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Deep Learning-Enabled Smart Serving Robots for Sustainable Supply Chain and Logistics Automation, A Review

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ABSTRACT

The rapid expansion of e-commerce and global supply chains has created an urgent need for efficient, sustainable, and automated logistics operations. Smart serving robots, including autonomous mobile robots, robotic arms, and drones, are increasingly deployed in warehouses and last-mile delivery to improve productivity and reduce human labor. Deep learning has become a critical enabler for these robots, providing advanced capabilities in perception, navigation, and decision-making within complex environments. This systematic review aims to map the existing literature on deep learning-enabled smart serving robots for supply chain and logistics automation, synthesize reported outcomes related to operational efficiency and sustainability, and identify key technological and operational challenges. We conducted a comprehensive literature search following the PRISMA guidelines across multiple academic databases and search engines. Studies were screened based on predefined inclusion and exclusion criteria, with data extraction and quality assessment performed independently by two reviewers. The synthesized evidence reveals a rapidly growing but fragmented research landscape. Deep learning techniques, particularly convolutional neural networks for object recognition and reinforcement learning for path planning, are widely applied in warehouse order picking, inventory management, and last-mile delivery. Operational outcomes consistently demonstrate improvements in path planning efficiency and task completion rates. However, sustainability outcomes are often addressed superficially, with few studies providing quantitative metrics on energy savings or lifecycle impacts. Key challenges include sensor noise, the sim-to-real gap, high deployment costs, and a lack of standardized sustainability benchmarks. We conclude that deep learning significantly enhances robot autonomy and adaptability in logistics, yet critical gaps remain in the substantive integration of sustainability metrics. Future research should prioritize standardized evaluation frameworks and explore multi-robot collaborative systems to advance both automation and sustainability.

Keywords: Deep Learning, Smart Serving Robot, Supply Chain, Sustainable

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Introduction

The global logistics and supply chain industry is undergoing a profound transformation, driven by the exponential growth of e-commerce, increasing consumer expectations for rapid delivery, and a pressing need for operational sustainability. Traditional warehouse and distribution center operations, which have long relied on manual labor for tasks such as picking, packing, sorting, and transportation, are facing significant challenges including labor shortages, rising operational costs, and the physical limitations of human workers [1]. To address these pressures, the industry is rapidly turning towards automation, with smart serving robots emerging as a pivotal technology. These robots, which encompass a diverse range of platforms including autonomous mobile robots (AMRs) for material transport, robotic arms for manipulation, and drones for inventory monitoring and last-mile delivery, promise to enhance throughput, reduce error rates, and improve workplace safety [2].

The integration of deep learning has been a critical catalyst in advancing the capabilities of these robotic systems beyond the limitations of classical automation. Traditional rule-based and heuristic approaches often struggle to cope with the high variability, clutter, and dynamic nature of real-world logistics environments [3]. Deep learning, a subfield of machine learning, provides powerful tools for learning complex representations directly from raw sensor data, enabling robots to perceive their surroundings with high accuracy, make intelligent decisions, and adapt to novel situations. For instance, convolutional neural networks (CNNs) have revolutionized object detection and recognition, allowing robotic arms to identify and grasp a vast array of products with varying shapes, sizes, and packaging [4]. Similarly, deep reinforcement learning (DRL) has enabled mobile robots to learn efficient navigation policies in crowded and changing environments, optimizing paths for energy consumption and time [5].

Despite the significant technological progress, the research landscape surrounding deep learning-enabled smart serving robots for logistics is both rapidly expanding and highly fragmented. A substantial body of work focuses on isolated sub-problems, such as improving the accuracy of a specific grasping algorithm or the convergence speed of a particular navigation policy. However, a comprehensive synthesis that maps the breadth of applications, evaluates the reported outcomes against both operational and sustainability metrics, and identifies the overarching challenges is currently lacking. This gap is particularly critical given the dual imperative of modern logistics: to increase efficiency while simultaneously reducing environmental impact. While many studies claim to contribute to "sustainable" automation, the specific metrics used to measure sustainability—such as energy consumption, carbon footprint, or lifecycle analysis—are often inconsistent, incomplete, or entirely absent [6]. This makes it difficult for practitioners and researchers to assess the true holistic value of these technologies.

