DIGITAL SOLUTIONS FOR ENHANCING ORDER-PICKING PERFORMANCE IN MODERN WAREHOUSES: A LITERATURE-BASED ANALYSIS

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Abstract

Order picking is widely recognised as one of the most labour-intensive and costly activities in warehouse operations, significantly influencing logistics efficiency and service performance. As supply chains become increasingly dynamic and customer expectations for rapid deliveries continue to grow, improving the efficiency and accuracy of order-picking processes has become a critical challenge for modern warehouses. This study examines how digital technologies can enhance order-picking performance in warehouse operations. The research is based on a literature analysis of scientific publications addressing digital solutions used in warehouse management. Particular attention is given to technologies such as Warehouse Management Systems (WMS), barcode scanning systems, radio frequency identification (RFID), pick-to-light technologies, and voice-directed picking systems. The results indicate that these technologies improve inventory visibility, increase picking accuracy, support warehouse workers during picking tasks, and enhance overall operational efficiency. The findings highlight that the integration of digital technologies plays an important role in improving order-picking performance and supporting more efficient warehouse operations.

Keywords: order picking, warehouse digitalisation, warehouse management systems (WMS), barcode scanning, RFID, pick-to-light, voice picking.

Introduction

Warehousing plays a critical role in modern supply chains by ensuring the efficient storage, handling, and distribution of goods. As supply chains become increasingly complex and customer expectations for rapid and reliable deliveries continue to grow, the performance of warehouse operations has become a key determinant of logistics efficiency and service quality (Christopher, 2016; Richards, 2018). Modern warehouses must therefore operate with high levels of accuracy, speed, and coordination in order to support effective order fulfilment processes.

Among the various warehouse activities, order picking is widely recognised as the most labour-intensive and costly process. Studies indicate that order picking may account for more than half of total warehouse operating costs due to the extensive movement and manual work required to retrieve products from storage locations (De Koster, Le-Duc, & Roodbergen, 2007; Bartholdi & Hackman, 2014). During this process, warehouse workers must locate items, collect them from storage areas, verify quantities, and prepare them for shipment. As a result, inefficiencies in order-picking operations can significantly affect overall warehouse productivity and operational costs.

Traditional order-picking methods often rely on manual procedures and paper-based instructions, which may lead to longer processing times and a higher likelihood of operational errors (Richards, 2018). In response to these challenges, many organisations have begun adopting digital technologies to improve warehouse efficiency. Technologies such as Warehouse Management Systems (WMS), barcode scanning, radio frequency identification (RFID), pick-to-light systems, and voice-directed picking solutions enable better inventory visibility, improve operational coordination, and support warehouse workers during picking tasks (Bartholdi & Hackman, 2014; Gu, Goetschalckx, & McGinnis, 2007).

Despite the growing adoption of these technologies, organisations still face challenges in selecting and integrating appropriate digital solutions to optimise order-picking performance. Therefore, this study focuses on examining how digital technologies can enhance order-picking efficiency and support more effective warehouse operations.

Research problem. Despite the increasing adoption of digital technologies in warehouse operations, many organisations still experience inefficiencies in order-picking processes, including high error rates, low productivity, and increased operational costs. This highlights the need for a structured evaluation of how different digital solutions contribute to improving order-picking performance and which technologies provide the most significant operational benefits.

Research questions: How do digital technologies influence order-picking performance in warehouse operations? Which digital solutions provide the greatest improvements in accuracy, speed, and productivity? What are the main operational benefits and challenges associated with implementing digital technologies in order-picking processes?

Research hypothesis. The implementation of digital technologies in warehouse operations significantly improves order-picking performance by increasing accuracy, productivity, and operational efficiency.

The aim of this study is to examine how digital solutions enhance order-picking performance and reduce operational costs in modern warehouses.

Research objectives:

1. To analyse the role of order picking within warehouse operations and its impact on logistics performance.
2. To examine digital technologies used to improve order-picking processes.
3. To evaluate the operational impact of digital technologies on order-picking performance.
4. To propose practical recommendations for the effective implementation of digital technologies to improve order-picking performance in warehouse operations.

