

Redefining warehouse workforce competencies and roles through human-robot collaboration

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Abstract

In the logistics industry, the emergence of autonomous mobile robots (AMRs) and collaborative robots (cobots) is changing the way people work in warehouses. The public debate about this transition often focuses on job loss, but a growing body of empirical and theoretical research shows that the transition is a more complex one, in which human workers are still essential, but their jobs are being structurally transformed. This article uses a secondary data methodology to review the peer-reviewed research and industry evidence published from 2022 to 2026 to explore how human-robot collaboration (HRC) is changing the skills and roles of workers in warehouses. The results show that successful warehouse HRC requires a portfolio of multi-dimensional competencies, including technical skills in robotic systems, cognitive and supervisory skills, communication and teamwork, and adaptive learning. Traditional jobs based on manual work are transforming into collaborative management and exception handling, demanding new cognitive and ethical skills from employees. At the same time, algorithmic management generates new challenges such as surveillance anxiety, loss of autonomy and risks of deskilling that affect workers' well-being and contribute to turnover. The study concludes with strategic recommendations for structured reskilling programs, human-centric system design, deliberate role enrichment, and participatory governance of AI-driven logistics environments. The results add to the growing conversation about Industry 5.0 and offer a blueprint for organizations, educators, and policymakers to help ensure that training programs meet the needs of today's warehouse automation.

Keywords: Human-Robot Collaboration; Warehouse Automation; Workforce Competencies; Industry 5.0; Algorithmic Management; Job Redesign

1. Introduction

The global warehousing sector is strategically undergoing a massive technological transformation. The rise of autonomous mobile robots (AMRs), collaborative robots (cobots), and AI-powered logistics systems is changing the way goods are stored, picked, sorted, and dispatched at a rate that would have been unimaginable just 10 years ago. The global market for AMR is estimated at USD 3.1 billion in 2025, and is expected to grow to USD 17 billion by 2035, with a compound annual growth rate (CAGR) of approximately 19.5% [1]. By 2026, more than 60% of global warehouses will implement some form of robotic technology [2] as a result of the compounding challenges of the growing e-commerce demand, persistent labor shortages and the increasing need for operational efficiency.

Despite this change, the dominant discourse about the transition tends to be a binary one: robots replace humans or robots work alongside humans. The truth is much more complicated. Empirical studies have confirmed that robotization in warehouse operations is not replacing all human jobs, but rather transforming human jobs into collaborative human-robot jobs that require qualitatively different skills [3]. Manual tasks such as order picking are being reconfigured to collaborate with robots, and human workers are still the most dexterous, contextually aware, and problem-solving parts of these systems [3].

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This shift is further put into perspective by the advent of Industry 5.0 as a governing paradigm. Industry 4.0 was about automation, connectivity and machine intelligence, whereas Industry 5.0 is about human-centric design, sustainability and societal resilience, with the human worker at the Centre of production and logistics systems [4]. This paradigm shift has far-reaching implications for the design, management and staffing of warehouse operations.

However, research on HRC in the manufacturing, construction, and agriculture sectors is growing, but research specific to the warehouse sector is still relatively limited [5]. This is important because the warehouse context has its own set of challenges, in terms of dynamic task variability, high volumes of orders, time pressure and increasingly complex sociotechnical configurations, which are quite different from those experienced on factory floors or construction sites. The study aims to address this gap by systematically reviewing recent empirical and theoretical literature on the impact of HRC on the competencies and professional roles of the workforce in warehouse operations. It also discusses ethical issues related to algorithmic management and provides strategic guidance for workforce readiness in the age of collaborative automation.

2. Theoretical Framework

The present investigation is based on the conceptual framework of the transition from Industry 4.0 to 5.0. The performance- and profit-oriented Industry 4.0 concept, driven by technology, is insufficient to understand how to enhance the prosperity of all actors in production and logistics systems [4]. Conceptually, Industry 5.0, introduced by the European Commission, is a framework for developing human-centric, resilient and sustainable systems where human and machine capabilities are deliberately aligned [4].

In this context, human-robot collaboration (HRC) is a way of organizing work in which humans and robots work together in the same workspace, each bringing to the table skills that the other cannot match. Robots bring speed, precision, endurance and scalability to repetitive, rule-based tasks like goods transport, shelf scanning and high-volume sortation. Humans, on the other hand, bring dexterity, improvisation in the face of uncertainty, contextual judgment, inter-personal communication, and adaptive decision-making, which are not yet available in current robotic systems in high-variability warehouse environments [3].

