency and gain a competitive advantage in an increasingly connected and dynamic global economy.

Future research could focus on enhancing the security of RFID systems to address potential privacy and cyber-attack concerns. Similarly, studies could be conducted on the environmental impact of RFID technology to ensure that the benefits in terms of efficiency do not come at the expense of the environment. Overall, the integration of RFID, GPS and WSN in warehousing offers promising prospects for improved efficiency, transparency, and traceability of goods throughout the supply chain. Companies that invest in these technologies could benefit in the long term from optimized logistics, reduced errors, and increased customer satisfaction.

References

Cai, J. and Liu, B. B., Design of Logistics Intelligent Warehouse Management System Based on Radio Frequency Identification Technology for 5G, *Wireless Communications and Mobile Computing*, p. 9796234, 2023.

Ching Lin, Y. and Lun Lin, K., Logistics Management Innovation, RFID Application on Intelligent Management of Valuable Assets, 2018 International Symposium on Semiconductor Manufacturing (ISSM), 2018.

Du, C., Logistics and Warehousing Intelligent Management and Optimization Based on Radio Frequency Identification Technology, *Journal of Sensors*, p. 2225465, 2021.

Hamadneha, S. Keskinb, E. Alshurideha, M. Al-Masria, Y. Al Kurdic, B. The benefits and challenges of RFID technology implementation in supply chain: A case study from the Turkish construction sector, *Uncertain Supply Chain Management*, 9, 4, pp. 1071-1080, 2021.

Hasani M. Wearable Passive RFID Tags in Advanced Uses: Detection Methods for RFID-Enabled Sensor Tags and RFID-based Localization, *PhD thesis, Tampare University of Technology, Tampare*, 2018.

Hehua, M., Application of Passive Wireless RFID Asset Management in Warehousing of Cross-Border E-Commerce Enterprises, *Journal of Sensors*, p. 6438057, 2021.

Kaiblinger, A. and Woschank, M., State of the Art and Future Directions of Digital Twins for Production Logistics: A Systematic Literature Review, *Applied Sciences*, 12, p. 669, 2022. DOI: 10.3390/app12020669

Miklautsch, P. and Woschank, M., A Framework of Measures to Mitigate Greenhouse Gas Emissions in Freight Transport: A Literature Review from a Manufacturer's Perspective, *Journal of Cleaner Production*, 366, p. 132883, 2022. DOI: 10.1016/j.jclepro.2022.132883

Pacher, C., Woschank, M., and Zunk, B. M., The Impact of Competence on Performance in Industrial Engineering and Management: Conceptualization of a Preliminary Research Model, *Procedia Computer Science*, 232, pp. 794-803, 2024. DOI: 10.1016/j.procs.2024.01.079.

Pacher, C., Woschank, M., and Zunk, B. M., The Role of Competence Profiles in Industry 5.0-Related Vocational Education and Training: Exemplary Development of a Competence Profile for Industrial Logistics Engineering Education, *Applied Sciences*, 13, 5, pp. 3280, 2023. DOI: 10.3390/app13053280.

Pacher, C., Woschank, M., Rauch, E., and Zunk, B. M., Systematic Development of a Competence Profile for Industrial Logistics Engineering Education, *Procedia Computer Science*, 200, pp. 758-767, 2022. DOI: 10.1016/j.procs.2022.01.274.

Pacher, C., Woschank, M., Zunk, B. M. et al., Engineering education 5.0: a systematic literature review on competence-based education in the industrial engineering and management discipline, *Production & Manufacturing Research*,12, 1, p. 2337224, 2024. DOI: 10.1080/21693277.2024.2337224.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E. et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews, *BMJ 2021*, 372, 71, 2020.

Pan, C. and Liu, M., Optimization of Intelligent Logistics Supply Chain Management System Based on Wireless Sensor Network and RFID Technology, *Journal of Sensors*, p. 8111909, 2021.

Prisma, Available: https://www.prisma-statement.org/, 2024

Scopus, Avaliable: www.scopus.com, 2024.

Tebaldi, L. et al., RFID technology in Retail 4.0: state-of-the-art in the Fast-Moving Consumer Goods field, *International Journal of RF Technologies: Research and Applications*, 13, 2, pp. 105-133, 2023.

Woschank, M., Rauch, E., and Zsifkovits, H.E. A Review of Further Directions for Artificial Intelligence, Machine Learning, and Deep Learning in Smart Logistics. Sustainability, 12, p. 3760, 2020. DOI: 10.3390/su12093760

Wu, W., et al. An IoT-enabled real-time logistics system for a third party company: A case study, Procedia Manufacturing, 49, pp 16-23, 2020.

Yuan, L., Research and Practice of RFID-Based Warehouse Logistics Management System, *International Conference on Smart Grid and Electrical Automation (ICSGEA)*, Xiangtan, China, 2019.

Zunk, B. M., and Marchner, A., Verbesserung der Kooperation zwischen Beschaffung und Produktentwicklung, *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 104, 12, pp. 1087–1092, 2009. DOI: 10.3139/104.110226.

Zunk, B. M., Positioning "Techno-Economics" as an Interdisciplinary Reference Frame for Research and Teaching at the Interface of Applied Natural Sciences and Applied Social Sciences: An Approach Based on Austrian IEM Study Programmes, *International Journal of Industrial Engineering and Management*, 9, 1, pp. 17–23, 2018. DOI: 10.24867/IJIEM-2018-1-102.

Zunk, B.M., Woschank, M., Reinisch, M. et al., Management of Critical Lower-Tier Suppliers in Global Networks: Practical Relevance, Literature Review and Management Perspectives, *Engineering Management Review (IEEE)*, 48, pp. 181-194, 2020, DOI: 10.1109/EMR.2020.3015544.

Biographies

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Acknowledgements

This research belongs to the project "SME 5.0 - A Strategic Roadmap Towards the Next Level of Intelligent, Sustainable and Human-Centered SMEs" (funded in the European Union's Horizon MSCA 2021 programme under the Marie Skłodowska-Curie grant agreement No. 10108648).