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Research Gaps in Radio Frequency Identification Technology Implementation in Warehouses

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Abstract

Warehouses play a crucial role in enabling efficient logistical activities. Integrating Radio Frequency Identification (RFID) technology has been recognized as a catalyst for warehouse operations innovation by reducing item tracking and management complexities. This study aims to identify novel research opportunities in integrating RFID technology within warehouse operations. Researchers conducted a comprehensive literature evaluation by examining Scopus-indexed articles. In addition to analyzing the objectives, findings, outputs, and gaps in each reviewed paper, this study strengthens understanding by including concrete examples or real-life case studies of RFID implementation in warehouses. Studies conducted by Govardhan demonstrate the positive impact of RFID usage in enhancing supply chain efficiency and inventory management in warehouses. Similarly, research by Tripicchio highlights increased inventory visibility and accuracy and accelerated inventory processes through RFID integration. This research contributes significantly by presenting a comprehensive and exhaustive literature review that has yet to be available in recent literature reviews on similar topics. Thus, incorporating concrete examples or real-life case studies enriches understanding of the potential and relevance of this research in the context of RFID implementation in warehouses.

Keywords: Inventory, Logistics, Optimization technology, RFID, SLR

1. Introduction

Warehouses play a crucial role in facilitating efficient resource management within logistic activities. To accomplish this goal, it is necessary to implement a logistic function that can effectively oversee the logistics and warehousing operations [1]. The core operations of warehouses, including the receipt and transportation of materials, significantly impact the overall effectiveness of the supply chain [2]. Furthermore, the rise in worldwide exportation has resulted in the transition from human-driven to machine-driven activities, with numerous sectors adopting robotic systems to enhance material handling efficiency [3].

The evaluation of supply chain performance is primarily based on two key measures: cost and customer responsiveness [4]. To adhere to these metrics, the logistics sector necessitates innovative measures to enhance its competitiveness. The proposed innovation involves developing a system with the potential to monitor and regulate the flow of items within storage facilities [5]. Conversely, warehouses exhibit a high degree of dynamism, characterized by varying quantities of items received and dispensed daily. RFID is a possible invention that can be utilized to enhance warehouse operations. Furthermore, each warehouse possesses distinct traits that set it apart. Hence, it is imperative to include contextual elements to identify and regulate all actions conducted within the warehouse effectively [6].

RFID technology significantly contributes to augmenting a company's capacity to get comprehensive data on any object physically affixed with a tag and scanned wirelessly. Moreover, RFID technology can be implemented across various business-to-business operations and processes inside the supply chain, encompassing services, intra-business logistics, marketing, and post-sales activities [7]. Implementing RFID technology is crucial to achieving an automated and intelligent warehouse management system while enhancing operational efficiency [8]. In this context, RFID technology

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has emerged as a promising solution. Using RFID in logistics and warehouse operations has proven to improve inventory management efficiency and address complex operational challenges. This study fills a theoretical gap in the literature concerning RFID technology in warehouse and supply chain management. Therefore, this research aims to understand how RFID addresses operational challenges in both fields comprehensively. For instance, research by Govardhan [9] has illustrated how RFID implementation can optimize the supply chain and expedite warehouse inventory management processes. Thus, RFID offers unique advantages compared to traditional tracking methods, and a deeper understanding of the implementation of this technology will strengthen the foundation for our research.

Recently, there has been a noticeable surge in the number of scholarly articles appearing in conference proceedings and international publications that present case studies on the practical application of RFID technology within warehouse environments. The study searched Scopus-indexed journals utilizing Harzing's Publish or Perish Software [10]. This search yielded 27 scholarly papers on deploying RFID technology in warehouses, spanning 2007 to 2023. However, no articles were found about RFID warehouses from the beginning of 2023 until the end of August 2023. In addition, only one of the 27 articles found was a literature review article [11]. Hence, this study conducted a thorough and systematic evaluation to identify areas of research that still need to be addressed and offer more understanding of the existing body of literature. The identified research gap might serve as a point of reference for assessing the originality of future research endeavors.