Research object and methods

The object of this research is digital solutions used to enhance order-picking performance in warehouse operations. The study focuses on widely applied technologies, including Warehouse Management Systems (WMS), barcode scanning systems, radio frequency identification (RFID), pick-to-light technologies, and voice-directed picking solutions.

This research is based on a qualitative literature analysis of scientific publications, academic books, and industry reports related to warehouse management and digital logistics technologies. The analysed sources include peer-reviewed journal articles and recognised academic publications addressing order-picking processes and digitalisation in warehouse operations (Gu et al., 2007; Ivanov et al., 2019; Richards, 2018). The selection of literature was based on relevance to the research topic and contribution to understanding the operational impact of digital technologies.

The literature analysis method was applied to identify, compare, and synthesise key findings related to the impact of digital technologies on order-picking performance. In particular, the analysis focused on evaluating how different technologies influence key performance indicators such as picking accuracy, speed, worker productivity, and inventory visibility. In addition, descriptive and comparative analysis methods were used to examine the differences between digital solutions and their operational contributions. These methods allowed for a structured comparison of technologies and the identification of their main advantages and limitations in warehouse environments. The use of literature-based analysis is appropriate for this study as it enables a comprehensive evaluation of existing scientific knowledge and provides a theoretical foundation for understanding how digital technologies contribute to improving order-picking processes.

Research results and discussion

Based on the analysis of existing scientific literature on warehouse management and logistics technologies, several digital solutions that significantly influence order-picking performance have been identified. These technologies include Warehouse Management Systems (WMS), barcode scanning, RFID systems, pick-to-light solutions, and voice-directed picking, all of which are widely discussed in warehouse management research (Richards, 2018; De Koster et al., 2007).

The analysis indicates that these technologies contribute to order-picking performance through different operational mechanisms. While some technologies, such as WMS and RFID, primarily enhance information processing and inventory visibility, others, including pick-to-light and voice-directed picking, directly support workers during picking tasks by improving navigation, reducing errors, and increasing operational speed.

Table 1 provides a structured comparison of these technologies, highlighting their key operational contributions and demonstrating how different digital solutions address specific aspects of order-picking performance.

Table 1. Key digital technologies and their impact on order-picking performance

Digital tool	Its potential benefit to order picking	Authors
Warehouse Management System (WMS)	Optimizes picking routes and improves inventory visibility	Bartholdi & Hackman (2014);Richards (2018)
Barcode Scanning	Reduce Picking errors and improve product identification speed	Ivanov et al. (2019); Richards(2018)
RFID	Enables automatic item tracking, improves inventory accuracy, and speeds up information processing	Ivanov et al. (2019); Richards (2018)
Pick-to-light	Guides workers visually, reduces search time, and improves picking speed and accuracy	Bartholdi & Hackman (2014); Richards (2018)
Voice picking	Enables hands-free operation, improves worker productivity, and reduces picking mistakes	Richards (2018); Gu et al. (2007)

Source: developed by the author based on Bartholdi & Hackman (2014); Richards (2018); Ivanov et al. (2019); Gu et al. (2007)

Table 1 highlights that the analysed technologies differ in how they contribute to order-picking processes. Rather than providing uniform improvements, each technology targets specific aspects of warehouse operations, resulting in different types of performance gains.

For example, WMS solutions primarily influence process coordination by optimising picking routes and improving workflow organisation, which reduces unnecessary movement within the warehouse (Richards, 2018; Bartholdi & Hackman, 2014). In contrast, RFID technologies enhance the accuracy and timeliness of inventory data through automated tracking, allowing for more reliable monitoring of stock movements (Ivanov et al., 2019).

At the operational level, worker-oriented technologies such as barcode scanning, pick-to-light systems, and voice-directed picking contribute more directly to task execution. These solutions simplify product identification, reduce search time, and minimise manual errors, leading to improvements in both speed and accuracy during picking operations.

This comparison highlights that the impact of digital technologies is not uniform, but rather depends on how each solution supports different stages of the order-picking process.

While Table 1 identifies the main digital technologies used to support order-picking operations, it does not fully capture how these technologies affect specific performance dimensions. In warehouse management research, order-picking efficiency is commonly evaluated through key indicators such as picking accuracy, operational speed, worker productivity, and inventory visibility (De Koster et al., 2007; Richards, 2018). Table 2 therefore provides a more detailed evaluation of the relative impact of the identified technologies on these performance factors, offering a clearer understanding of how digital solutions contribute to improvements in order-picking processes.