According to Olukanni et al. (2024), competency theory as applied in HRC contexts is the ability of the workforce to perform tasks effectively, which is an integrated combination of knowledge, skills and abilities [6]. Competency frameworks identified in the HRC literature are predominantly based on manufacturing and construction, and this study draws on these frameworks, but adds cross-industry evidence and tailors it to the logistical context of warehouse work.

3. Materials and Methods

The methodology used in this study is secondary data, which is obtained from peer-reviewed academic journals, systematic reviews, and credible market intelligence reports from 2022 to 2026. Secondary data methodology is suitable for synthesizing existing knowledge in interdisciplinary areas where primary data collection would be redundant in terms of concepts [6,7]. Literature was identified by conducting systematic searches in Scopus, Web of Science, PubMed, and Google Scholar with the following keywords: human-robot collaboration, warehouse workforce, HRC competencies, Industry 5.0 logistics, algorithmic management warehouse, autonomous mobile robots adoption, and warehouse automation workforce.

The inclusion criteria were that sources: (i) discussed HRC in operational, warehouse or logistics contexts, or offered competency frameworks that could be directly applied to these contexts; (ii) were published in English in peer-reviewed journals or credible industry sources; and (iii) provided empirical, systematic review or theoretically grounded evidence. Only publications that were not about workforce dimensions and only publications that were published before 2022 were included. Where quantitative market data was needed but not available from peer-reviewed sources, market intelligence reports were included. Data extracted from reviewed sources were thematically synthesized according to the following analytical categories: (a) automation adoption landscape; (b) emerging competency requirements; (c) role transformation patterns; (d) ethical and organizational challenges; and (e) strategic workforce readiness interventions.

4. Results and Discussion

4.1. The Evolving Landscape of Warehouse Automation and Human Employment

The strategic level of robotic adoption in warehousing has arrived. The global AMR market is expected to grow by over 5 times from USD 3.1 billion in 2025 to USD 17 billion in 2035, as shown in Figure 1 and Table 1 [1]. The current largest market segment for AMRs by revenue is goods-to-person picking systems, which move shelving or totes to stationary human pickers, and are expected to continue growing at a rapid pace as e-commerce continues to grow and the need for fast and accurate order fulfilment increases [1].

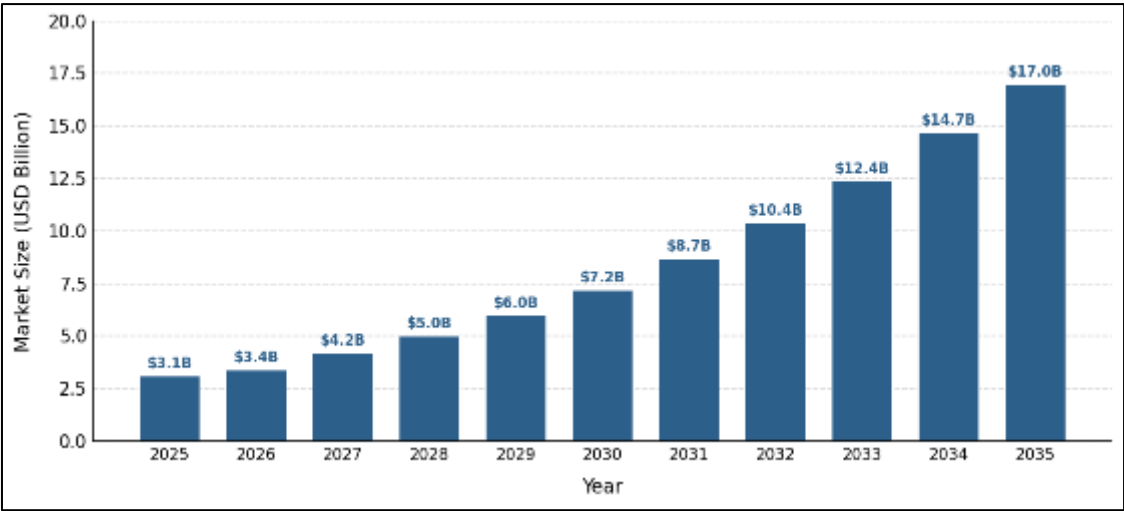


Figure 1 Global Autonomous Mobile Robots Market Growth Projections, 2025–2035

Table 1 Global Autonomous Mobile Robots (AMR) Market Size Projections, 2025–2035 (Source: Global Market Insights, 2025 [1])