2. Research Method

This literature review employed a systematic literature review (SLR) approach. The SLR consists of formulating research questions, identifying search strings, and selecting journal articles [12]. The SLR was adjusted to the predetermined topics, “RFID and warehouse,” to display gaps that can provide an overview of the novelty of further research.

2.1. Planning the Review

The first step is the research question, which is the initial and essential section of the SLR implementation. The research question is applied to guide searching and extracting articles. SLR was conducted to ensure that the literature review was more concentrated using inclusion criteria such as subject areas, keywords, and years of publications. Scopus-indexed articles published in international journals were searched using the keywords "RFID" and "warehouse." In this study, 27 articles were obtained from Scopus journal sources.

2.2. Applying Screening Criteria

The articles obtained were selected based on the year of publication, type of publication, and the publication's scope regarding RFID in the warehouse. A search string is then used in each data source to check the paper title [13]. To mitigate potential bias, we carefully established inclusion criteria in the literature selection and conducted thorough analysis, considering various perspectives to ensure the precision and reliability of our research methodology.

2.3. Analyzing the Review

The last step of the SLR was the discussion of topics related to problems that had been identified previously in the literature review. The analysis was performed based on the screening criteria. Each issue can be derived from gaps that exist in the current literature. The review protocol identified three aspects: bibliography, case study, focus, and publication content. The bibliography review includes author, year, title, journal name, volume, issue, and page. Table 1 provides information on the paper’s title and the method or approach used in each article reviewed.

Table 1. List of Reviewed Articles

No	Author	Method or Approach
1	Govardhan [9]	RFID warehouse
2	García [14]	RFID warehouse
3	Mandy [15]	RFID-enhanced
4	Scalia [16]	RFID warehouse

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No	Author	Method or Approach
5	Dimitropoulos [17]	RFID warehouse
6	Wang [18]	RFID-based digital warehouse
7	Xue [19]	RFID-based intelligent warehouse
8	Bevilacqua [20]	RFID warehouse
9	Scalia [21]	RFID warehouse
10	Xue [22]	RFID warehouse
11	Bottani [23]	RFID warehouse
12	Xu [24]	RFID-enabled warehouse
13	Chen [25]	RFID warehouse
14	Lim [11]	RFID warehouse
15	Zhou [26]	RFID warehouse
16	Kallarani [27]	RFID warehouse
17	Bektaş [28]	RFID warehouse
18	Li [29]	RFID warehouse
19	Fera [30]	RFID warehouse
20	Chen [31]	RFID-based bonded warehouse
21	Oner [32]	RFID-based warehouse
22	Trab [33]	RFID IoT-enabled warehouse
23	Selvaraj [34]	RFID warehouse
24	Setyawan [35]	RFID warehouse
25	Kokkonen [36]	RFID warehouse
26	Rungruengkultorn [2]	RFID warehouse
27	Tripicchio [3]	RFID warehouse

A review protocol specifies the methods used in the SLR. The review protocol is needed to reduce the possibility of researcher bias [37]. The review protocol of one article reviewed is presented in Table 2.

Table 2. Review Protocol

Bibliography	
Title	Development of Automatic Real Time Inventory Monitoring System using RFID Technology in Warehouse
Author	E. B. Setyawan
Year	2022
Page	636-642
Volume	6
Edition	3
Publisher	International Journal on Informatics Visualization
Type of Publication	Journal
Scope of Publication	International
Case study	

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Type of Company	Automotive
Area/Country	Indonesia
	Content
Background	Warehousing activities in a case study were still performed manually without considering a technology. The problems raised in the paper were delays in inventory control, where information on material flows cannot be obtained in real time.
Description/finding	Implementing RFID in warehousing operations can provide convenient stock monitoring. Information can be accessed in real time, and the efficiency of inventory control can be increased as operators no longer need to count stocks manually.
Impact	Aims to design an RFID-based real-time stock monitoring system that integrates the warehousing system in a company.
Results	RFID system improves the efficiency and effectiveness of inventory control.
Strengths	Considers the warehouse layout to measure the efficiency of RFID in stock monitoring.
Research opportunities	Integrating the inventory optimization model with real-time inventory control using RFID is necessary. The integration of real-time monitoring technology can be used as input for the inventory optimization model. Implementation of this strategy can help management in obtaining accurate purchasing decisions.