The primary motivation for this systematic review is, therefore, to provide a structured and comprehensive overview of the field, bridging the gap between the technical advancements in deep learning for robotics and the practical, sustainability-oriented needs of the supply chain industry. We aim to move beyond a simple cataloging of techniques and instead synthesize the evidence regarding how these

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technologies impact both operational efficiency and environmental sustainability. The significance of this work lies in its potential to inform future research directions, guide technology adoption in industry, and highlight areas where the integration of sustainability metrics is most urgently needed. By systematically analyzing the existing literature, we seek to identify not only the most promising deep learning architectures and applications but also the critical bottlenecks that hinder their widespread and sustainable deployment.

The remainder of this paper is organized as follows: Section 2 details the systematic methodology employed for the literature search, screening, and data extraction, following the PRISMA guidelines. Section 3 presents the results of our analysis, beginning with an overview of research trends and the characteristics of included studies, followed by a deep dive into the three core application areas: deep learning for perception and manipulation in picking tasks, deep reinforcement learning for mobile robot navigation and path planning, and integrated deep learning systems for warehouse automation and logistics. Section 4 discusses the synthesized findings, highlighting the key technological and operational challenges, the superficial treatment of sustainability, and the implications for future research and practice. Finally, Section 5 concludes the paper by summarizing the main contributions and outlining a roadmap for advancing the field towards truly sustainable and intelligent logistics automation.

Methodology

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [7] to ensure a rigorous, transparent, and reproducible process. The methodology encompasses the formulation of a detailed review protocol, a comprehensive literature search across multiple databases, the application of explicit inclusion and exclusion criteria, and a systematic study selection and quality assessment procedure.

Review Protocol

A detailed review protocol was established prior to the commencement of the literature search to define the scope, search strategy, and analytical framework. The research question was formulated using the SPICE framework, which guided the identification of key concepts related to the Setting (supply chain and logistics), Perspective (deep learning and robotics), Intervention (smart serving robots), Comparison (traditional methods or alternative approaches), and Evaluation (sustainability and operational outcomes). This framework ensured that the search strategy was both comprehensive and focused.

The literature search was executed across seven major academic databases and search engines, each selected for its relevance and coverage of the interdisciplinary research domain. IEEE Xplore was chosen for its extensive repository of high-quality conference proceedings and journals in robotics, artificial intelligence, and automation. ACM Digital Library provided access to a broad range of computing and information systems literature, including human-robot interaction and software systems. Scopus and Web of Science were selected for their comprehensive, multidisciplinary coverage and robust citation tracking capabilities, which are

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essential for identifying influential works and mapping research trends. ScienceDirect and SpringerLink were included for their strong collections in engineering, computer science, and operations research, particularly in the areas of logistics and supply chain management. arXiv was chosen to capture the latest preprints and emerging research that may not yet be indexed in traditional databases, reflecting the fast-paced nature of deep learning research. Finally, Google Scholar was used as a supplementary search engine to ensure broad coverage and to identify grey literature and non-indexed publications.

The search strategy employed a combination of keywords and Boolean operators to capture the core concepts of the review. The primary search string was constructed as follows: (deep learning OR neural network OR AI OR machine learning) AND (smart serving robot OR service robot OR autonomous delivery robot) AND (supply chain OR logistics OR warehouse automation OR last-mile delivery). This string was adapted for each database to comply with its specific syntax and search capabilities. For example, in IEEE Xplore, the search was performed using the "Command Search" feature with the string: ("deep learning" OR "neural network" OR "AI" OR "machine learning") AND ("smart serving robot" OR "service robot" OR "autonomous delivery robot") AND ("supply chain" OR "logistics" OR "warehouse automation" OR "last-mile delivery"). In Scopus, the search was executed in the "Advanced Search" field using TITLE-ABS-KEY (("deep learning" OR "neural network" OR "AI" OR "machine learning") AND ("smart serving robot" OR "service robot" OR "autonomous delivery robot") AND ("supply chain" OR "logistics" OR "warehouse automation" OR "last-mile delivery")). The search was limited to English-language publications, and no date restrictions were applied to capture the full historical development of the field.