Year	Market Size (USD Billion)	CAGR (%)
2025	3.1	–
2026	3.4	~10%
2027	4.2	~24%
2028	5.0	~19%
2029	6.0	~20%
2030	7.2	~20%
2031	8.7	~21%
2032	10.4	~20%
2033	12.4	~19%
2034	14.7	~19%
2035	17.0	~16%

However, these figures do not directly represent the displacement of human workers. In a real-effort experiment in a semi-robotized warehouse, Pasparakis et al. (2023) found that the employment of robots in warehouse operations is growing but human jobs remain relevant [3]. The use of robots in warehouse-related jobs is increasing, while jobs involving humans are still relevant, Pasparakis et al. (2023) [3] found. They demonstrate that the division of labor

between robots and humans could be appropriately designed so that the self-efficacy and job satisfaction of human workers are maintained and even improved [3]. In a study covering warehouse logistics and two other industrial sectors across nine European countries, Pietrantoni et al. (2024) also reported a positive attitude towards cobots among experts, especially when it comes to their societal benefits, and a positive perception of safety, which further reinforces the perception of cobots as augmentative rather than substitutive [8].

The labor market context is an important one. Across nine European countries, Pietrantoni et al. (2024) also reported a positive attitude towards cobots among experts, especially when it comes to their societal benefits, and a positive perception of safety, which further reinforces the perception of cobots as augmentative rather than substitutive [8].

The labor market context is an important one. The turnover rate for warehouse workers is about 36 % and the cost of replacing a worker can range from 25% to 150 % of the employee's annual salary [2]. In some cases, turnover has been reported to be as high as 150% and as low as 73% year-over-year [3]. This labor volatility also encourages the use of automation and increases the value of keeping skilled staff who can work with robots. The paradox is obvious: the very same labor pressures that drive robotization also make it essential to invest in the human dimension of the automated warehouse.

4.2. Emerging Workforce Competencies in HRC Environments

Empirical studies, systematic literature reviews, and Delphi-based expert assessments converge to suggest a multi-dimensional competency framework for effective HRC. The most extensive competency investigations have been carried out in the construction industry, but the results are structurally transferable to warehouse contexts, as there are parallels in the human-robot task-sharing dynamics [5]. Table 2 provides a summary of the HRC competency framework that was developed through a synthesis of the literature reviewed, and Figure 2 shows the relative importance of the core competency domains based on the evidence base.

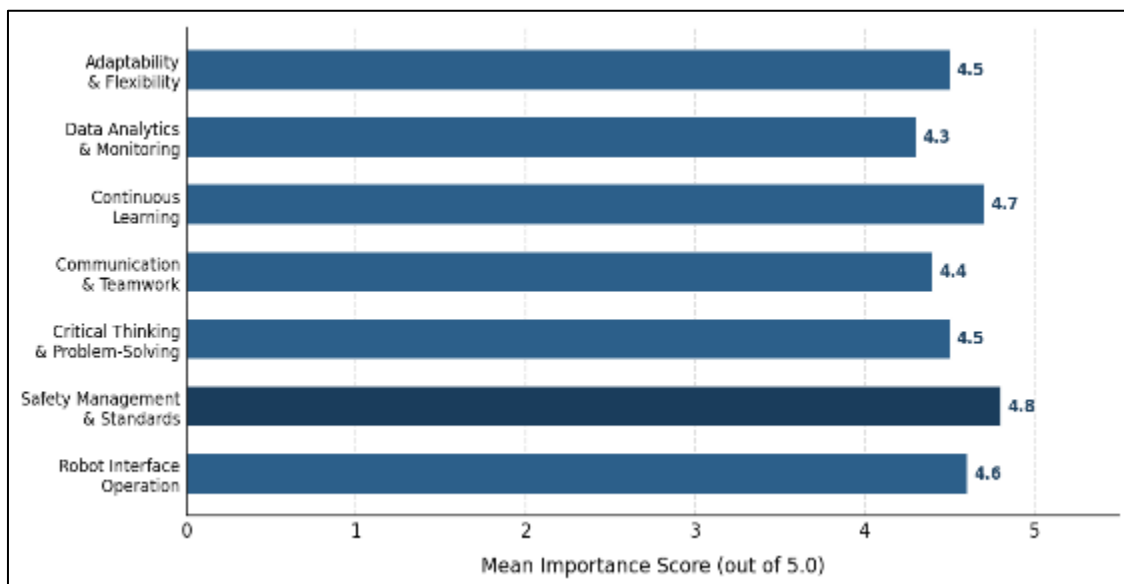


Figure 2 Relative Importance of Workforce Competencies in HRC Warehouse Environments