3. Results and Discussion

This paper reviewed articles on RFID implementation in warehouses. Three aspects were analyzed in this literature review: bibliography, case study, and research gap.

3.1. Bibliography Analysis

The articles reviewed in this study were Scopus-indexed articles published from 2007 to 2023. All selected papers were delivered in English. The distribution of articles based on the year of publication is depicted in figure 1. The number of publications changed between 2017 and 2022, with the highest number of articles recorded in 2013 and 2022, totaling four publications each year. Furthermore, there was a fluctuation in the number of publications, with a single publication recorded in 2009, 2017, and 2021, three in 2010 and 2018, and two in the remaining years.

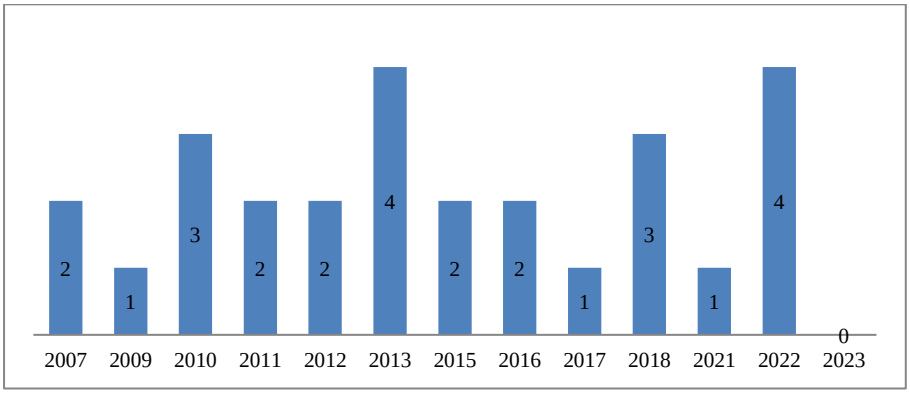

Figure 1. Years of article publication

The distribution of articles per journal name, as illustrated in Figure 2, reveals that most articles originate from several prominent journals, particularly the International Journal of RF Technologies: Research and Application. This suggests a greater focus on RFID topics in these journals. However, other factors, such as journal reputation and editorial policies, may influence this distribution. Further analysis of this distribution trend could provide deeper insights into the research landscape in this domain. Additionally, it is noteworthy that within this sample, two articles each were sourced from the International Journal of Advanced Manufacturing Technology and the International Journal of Radio Frequency Identification Technology and Applications, collectively contributing 7% to the overall sample. Subsequently, one journal, comprising 3.7% of the overall sample, was contributed by each of the subsequent journals:

International Journal of Applied Engineering Research, Journal of Central South University, International Journal of Production Economics, International Journal of Production Research, International Journal of Embedded Systems, Journal of Physics: Conference Series; International Journal of Logistics Research and Applications, Papers from the International Journal of Mathematics and Computer Science, Journal of Networks, International Journal of Production Research, International Journal of Manufacturing Technology and Management, IEEE Journal of Radio Frequency Identification, International Journal of Value Chain Management, Journal of Software, International Journal of Simulation: Systems; Science and Technology, International Journal of Radio Frequency Identification Technology and Applications, International Journal of Computer Information Systems and Industrial Management Applications, and International Journal on Informatics Visualization.