Analytical Taxonomy for Literature Classification

To systematically organize and synthesize the diverse body of literature identified in this review, we developed an analytical taxonomy based on the primary deep learning function and the specific logistics task addressed. This taxonomy reflects the core technological dimensions of the research and facilitates a structured comparison of findings across studies. The taxonomy comprises three primary categories, which are derived from the fundamental capabilities required for a smart serving robot to operate effectively in a logistics environment: perception and manipulation, navigation and path planning, and integrated system-level automation.

The first category, "Deep Learning for Perception and Manipulation in Picking Tasks," encompasses studies that focus on the use of deep learning models, particularly convolutional neural networks (CNNs) and their variants, to enable robots to perceive and interact with objects in their environment. This includes research on object detection and recognition for identifying items in cluttered bins, grasp planning algorithms that learn optimal hand configurations for diverse product geometries, and visual servoing techniques that guide robotic arms to precisely pick and place items.

The second category, "Deep Reinforcement Learning for Mobile Robot Navigation and Path Planning," groups together studies that apply deep reinforcement learning (DRL) algorithms to train autonomous mobile robots (AMRs) and drones to navigate efficiently and safely within warehouse or delivery environments. This research often

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addresses challenges such as dynamic obstacle avoidance, multi-robot coordination, and energy-aware path optimization. The third category, "Integrated Deep Learning Systems for Warehouse Automation and Logistics," includes studies that propose and evaluate holistic systems where multiple deep learning components are combined to automate a complete logistics workflow, such as end-to-end order fulfillment or autonomous inventory management. These works typically integrate perception, navigation, and decision-making modules into a unified architecture. A small number of studies that did not fit neatly into these three primary categories, such as those focusing on predictive maintenance or demand forecasting using deep learning for logistics robots, were classified under a fourth, residual category. This taxonomy provides a clear and coherent framework for analyzing the state of the art and identifying the specific contributions and limitations of the included studies.

Inclusion and Exclusion Criteria

The establishment of clear inclusion and exclusion criteria was essential to ensure the relevance, consistency, and quality of the studies selected for this systematic review. The inclusion criteria were designed to capture studies that directly address the core research question concerning deep learning-enabled smart serving robots for sustainable supply chain and logistics automation. Specifically, studies were considered eligible if they focused on the application of deep learning techniques, including but not limited to convolutional neural networks, recurrent neural networks, transformers, and deep reinforcement learning, for the control, perception, navigation, or task planning of smart serving robots. The robots in question had to be explicitly deployed within the context of supply chain and logistics automation, such as warehousing, inventory management, order fulfillment, or last-mile delivery. Furthermore, the study had to substantively address or discuss sustainability aspects, which could include energy efficiency, waste reduction, resource optimization, or lifecycle impact, rather than merely mentioning the term in passing. Only full-length research articles, preprints, or systematic reviews and meta-analyses written in English and with accessible full text were considered.

Conversely, the exclusion criteria were applied to filter out studies that did not meet the required standards of relevance and rigor. Studies that relied solely on classical, non-deep learning robotics or optimization methods were excluded, as the focus of this review is specifically on the enabling role of deep learning. Papers where the robot was not performing a "serving" function within the logistics domain, such as manufacturing assembly robots or surgical robots, were also excluded. A critical exclusion criterion was the superficial treatment of sustainability; studies that mentioned sustainability only in the introduction or conclusion without providing any substantive analysis, metric, or design consideration related to sustainability were not included. Opinion pieces, editorials, short abstracts, posters, and non-archival workshop papers that lacked sufficient methodological detail were excluded. Duplicate publications of the same study, such as a conference paper later expanded into a journal article, were handled by retaining only the most complete and recent version. Finally, studies that were purely theoretical with no experimental validation or simulation results on a relevant logistics or supply chain task were excluded to ensure the review was grounded in empirical evidence.

