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SMART WAREHOUSING AND COLLABORATIVE ROBOTS: TECHNOLOGIES AND SOLUTIONS FOR MODERN LOGISTICS

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Abstract

Smart warehousing technologies are transforming logistics by improving efficiency, accuracy, and flexibility in warehouse operations. This article examines how collaborative robots (cobots), autonomous mobile robots (AMRs), and human–robot collaboration (HRC) contribute to modern intralogistics.
The study also analyses experimental findings on AMR–cobot energy consumption to understand the technical challenges of hybrid robotic systems. A literature review was conducted using scientific articles and industry reports to identify the main benefits, limitations, and practical applications of these technologies.
The results show that cobots improve ergonomics and reduce manual workload, AMRs optimise internal transport, and smart warehousing systems enhance real-time visibility and decision-making. However, challenges remain, including high investment costs, integration complexity, and increased energy demand when cobots operate together with AMRs.
The article concludes that smart warehousing technologies can significantly improve logistics performance when supported by proper planning, employee training, and energy-aware system design.

Keywords: smart warehousing, collaborative robots, AMRs, human–robot collaboration, logistics automation.

Introduction

Warehousing plays a central role in logistics performance, especially as companies face increasing pressure to deliver goods faster and more accurately. Traditional warehouses often struggle with labour shortages, repetitive manual tasks, and limited visibility of operations, which reduce efficiency and increase operational costs. These challenges have encouraged organisations to adopt smart warehousing technologies to modernise their logistics processes (Boysen et al., 2019).

Collaborative robots (cobots) and autonomous mobile robots (AMRs) are among the most widely adopted technologies in modern warehouses. Cobots assist workers in picking, packing, and handling tasks, while AMRs transport goods autonomously. Research shows that cobots were developed to bridge the gap between manual and fully automated production and support flexible operations (Villani et al., 2018). Other studies demonstrate that AMRs improve internal transport by navigating safely and efficiently in dynamic environments (Bogue, 2018).

Despite these advantages, companies still face challenges when adopting robotics. These include high investment costs, integration difficulties, and concerns about worker acceptance. In addition, recent research shows that combining AMRs with cobots increases energy consumption, which affects sustainability and operational planning (Aliev et al., 2021).

The rapid growth of e-commerce and rising customer expectations have further intensified the need for efficient warehouse operations. Companies must process larger order volumes while maintaining accuracy and reducing lead times. Smart warehousing technologies offer scalable solutions that can be adapted to different warehouse sizes and layouts, making them suitable for both large distribution centres and smaller fulfilment facilities (Boysen et al., 2019). As digitalisation accelerates, the integration of robotics, data analytics, and connectivity becomes essential for maintaining competitiveness in modern logistics.

The aim of this research is to analyse how smart warehousing technologies—particularly cobots, AMRs, and hybrid AMR–cobot systems—improve logistics operations. The main objectives are to:

1. examine the role of cobots and AMRs in warehouse automation.
2. identify the benefits and challenges of human–robot collaboration.
3. analyse energy-consumption behaviour in hybrid robotic systems.

Research object and methods

The research object is the use of collaborative robots (cobots) and autonomous mobile robots (AMRs) in smart warehousing, focusing on their role in handling, transport, and human–robot collaboration. The study also considers how workers interact with robotic systems, as this relationship strongly influences the success of automation initiatives. Understanding employee acceptance, safety, and training needs is essential for evaluating the practical feasibility of smart warehousing solutions (Gualtieri et al., 2021).

The research is based on a structured review of peer-reviewed journal articles, conference papers, and selected industry reports published in the last decade. Sources were chosen for their relevance to robotics, intralogistics, and human–robot collaboration. Comparative analysis was used to identify similarities and differences in reported benefits, challenges, and performance indicators. Data interpretation was applied to experimental studies, such as AMR–cobot energy-modelling research, to understand technical implications for logistics operations (Aliev et al., 2021).

Methods used:

- Literature review: Scientific articles on cobots, AMRs, and smart warehousing were analysed to identify technological trends and challenges.
- Comparative analysis: Findings from different studies were compared to evaluate the benefits and limitations of each technology.
- Data interpretation: Experimental results from AMR–cobot energy-modelling research were examined to understand technical implications for logistics.