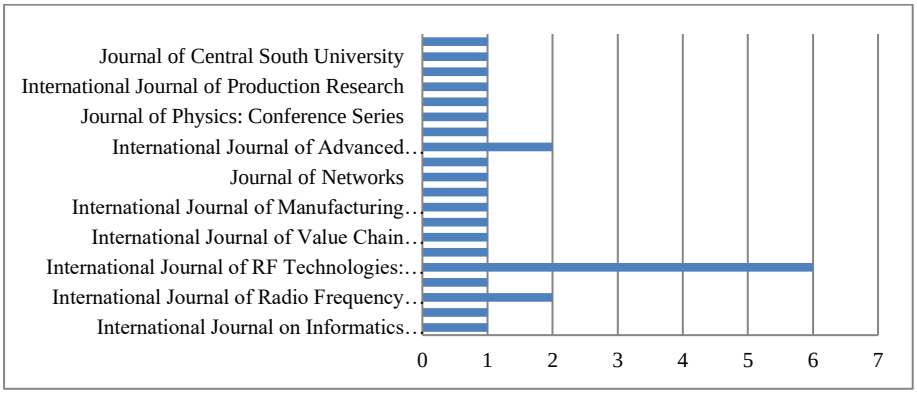

Figure 2. Journal of publication

3.2. Details of Case Study Analysis

Numerous scholars from various regions across the globe, including Asia, Africa, North America, and Europe, have undertaken extensive investigations into the use of radio RFID technology within warehouse environments. Every nation possesses unique attributes inside its warehouse management system. Figure 3 presents data regarding implementing RFID technology in warehouses, categorized by country.

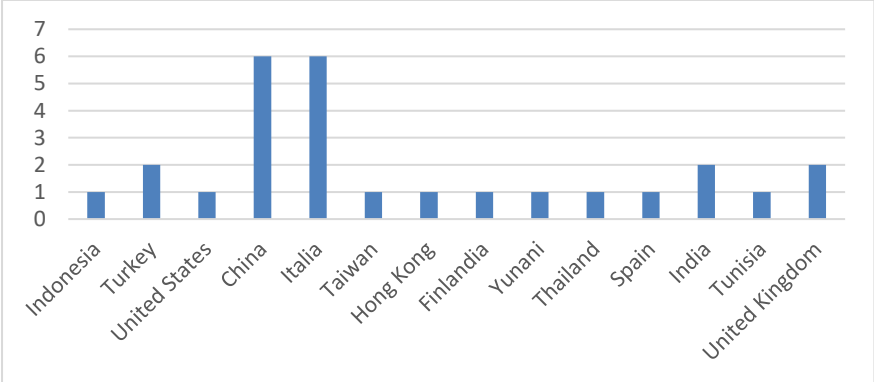

Figure 3. Area/country of publication

According to the data presented in Figure 3, 16 countries were identified as the subject of case studies referenced in the evaluated papers. Italy and China emerged as the most often mentioned countries in the reviewed publications, accounting for over five articles or around 22% of the documents examined. Turkey, India, and the United Kingdom each contributed two articles, accounting for 7% of the total. The remaining nations, including Indonesia, the United States, Taiwan, Hong Kong, Finland, Yunani, Thailand, Spain, Tunisia, and China, each provided one piece, representing 4% of the total.

Cultural differences or local regulations can significantly impact the global adoption of warehouse RFID technology. The distribution of articles from various countries suggests that certain nations, like Italy and China, may be more inclined to adopt RFID technology in their warehouse management. Cultural factors such as local business preferences and differing government regulations can influence the adoption and usage of RFID across different countries. Varying

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cultures may affect preferences and readiness to adopt new technology, while diverse rules in each country can impact policies regarding warehouse RFID use.

The localization system plays a crucial role as a supportive tool in enhancing the potential for value addition in warehouse management. Implementing RFID features is prevalent throughout many business sectors, following each organization's requirements [21]. Figure 4 illustrates the utilization of RFID technology throughout diverse business industry sectors. Among them, automobile companies accounted for 3% of the sample, while tobacco, railroad, spare parts, and wool yarn companies collectively represented 4%. Additionally, manufacturing companies constituted 7% of the total. Nevertheless, a significant proportion of the articles (74%) did not specify the organization employed as a subject of investigation.