Table 2 Consolidated HRC Workforce Competency Framework for Warehouse Operations (Synthesized from [5,6,8,9])

Competency Domain	Core Competencies	Relevance to Warehouse HRC
Technical	Robot interface operation; fleet management software; sensor systems; safety protocols; robot control systems	Enables interaction with AMRs, cobots, and warehouse execution systems
Cognitive / Supervisory	Critical thinking; problem-solving; real-time decision-making; exception management; data interpretation	Supports oversight of automated processes and handling of system anomalies
Communication and Teamwork	Verbal and digital communication; cross-functional coordination; human-robot interaction awareness	Facilitates collaboration with supervisors, colleagues, and robotic systems
Adaptive / Continuous Learning	Adaptability; openness to change; self-directed learning; tolerance for ambiguity	Critical in rapidly evolving warehouse technology environments
Safety and Ethical Awareness	HRC safety standards compliance; understanding of surveillance impacts; privacy considerations	Protects worker welfare and ensures regulatory compliance in AI-managed settings

4.2.1. Technical Competencies

The basic level of HRC competency is technical proficiency. By using a Task-Technology Fit theoretical framework, Olukani et al. (2026) performed a systematic literature review and bibliometric analysis to identify the knowledge areas, skills and abilities needed for human-robot collaboration, resulting in 20 knowledge areas, 10 skills and 12 abilities [9]. From a warehouse perspective, this includes an understanding of robot fleet management software, warehouse execution systems, sensor technologies, safety protocols and the ability to monitor robot performance dashboards, adjust pick paths and troubleshoot navigation or sensor issues. Jonczyk et al. (2025) systematically reviewed 47 empirical studies on robotization and work characteristics [7]. They found a positive trend for knowledge characteristics in the context of robotization, i.e. the demand for higher-order technical knowledge is increasing, whereas the physical dimension of work is decreasing.

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4.2.2. Cognitive and Supervisory Competencies

As robots take over repetitive physical work, human jobs shift towards more supervisory, exception and quality assurance work which requires critical thinking, real-time decision making and contextual judgment. In a study of logistics experts from nine countries, in exceptional situations, adaptable control systems and human judgement are the two dimensions of effective HRC identified by Pietrantoni et al. [8] showing that human cognition remains relevant, particularly in the event of the failure of robotic systems. In addition, Pasparakis et al. (2023) also demonstrated that workers' self-efficacy in HRC, i.e. the feeling of being able to operate efficiently together with robots, is a predictor of their performance and job satisfaction. This indicates a clear necessity: training courses should boost worker confidence in addition to their cognitive skills [3].

4.2.3. Interpersonal, Communication, and Adaptive Competencies

Olukanni et al. (2025) performed a three-round Delphi study with industry and academic experts and found the top-rated HRC competencies from both groups to be effective communication, safety management, teamwork, continuous learning, problem-solving, and adaptability [5]. These soft skills are especially important in a warehouse environment, where employees need to interact with robotic systems as well as with supervisors, colleagues and data-driven management software. One of the most important is the capacity to learn. Warehouse technology is basically advancing

quickly, and workers must continually update their knowledge and skills to keep up with the latest generation of AMRs, software interfaces and AI-powered scheduling systems.

4.3. Role Transformation: From Manual Labor to Collaborative Oversight

The adoption of HRC in the warehouses is not just an addition to current jobs, but a complete transformation of the nature of work in all major functional areas. Table 3 shows this transformation across six major warehouse functions, from physical execution to supervisory, analytical and adaptive roles.