Theoretical Framework and Literature Review

Smart warehousing refers to the use of digital and robotic technologies to improve warehouse operations. It integrates automation, data analytics, and connectivity to create efficient and responsive logistics systems. Smart warehouses rely on real-time data, advanced sensors, and interconnected systems to support decision-making and optimise workflows (Boysen et al., 2019).

Three main technologies are widely discussed in the literature:

- Collaborative robots (cobots): Cobots work safely alongside humans and support tasks such as picking, sorting, and packaging. Studies show that cobots reduce physical strain and increase accuracy in repetitive tasks (Villani et al., 2018).
- Autonomous mobile robots (AMRs): AMRs transport goods autonomously using sensors and navigation systems. They improve material flow and reduce walking distances for workers (Bogue, 2018).
- Human–robot collaboration (HRC): HRC focuses on safe and effective interaction between workers and robots. Research highlights the importance of trust, safety systems, and clear task allocation (Gualtieri et al., 2021).

Smart warehousing is also closely linked to Industry 4.0 principles, which emphasise connectivity, decentralised decision-making, and cyber-physical systems. Robots are not isolated machines but components of a larger digital ecosystem. Technologies such as warehouse management systems (WMS), Internet of Things (IoT) sensors, and cloud-based platforms enable real-time communication between humans, robots, and software (Boysen et al., 2019). This integration supports predictive maintenance, dynamic task allocation, and continuous optimisation of workflows.

Another important concept in the literature is warehouse flexibility. Traditional automation systems, such as conveyor belts, are efficient but rigid. In contrast, cobots and AMRs offer mobility and adaptability, allowing warehouses to reconfigure processes quickly in response to seasonal peaks or layout changes. This flexibility is particularly valuable in industries with high product variety or unpredictable demand patterns (Bogue, 2018).

Recent studies also examine the technical performance of hybrid AMR–cobot systems. One experiment measured battery-discharge behaviour and found that energy consumption increases significantly when a cobot operates on top of an AMR (Aliev et al., 2021). This finding is important for planning charging cycles and scheduling tasks in smart warehouses.

Research results and discussion

The analysis shows that smart warehousing technologies address several challenges in modern logistics, including labour shortages, slow manual processes, and limited visibility. Many warehouses still depend on repetitive manual work, which increases fatigue and the likelihood of errors. Smart technologies help automate routine tasks, improve accuracy in order handling, and support workers in physically demanding activities (Villani et al., 2018). They also provide real-time information about inventory and material flow, allowing managers to make faster and more informed decisions. As a result, warehouses become more efficient, responsive, and capable of handling higher workloads during peak periods (Boysen et al., 2019).

Collaborative robots (cobots) play an important role in improving warehouse performance. They assist workers in picking, packing, and sorting tasks, reducing physical strain and increasing consistency. Cobots are designed to operate safely alongside humans, which allows companies to introduce automation without major changes to warehouse layout. Studies show that cobots can increase productivity by supporting workers in repetitive and ergonomically challenging tasks (Villani et al., 2018).

Autonomous mobile robots (AMRs) improve internal transport by moving goods independently and avoiding obstacles. They reduce walking distances for workers and help maintain a continuous flow of materials. AMRs also support real-time tracking through integrated sensors, which improves visibility and reduces delays caused by misplaced items or inefficient routing (Bogue, 2018). Their flexibility makes them suitable for warehouses with frequently changing layouts.

Human–robot collaboration (HRC) is essential for ensuring that workers and robots can operate together effectively. Research highlights the importance of safety systems, clear task allocation, and proper training to build trust among employees (Gualtieri et al., 2021). When implemented correctly, HRC improves both productivity and workplace ergonomics. Workers report higher satisfaction when robots assist with physically demanding or repetitive tasks.

The main impacts of these technologies are summarised in Table 1.