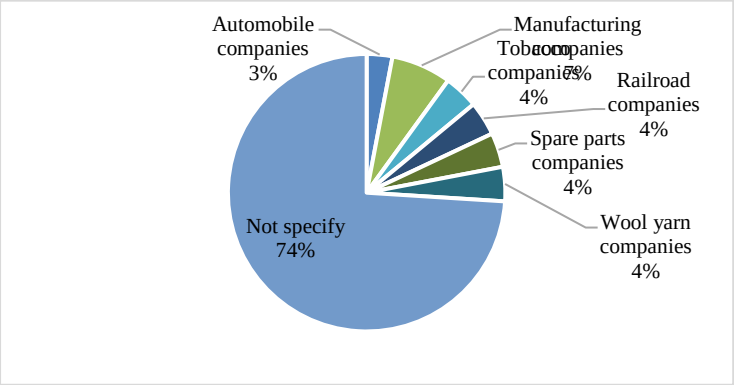

Figure 4. The types of companies mentioned as a case study

Numerous scholars have evaluated RFID technology's impact in enhancing warehouse management efficiency. The publications were classified into four categories: analytical research, simulation-based research, empirical research, and literature review. Figure 5 depicts the categorization of the literature that was examined. According to the data presented in Figure 5, most papers, precisely 12 articles, were classified as empirical research. Furthermore, the dataset consisted of eight publications classified as analytical research, six as simulation studies, and one as a literature review paper.

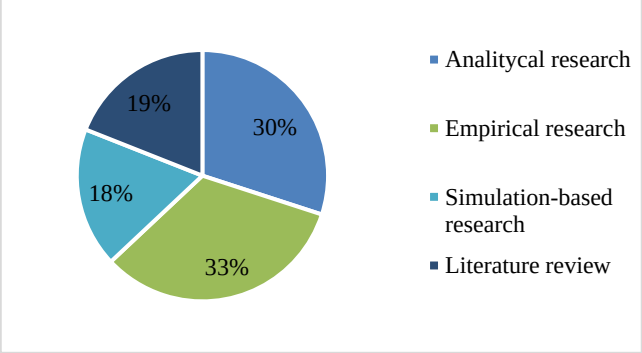

Figure 5. Article's classification

3.3. Focus and Content Analysis

Figure 6 illustrates the significance of RFID applications within the warehouse context, precisely the RFID deployment objectives of each respective company. According to the findings presented in Figure 6, it was observed that a total of seven papers, accounting for 26% of the sample, explicitly stated that the objective of their research was to develop a technology-based system. Moreover, 22% (equivalent to six articles) focused on creating comprehensive strategic management, while 19% (equal to five papers) were dedicated to designing innovative warehousing policies. However, a limited number of studies have focused on analyzing the characteristics of warehouses that facilitate the implementation of RFID and Internet of Things (IoT) technologies. These parameters aim to decrease product damage,

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enhance operational efficiency, and minimize costs. The implementation of warehouse policies might offer advantages regarding monitoring items from economic and technological standpoints [23].