Table 2. Effect of warehouse digital technologies on accuracy, speed, productivity, and inventory visibility

Technology	Accuracy improvement	Picking speed	Worker productivity	Inventory visibility	Key references
WMS	Medium	Medium	Medium	High	Richards (2018); Bartholdi & Hackman (2014)
Barcode scanning	High	Medium	Medium	Medium	Richards (2018); Ivanov et al. (2019)
RFID	High	High	Medium	High	Ivanov et al. (2019)
Pick-to-light	High	High	High	Medium	De Koster et al. (2007)
Voice-Directed Picking	High	Medium	High	Medium	Gu et al. (2007); Richards (2018)

Source: developed by the author based on De Koster et al. (2007); Richards (2018); Ivanov et al. (2019); Gu et al. (2007)

The impact levels presented in Table 2 ("High" and "Medium") are based on a qualitative comparison of findings from the analysed literature. A "High" impact indicates that multiple studies consistently report strong positive effects of a technology on a given performance indicator, while a "Medium" impact reflects more moderate or less consistent improvements. Based on this evaluation, the results presented in Table 2 show that several digital technologies significantly contribute to improving order-picking accuracy.

Technologies such as barcode scanning and RFID systems play an important role in ensuring correct product identification during picking operations. Barcode scanning enables workers to verify item codes before completing the picking process, reducing the likelihood of selecting incorrect products (Bartholdi & Hackman, 2014). Similarly, RFID technology enhances inventory accuracy by allowing automatic identification and tracking of items through radio-frequency communication, which reduces manual verification requirements and improves data reliability within warehouse systems (Ivanov et al., 2019).

In addition to improving accuracy, several digital technologies contribute significantly to increasing picking speed. Pick-to-light systems are particularly effective in reducing search time during manual picking operations by guiding workers directly to the required storage locations through visual indicators. This visual assistance enables workers to locate items more quickly and complete tasks with minimal navigation effort (De Koster et al., 2007). RFID technologies also enhance speed by enabling simultaneous identification of multiple items without requiring line-of-sight scanning, thereby accelerating data collection and inventory tracking processes (Ivanov et al., 2019). These findings indicate that technologies providing direct visual guidance or automated identification play a crucial role in reducing operational delays and improving picking efficiency. However, some studies suggest that the extent of these improvements may depend on factors such as warehouse layout and system implementation, indicating that performance gains are not uniform across all operational contexts.

Worker productivity represents another key performance dimension influenced by digital warehouse technologies. Voice-directed picking systems are widely recognised for improving worker efficiency by enabling hands-free operation during picking tasks. Through audio instructions delivered via headsets, workers can receive real-time guidance without relying on paper lists or handheld devices, allowing them to focus entirely on task execution (Gu et al., 2007; Richards, 2018). Similarly, pick-to-light systems simplify navigation within storage areas, enabling faster and more accurate task completion. As a result, these technologies reduce both physical and cognitive workload, leading to measurable improvements in worker productivity. Nevertheless, the extent of productivity improvements may vary depending on factors such as worker training, system usability, and integration with existing processes, suggesting that technological benefits are influenced not only by system capabilities but also by organisational conditions.

A further important dimension is inventory visibility, which is significantly enhanced by digital technologies. Systems such as Warehouse Management Systems (WMS) and RFID improve the ability to monitor inventory levels and track product movements in real time. By providing accurate and up-to-date information on stock locations and quantities, these technologies reduce discrepancies and improve coordination between warehouse processes and order-picking activities (Richards, 2018; Ivanov et al., 2019). This highlights the critical role of information-oriented technologies in supporting decision-making and ensuring operational transparency within warehouse systems. At the same time, some studies emphasise that the effectiveness of these technologies depends on data accuracy and system reliability, indicating that benefits may be limited if information systems are not properly maintained or integrated.