Table 1. Impact of Smart Warehousing Technologies

Technology	Key Benefit	Example Application	Impact
Cobots	Reduced manual workload	Picking and packing	20–30% higher productivity
AMRs	Faster internal transport	Goods movement	25% shorter travel time
AMR–cobot systems	Flexible hybrid tasks	Transport + handling	Higher energy demand

***Source**: Adapted from Vivaldini et al. (2025); Wagner & Ingaldi (2025);Villani et al. (2018).*

Beyond productivity, smart warehousing technologies contribute to higher operational accuracy. Cobots equipped with vision systems can identify items with greater precision, reducing picking errors and improving order quality (Villani et al., 2018). AMRs equipped with advanced navigation algorithms minimise the risk of collisions and ensure consistent transport routes, which enhances safety and reduces product damage (Bogue, 2018).

Another important aspect is workforce transformation. Rather than replacing workers, cobots and AMRs often shift employees toward supervisory, coordination, and quality-control roles. This can improve job satisfaction by reducing physically demanding tasks and allowing workers to focus on activities that require decision-making or problem-solving (Gualtieri et al., 2021). However, successful implementation requires training programmes that help employees understand robot capabilities and limitations.

From an economic perspective, the adoption of smart warehousing technologies involves both short-term and long-term considerations. Initial investment costs can be high, especially for companies with limited automation experience. However, long-term benefits such as reduced labour costs, improved throughput, and fewer operational disruptions often justify the investment (Boysen et al., 2019). Several studies emphasise that the return on investment depends on warehouse size, order volume, and the degree of integration with existing systems.

Energy consumption is another important factor in smart warehousing, especially when combining AMRs with cobots. Hybrid AMR–cobot systems allow a cobot to perform handling tasks while the AMR transports goods, creating a flexible and mobile robotic unit. However, experimental studies show that these systems require significantly more energy when the cobot is active (Aliev et al., 2021). This affects charging schedules, task planning, and overall sustainability.

Table 2 summarises the experimental results on battery-discharge behaviour in three scenarios: AMR alone, AMR with cobot mounted but inactive, and AMR with cobot operating.

Table 2: Energy-Consumption Behaviour of AMR–Cobot Systems

Scenario	Battery-Discharge Slope	Interpretation
AMR alone	-3.788×10^{-3}	Baseline energy use
AMR + cobot OFF	-3.729×10^{-3}	Similar to baseline; weight has little effect
AMR + cobot ON	-8.606×10^{-3}	Battery drains more than twice as fast

Source: *Adapted from Aliev et al. (2021).*

The results show that cobot activity—not weight—is the main factor increasing energy consumption. When the cobot is switched off, the AMR’s energy use remains almost unchanged, indicating that the additional mass does not significantly affect performance. However, when the cobot is active, the battery drains more than twice as fast. This has important implications for warehouse planning, as hybrid systems may require more frequent charging, shorter task cycles, or additional charging stations (Aliev et al., 2021).

Sustainability is another emerging topic in warehouse automation. While hybrid AMR–cobot systems consume more energy, they can also reduce waste, optimise space utilisation, and support greener logistics strategies. For example, improved accuracy reduces the number of returned orders, and optimised transport routes lower overall energy consumption (Boysen et al., 2019). Future research is expected to focus on energy-efficient robot designs, smart charging strategies, and renewable-energy integration in warehouses.

Overall, the findings demonstrate that smart warehousing technologies can significantly improve logistics performance, but they also introduce new technical considerations that must be managed carefully.

Conclusions

1. Smart warehousing technologies significantly improve logistics performance by increasing efficiency, accuracy, and operational flexibility. Cobots support workers in handling tasks, while AMRs optimise internal transport and reduce manual movement within warehouses.
2. Human–robot collaboration enhances workplace ergonomics and safety. When supported by proper training and clear task allocation, workers adapt more easily to automation and benefit from reduced physical strain.
3. Hybrid AMR–cobot systems offer high operational flexibility but require careful energy-aware planning. Experimental results show that cobot activity substantially increases energy consumption, influencing charging schedules and workflow design.

4. Successful implementation of smart warehousing technologies depends on organisational readiness, investment in safety systems, and continuous employee training. Long-term benefits include improved throughput, reduced errors, and greater resilience during demand fluctuations.

5. Future developments will likely focus on the integration of artificial intelligence, predictive analytics, and energy-efficient robotic systems. These advancements will further enhance the adaptability and sustainability of automated warehouses.

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