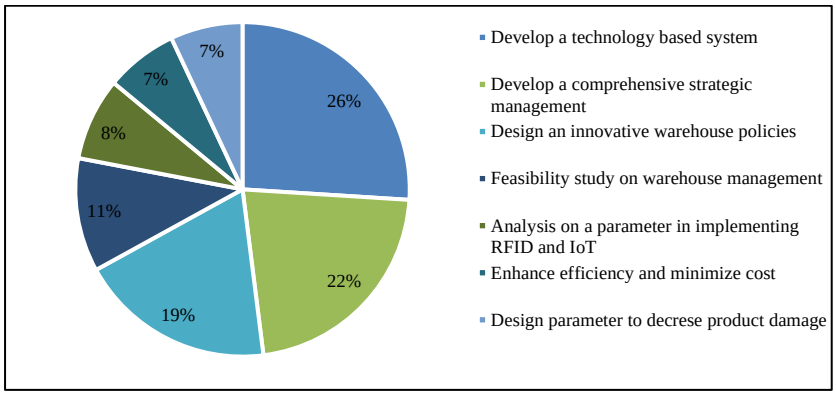

Figure 6. Research Objectives

In assessing the extent to which the paper's objectives reflect the practical needs of the industry, it is essential to consider their relevance, effectiveness, feasibility, impact, and alignment with warehouse industry requirements. The provided references can be utilized as a guide to bolster arguments and provide richer context in such critical evaluation. For instance, the case study [1] offers insights into the effectiveness of RFID technology in enhancing warehouse operational efficiency. Similarly, Rungruengkultorn [2] provides insights into how well RFID technology can be integrated with Lean management practices in the warehouse industry. Using these references as a foundation, critical evaluation can offer a more comprehensive understanding of the relevance and potential contributions of the paper's objectives to real-world warehouse practices and operations.

The dynamics of organization and employee perceptions affect the success of RFID technology in warehouses. This includes resistance to change, lack of understanding, and management support. It is essential to consider these factors in designing implementation strategies. This analysis strengthens the knowledge of how organizational dynamics and employee perceptions can influence the implementation of RFID technology in warehouse operational environments.

The study findings evaluated from the 27 papers are presented in Figure 7. According to the data shown in Figure 7, it can be observed that a total of five studies, accounting for 19% of the sample, have acknowledged the potential of technology-based simulations in enhancing control systems capabilities and fostering the development of novel techniques. On the other hand, using simulation techniques to manipulate system parameters has yielded valuable phenomenological insights for addressing challenges in warehouse control, as indicated by a collection of five scholarly works, accounting for 18% of the literature reviewed. Furthermore, nine publications, accounting for 33% of the sample, assert that using RFID technology can enhance quality and yield benefits if effectively integrated into the organizational framework to uphold firm performance. In layout localization development, implementing policies offers a comprehensive system overview, demonstrating the proposed system's viability. This assertion is supported by eight papers, accounting for 30% of the existing literature.

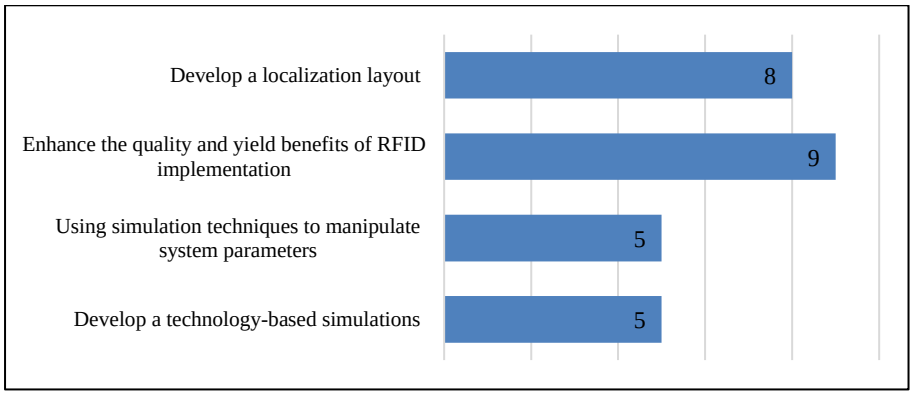

Figure 7. Research Findings

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Twenty-seven articles have been reviewed to examine the utilization of RFID technology within warehouse operations. This comprehensive evaluation summarizes the research outcomes, as depicted in Figure 8. According to a review of 14 studies, implementing RFID technology in warehouse operations can significantly enhance the efficiency and effectiveness of various activities. This finding is consistent with the analysis of five distinct categories. Implementing RFID technology in warehouse operations can yield several advantages, such as reducing manual labor and enhancing workflow efficiency through automated data transmission [31].

Furthermore, six publications, accounting for 22% of the sample, highlighted the advantages of adopting RFID technology for mistake reduction. The localization capability of the designed RFID system enables the convenient detection and subsequent management of mistakes. A highly dependable and compact control system would facilitate future upgrades [34].