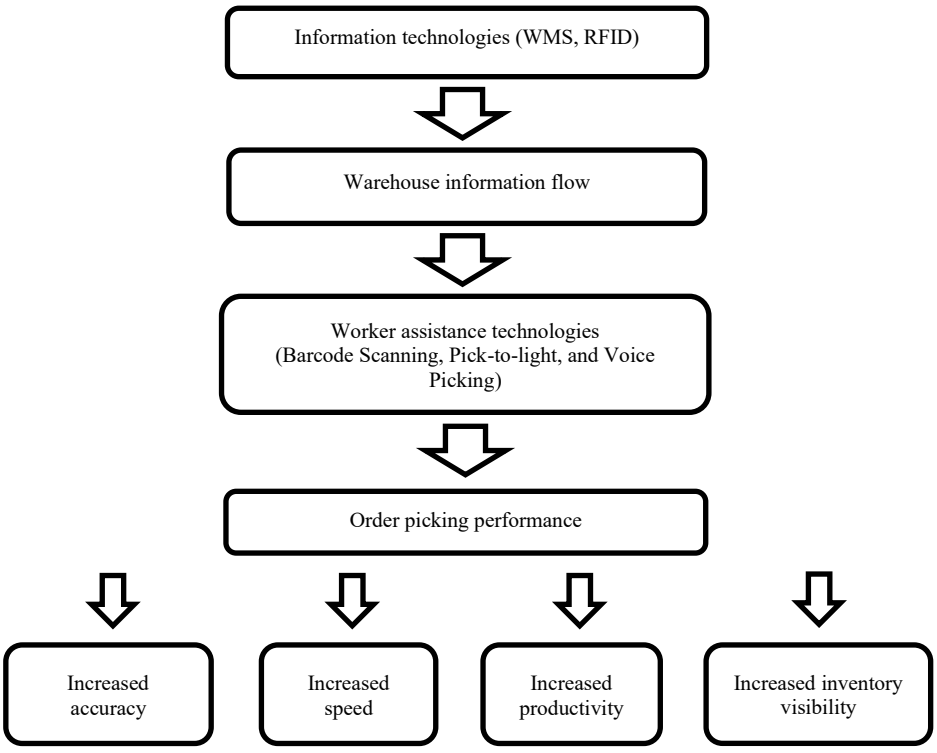
Despite these benefits, the implementation of digital technologies also presents several technological and organisational challenges. Factors such as investment costs, infrastructure requirements, system compatibility, and employee training can significantly influence the successful adoption of digital solutions in warehouse environments (Richards, 2018; Ivanov et al., 2019). Therefore, alongside their operational advantages, it is essential to consider the practical limitations associated with each technology. This indicates that, although digital technologies offer clear performance improvements, their effectiveness is not guaranteed and depends heavily on implementation strategies and organisational readiness.

Among these challenges, financial investment represents one of the most significant barriers. Advanced technologies such as Warehouse Management Systems and RFID require substantial costs related to software acquisition, infrastructure development, and system integration (Richards, 2018; Ivanov et al., 2019). For many organisations, particularly small- and medium-sized enterprises, these initial costs may limit the feasibility of adoption. This suggests that the economic viability of digital solutions must be carefully evaluated in relation to their expected operational benefits, as high implementation costs may not always lead to proportional performance improvements.

Beyond financial constraints, the implementation of digital technologies also involves technological and operational complexities. Modern warehouses typically rely on multiple interconnected information systems, which must exchange data efficiently to support real-time decision-making. Integrating new technologies with existing warehouse management and enterprise resource planning systems, therefore requires technical expertise and careful system configuration (Bartholdi & Hackman, 2014). For instance, RFID systems depend on effective communication between tags, readers, and data platforms, which may require adjustments to infrastructure and data management processes to ensure reliable operation (Ivanov et al., 2019). These challenges highlight that technological compatibility and integration are critical success factors, and poorly implemented systems may reduce rather than improve operational efficiency.

In practical warehouse environments, the effectiveness of digital technologies largely depends on their integration within a unified management framework. Rather than operating as isolated tools, technologies such as WMS, barcode scanning, RFID, and worker-assistance systems are typically implemented as interconnected components of a broader digital infrastructure. For example, a WMS may coordinate inventory locations and picking routes, while barcode scanning, pick-to-light, and voice-directed systems support task execution. The integration of these technologies enables real-time information exchange, improves coordination, and enhances overall operational efficiency. However, this also suggests that the benefits of individual technologies are maximised only when they are implemented as part of a coordinated system rather than as standalone solutions.