Table 3 Transformation of Key Warehouse Roles Through Human-Robot Collaboration (Synthesized from [3,4,10,11])

Warehouse Function	Pre-HRC Role (Traditional)	Post-HRC Role (Collaborative)
Order Picking	Manual walking and picking across warehouse aisles; high physical demand	Robot-guided or goods-to-person picking; oversight of robot pick accuracy; exception handling
Inventory Management	Manual stock counting; periodic audits; paper-based records	Real-time data monitoring via warehouse management systems; exception resolution; accuracy validation
Goods Transportation	Manual pallet and trolley movement; forklift operation	AMR fleet supervision; traffic coordination; loading/unloading at robot handoff points
Quality Control	Periodic manual inspection; sampling-based defect detection	Continuous monitoring via sensor dashboards; human judgment for edge-case defect assessment
Maintenance Oversight	Reactive fault reporting; basic mechanical checks	Predictive maintenance monitoring; robot diagnostics; coordination with technical teams
Supervisory / Team Lead	Primarily people management and shift scheduling	Hybrid people-technology management; fleet performance oversight; algorithmic system accountability

Jonczyk et al. (2025) compiled empirical evidence that robotization is associated with a decrease in the variety of physical tasks but an increase in the variety of tasks with higher knowledge characteristics, such as monitoring, data interpretation, and inter-system communication [7]. This is dangerous and an obvious opportunity. If not intentionally designed, skill-narrowing and demeaning of the work can be a problem for workers when the redesign of their roles occurs without planning. They can be given a substantially higher value of responsibilities with deliberate intervention, which are in line with the human-centric principles of Industry 5.0.

In a qualitative study of the perspectives of the warehouse workers themselves, Malik et al) .2026 (discovered that workers are very aware of this shift and express a need for robotic systems that enable them rather than just monitor them]10 .[Workers imagine co-operative arrangements where robots take over physically demanding and repetitive tasks, and where human workers retain meaningful agency, creative problem solving and interpersonal interaction. This worker-centered approach is a welcome counterpoint to the top-down stories that see workforce transformation as a side effect of technological investment.

4.4. Challenges and Ethical Considerations

There are many challenges to integrating HRC into a warehousing environment that can't be solved with technical competency development. From the literature three related issues arise as especially pressing: algorithmic management and surveillance, loss of autonomy and deskilling, and the resulting impact on job satisfaction and worker retention.

4.4.1. Algorithmic Management and Surveillance

One of the most prominent aspects of the modern robotized warehouse is the omnipresence of algorithmic management, which involves the use of machine-learning systems to assign tasks, track performance, assess outputs, and punish workers [11]. Algorithmic management is described by Zhang et al. (2025) as both improving coordination and efficiency, and creating serious issues of surveillance, bias, dehumanization and worker alienation [11]. In the warehouse setting, these are realized through real-time productivity monitoring with handheld scanning devices, AI-driven performance metrics, automated disciplinary triggers and algorithmic shift planning, which are well-documented in high-volume fulfilment centers.

Malik et al. (2026) reported that warehouse workers feel that robot-mediated monitoring is an extension of existing micromanagement practices [10]. Workers also reported that the constant data collection creates surveillance anxiety, with measurable psychological costs, and that the imbalance in information between automated management systems and individual workers reduces their dignity and autonomy in the workplace [10]. The results build on and expand upon previous studies on algorithmic control as a managerial power that reduces worker discretion.

4.4.2. Deskilling Risk and Autonomy Erosion

Hosseini et al. (2024) used a holistic ethical lens, based on the principles of non-maleficence, beneficence, autonomy, and justice, to analyze the evaluation of AI-driven warehouse environments and found that a unique risk is that workers might shift from actively using skills to passively monitoring them as picking processes become more automated [12]. Actively using skills to passively monitor them as picking processes become more automated [12]. This change reduces the meaningfulness of work and is a violation of the non-maleficence principle insofar as meaningfulness of work is defined as a part of human flourishing and professional dignity [12]. Additionally, Jonczyk et al. (2025) found that the characteristics of social work are negatively associated with robotization, specifically a reduction in collegial interaction, feedback from the work itself and a sense of task significance, all of which decrease intrinsic motivation [7]. The review by Jonczyk et al. (2025) makes the risk more explicit: it shows that robotization reduces collegial interaction, eliminates the feedback workers got from the work process before, and decreases their sense of the importance of this process, reducing the intrinsic motivation to work [7].

4.4.3. Job Satisfaction and Turnover Implications

In the study conducted by Pasparakis et al., the researchers discovered that the level of worker autonomy in HRC was statistically significant with factors like job satisfaction and core self-evaluation, a key factor in predicting turnover intention [3]. The finding has strategic implications, as in a sector already defined by high turnover, HRC system designs that systematically erode worker autonomy may worsen, not solve, recruitment and retention issues. The irony is that automation that is supposed to replace labor can, if not designed well, create the very discontent that fuels labor shortages.