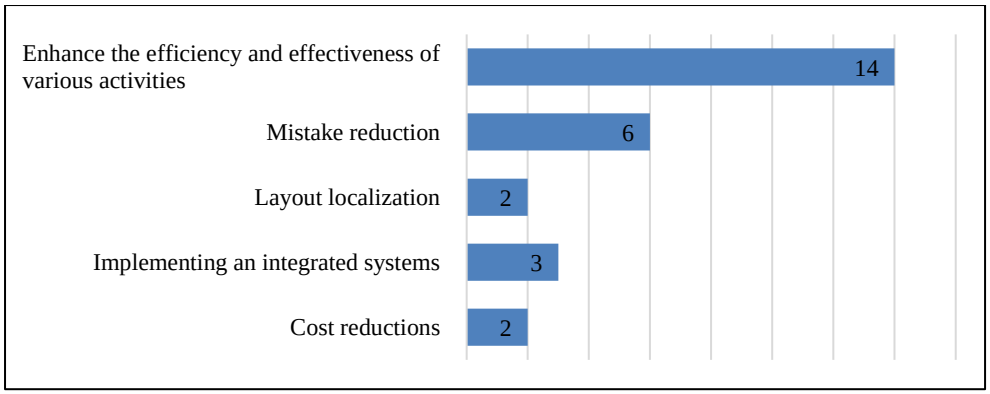

Figure 8. Research Outcomes

The topic of layout localization is examined in two scholarly works, which collectively account for 8% of the existing research in this field. The articles presented a comprehensive examination of the principles and protocols for accurately identifying and determining the location of targets. The effective utilization of the created model has the potential to facilitate the robot in successfully acquiring the desired object and transporting it to the designated warehouse [19]. Implementing an integrated system aims to enhance the profitability of businesses across many sectors by establishing warehouses. This information was reported in three scholarly articles, accounting for 11% of the total sources. Utilizing a mutually integrated system entails a fundamental depiction that the extent of the process management framework can be tailored through graphical tools [17]. The advantages associated with cost reductions are exemplified by two articles or a percentage equivalent to 7%. Additional assessments can be conducted to determine the economic viability of implementing the RFID system [32].

RFID has two components, namely active RFID technology and passive RFID technology. The Active (Alien 2850 MHz Series) and the Passive (Alien 9800 series) RFID apparatus are commonly used in warehouses [1]. Passive RFID is usually more effectively used for warehouse environments with consideration of lower implementation costs compared to active RFID (between $1000 and $2500 for readers and $0.07-1.00 for tags). The implementation of RFID can change the job assignment process from manual-based to automated, increasing warehouse capacity [18] and providing much better results in time savings and labor utilization [1], [6], [18]. Implementing lean technologies and RFID can streamline operating time, reducing waiting time and flat labor [2] [25].

RFID implementation can provide essential savings for companies regarding time and cost. Research by Bevilacqua et al. [20] shows that the initial investment cost of RFID implementation is around € 93,000. With a payback rate of about € 24,000, the payback period is about four years for applying the technology. Research by Bottani and Montanari [23] shows that the implementation investment (about € 357,000) can be quickly paid back in less than three years thanks to annual savings of € 172,000/year. The research of Oner et al. reinforces this result [32], which shows the investment in RFID implantation will be returned within 45 months, approximately equal to 3.75 years.

3.4. Research Gap

The identification of research opportunities was undertaken by a comprehensive review of 27 papers, employing a systematic literature review methodology. The primary objective of this endeavor was to discern areas of research that possess the potential to bridge the divide between theoretical and practical realms of inquiry. Identifying research gaps in RFID applications within the context of the supporting supply chain can serve as potential avenues for future research endeavors. The possible areas for future research encompass the optimization of localization algorithms, as indicated in seven scholarly articles. Additionally, technology integration is highlighted in five papers, while system functionality improvement is addressed in four articles. Furthermore, cooperative testing of various challenges is explored in four articles.

When considering the success of integrating RFID technology with automation systems in warehouse environments, it is noteworthy that some studies still need to highlight this aspect fully. One relevant article, published by Rungruengkultorn [2], examines warehouse process improvement using RFID technology. Although this article does not directly address the integration of RFID with automation systems, it provides insights into how RFID technology is utilized in modern warehouse management. Therefore, there is room to complement this research with further studies specifically exploring the interaction between RFID technology and automation systems in warehouse settings.