The integration of these technologies within warehouse operations can be conceptualised as a digital order-picking system in which information technologies and worker-assistance tools jointly support operational performance. Figure 1 illustrates how information management technologies such as WMS and RFID interact with worker-assistance technologies such as barcode scanning, pick-to-light, and voice-directed picking to influence key performance indicators in warehouse order-picking operations



Source: developed by the author based on Richards (2018); De Koster et al. (2007); Ivanov et al. (2019).

Fig. 1. Conceptual framework of digital technologies influencing warehouse order-picking performance

The figure presents a conceptual framework illustrating the interaction between digital technologies and order-picking performance in warehouse operations. It demonstrates a structured relationship in which information-oriented technologies, such as Warehouse Management Systems (WMS) and RFID, form the foundational layer of digital warehouse management by enabling real-time data processing, inventory tracking, and operational coordination. These technologies generate and manage information flows that support decision-making and planning processes within warehouse environments.

This information is transmitted through warehouse information systems, which act as an intermediate layer connecting data processing with operational execution. At the execution level, worker-assistance technologies such as barcode scanning, pick-to-light systems, and voice-directed picking directly support employees during order-picking tasks. These systems guide workers, facilitate product identification, and reduce navigation complexity within storage areas.

The framework highlights that improvements in order-picking performance are not driven by individual technologies in isolation, but rather by the interaction between information management and task-execution systems. While WMS and RFID enhance coordination and data accuracy, worker-assistance technologies translate this information into efficient physical operations. This layered relationship indicates that performance improvements emerge from the alignment between informational and operational processes within the warehouse.

As a result, the integration of these technologies contributes to improvements across key performance indicators, including picking accuracy, speed, worker productivity, and inventory visibility. This suggests that the effectiveness of digital technologies depends not only on their individual capabilities but also on the degree of integration within a unified system. In this context, fragmented or isolated implementation may limit the overall performance gains.

Furthermore, the framework supports the argument that warehouse digitalisation should be approached as a system-level transformation rather than the adoption of standalone tools. This perspective reinforces the findings discussed in the previous analysis, which emphasise that technological benefits are context-dependent and influenced by implementation quality and system compatibility.

The continuous development of digital technologies is expected to further transform warehouse operations in the coming years. Emerging solutions such as the Internet of Things (IoT), artificial intelligence, and autonomous mobile robots are increasingly being explored to support automated decision-making and advanced warehouse coordination. These technologies have the potential to enhance real-time data processing, improve operational flexibility, and further optimise order-picking processes. Future research may therefore investigate how these emerging technologies can be effectively integrated with existing warehouse management systems to support more advanced digital warehouse ecosystems.

Despite these contributions, it is important to acknowledge several limitations of this study. The research is based on a qualitative analysis of existing literature, which may limit the objectivity of the evaluation and does not allow for statistical validation of the findings. In addition, the study focuses on commonly used digital technologies in warehouse operations and does not include emerging solutions such as artificial intelligence or autonomous systems in depth. Furthermore, the analysis does not consider specific industry contexts or warehouse configurations, which may influence the applicability of the results. Future research could address these limitations by applying quantitative methods, conducting empirical case studies, and examining the impact of advanced digital technologies in different operational environments.

Conclusions

1. This study demonstrates that the adoption of digital technologies in warehouse operations effectively addresses key challenges related to order-picking efficiency and accuracy. The research confirms that digitalisation plays a critical role in improving overall warehouse performance and supporting more efficient logistics operations.

2. The findings show that digital technologies contribute to significant improvements in key performance indicators, including accuracy, speed, worker productivity, and inventory visibility. Technologies such as WMS, RFID, barcode scanning, pick-to-light, and voice-directed picking enhance different aspects of the order-picking process and collectively improve operational outcomes.

3. The effectiveness of digital technologies depends on their integration within a coordinated warehouse management framework. The interaction between information systems and worker-assistance technologies is essential for achieving optimal performance, indicating that isolated implementation of digital tools may limit their overall impact.

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