4.5. Strategic Recommendations for Workforce Readiness

The synthesis of evidence on competency development, role transformation, and ethical issues identifies four interrelated strategic priorities for organizations, policy makers and educators.

4.5.1. Structured Reskilling and Upskilling Programs

The shift from manual to supervisory and collaborative work demands formal investment in workforce training, both in technical and soft competency areas. As reported in community-based programs in manufacturing and logistics areas, effective reskilling programs integrate technical training on robotic systems and digital tools with soft skills training in communication, adaptability and lifelong learning [13]. Industry, education and government partnerships have been found to deliver training programs that are closely linked to the needs of the workforce in a particular sector and region [13]. Importantly, these programs should be open to existing employees and not just new employees.

4.5.2. Human-Centered System Design

In the context of a warehouse, Hosseini et al. (2024) propose that the ethical implementation of AI and robotic technologies should be based on the ethical principles of non-maleficence, beneficence, autonomy, and justice, and that workers should be included as active partners in the design and management of AI and robotic systems, not mere objects of technological change [12]. Malik et al. (2026) implement this concept in specific design recommendations, including zoned privacy controls, notification systems for workers when surveillance is occurring, manual override systems, and systems that include algorithmic transparency in worker performance and management actions [10]. These design features are not just a part of the technology but are crucial to the sustainable and ethical implementation of HRC.

4.5.3. Deliberate Role Enrichment

In order to avoid monotony in the workplace, managers and system designers should try to introduce some complexity and variability in the human roles in robotized systems [7]. This means that exception-management, inter-team coordination, continuous improvement, and creative problem-solving tasks must be deliberately assigned to human workers, while the HRC configurations improve the intrinsic quality of work.

4.5.4. *Ethical Governance and Policy Engagement*

Zhang et al. (2025) urge for ethical governance and responsible design of algorithmic management systems, which involve transparency, bias auditing, and worker involvement in system assessment [11]. Minimum standards for the rights of workers in algorithm management warehouses should be established by policymakers and industry groups, including the right to an explanation, contestation of decisions, and meaningful ceilings on automated disciplinary systems. The purpose of the regulations must be to ensure that the advantages of the HRC in the warehouse are fairly shared between employers and employees. The regulations are required to ensure that the efficiency gains of warehouse HRC are distributed fairly between employers and employees.

5. Conclusion

The integration of humans and robots in warehouses is not a simple tale of job loss or a seamless success of efficiency. It is a sociotechnical change that is actively transforming the nature of warehouse work, and so new skills, new jobs, new moral responsibilities and new organizational forms are emerging. The findings of this study suggest that human work is still essential in the era of AMRs and cobots, but the role of humans is evolving from physical action to cognitive and adaptive abilities. This transformation should be paralleled and purposefully driven by a transformation in the competency development of the workforce, from technical skills, problem-solving, safety management, communication, and continuous learning.

The difficulties that come with this change are significant and morally relevant, such as algorithmic surveillance, loss of autonomy, deskilling, and turnover due to dissatisfaction. They require answers beyond investments in training to participatory system design, intentional role enrichment, and regulatory governance of AI-enabled workplaces. It is not only a moral obligation to put the warehouse worker at the heart of the design of the system, but also a prerequisite for the sustainability and competitiveness of the sector in terms of its operation.

Future research should continue with longitudinal empirical studies in the context of HRC deployments in specific warehouses, monitoring the competency development process, job satisfaction trends, and the organizational context in which collaborative automation truly improves worker well-being. The field of operations management, human factors research and workforce development will continue to be vital to the future of the sector and must continue to evolve alongside the increasing adoption of robots, ensuring that the warehouses of the future are places where human dignity and technological efficiency are not mutually exclusive goals.

Compliance with ethical standards

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Disclosure of conflict of interest

No financial or non-financial conflicts of interest to disclose.

Statement of ethical approval

This study is based exclusively on secondary data obtained from peer-reviewed publications and publicly available market intelligence reports. No primary data collection involving human participants was conducted.

Statement of informed consent

Accordingly, no ethical approval was required for this research. All cited sources are properly attributed in accordance with the Vancouver referencing standards of the International Journal of Science and Research Archive.

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