In this study, we enrich the discussion on the impact of RFID technology on supply chain performance by considering additional metrics such as inventory accuracy and order fulfillment rate. Findings from previous research indicate that using RFID technology can significantly enhance inventory accuracy and shipment efficiency within the supply chain [1], [2], [5]. The implementation of RFID-based logistics management systems has been shown to yield improvements in inventory management and shipment handling across various warehouse environments, thereby enhancing the overall performance of the supply chain.

In addition, several additional study opportunities have been documented in a limited number of scholarly studies. These include investigations into enhancing deviation tracking, implementing RFID in transportation systems, and utilizing technology-based modeling. Therefore, we have reviewed findings from previous literature to identify research gaps that need to be fully addressed. The following is a summary of the identified research gaps:

Table 3. Research Gap

Research opportunity	References
Technology integration	[35], [19], [22], [2], [33]
System functionality improvement	[28], [15], [18], [25]
Cooperative testing of various challenge	[15], [36], [24], [18]
Use different alternative methods	[22], [32], [3]
Optimization of localization algorithms	[35], [19], [36], [24], [22], [3], [33]
Enhancing deviation tracking	[3]
Implementing RFID in transportation systems	[25]
Utilizing technology-based modeling	[2], [3]

In research mainly focusing on the optimization gap of localization algorithms, several challenges must be addressed to enhance their effectiveness and accuracy. One major challenge is achieving adequate accuracy, especially in complex or disturbed environments. Additionally, some algorithms may require long computation times or significant resources, hindering their usage in fast-paced warehouse operations. Moreover, algorithms must resist disturbances like signal loss or electromagnetic interference. Handling large warehouse environments with many RFID tags is crucial without sacrificing performance or accuracy. Furthermore, it's important to consider integrating localization algorithms with other warehouse technologies, like warehouse management or automation systems. By addressing these challenges, researchers and practitioners can develop more effective solutions to enhance warehouse RFID implementation.

4. Conclusion

The systematic literature review provided a comprehensive analysis of the implementation of RFID technology in warehouses but also offered practical recommendations for practitioners and policymakers to enhance its application. These recommendations include technology integration, the development of alternative methods, collaborative testing, optimization of localization algorithms, and improvement in deviation tracking, aligning with the identified research gaps. This article will deliver excellent value and relevance to industrial stakeholders by including actionable recommendations. By identifying and addressing these gaps, practitioners and policymakers can develop more effective solutions to enhance warehouse operations' efficiency, productivity, and accuracy. The enhancement of warehouse control can be achieved by strategically localizing the layout and implementing an integrated system to manage and mitigate any faults effectively. The successful implementation of an approach enhances the efficiency and efficacy of activities, resulting in cost savings for warehouse operations. The main contribution of this study lies in identifying various research gaps that can serve as potential research opportunities for enhancing the deployment of RFID technology in supply chain management. Future research endeavors should consider employing further literature review analyses as a viable choice to enhance the depth of understanding. The recent advancements in RFID technology, such as sensors and blockchain integration, have the potential to streamline and secure warehouse management. While requiring significant initial investment, using RFID can save time and money in the long run. This presents an opportunity for further research to explore how this technology can be optimized for warehouse benefits in the future.

5. Declarations

5.1. Author Contributions

Conceptualization: H., Q., D.S., and S.; Methodology: Q.; Software: H.; Validation: H., Q., D.S., and S.; Formal Analysis: H., Q., D.S., and S.; Investigation: H.; Resources: Q.; Data Curation: Q.; Writing Original Draft Preparation: H., Q., D.S., and S.; Writing Review and Editing: Q. and H.; Visualization: H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received financial support for the research and publication of this article from the Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta, Indonesia.

5.4. Institutional Review Board Statement

Not applicable.

5.5. Informed Consent Statement

Not applicable.

5.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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