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Study Selection Process

The study selection process was conducted in multiple stages, following the PRISMA flow diagram to ensure transparency and reproducibility. The initial search across all seven databases and search engines yielded a total of 642 records. These records were imported into a reference management tool, where 233 duplicate records were identified and removed, leaving 409 unique records for screening. The screening of titles and abstracts was performed independently by two reviewers against the predefined inclusion and exclusion criteria. During this phase, 289 records were excluded as they clearly did not meet the eligibility criteria, for reasons such as an irrelevant focus (e.g., surgical robotics, non-logistics applications), a lack of deep learning methodology, or an absence of any sustainability discussion. The remaining 120 records were sought for retrieval of their full-text versions. However, full-text access could not be obtained for 14 of these records, despite efforts through institutional subscriptions and inter-library loans, leaving 106 reports to be assessed for eligibility.

The full-text assessment was conducted independently by the same two reviewers, who evaluated each report against the detailed inclusion and exclusion criteria. Any disagreements between the reviewers were resolved through discussion and consensus. During this phase, 72 reports were excluded. The primary reasons for exclusion included: the study did not focus on a smart serving robot (e.g., it was about a manufacturing robot or a purely software-based system), the deep learning component was not central to the robot's function (e.g., it was used only for post-hoc data analysis), the sustainability aspect was mentioned only superficially without any substantive analysis or metric, or the study lacked sufficient methodological detail or experimental validation. Following this rigorous assessment, a final set of 34 studies was deemed eligible and included in the systematic review. The entire study selection process is illustrated in the PRISMA flowchart presented in Figure 1.

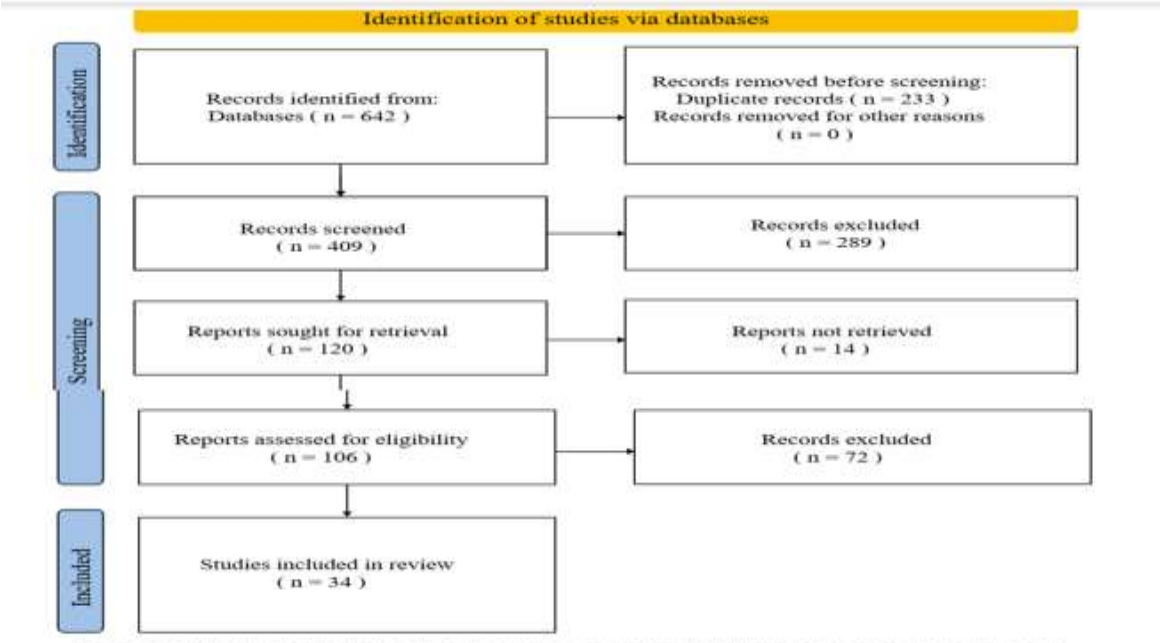


Figure 1. PRISMA flowchart illustrating the study selection process from initial database search to final inclusion of 34 studies.

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The study selection process, while rigorous, is subject to certain limitations and potential biases. The search was limited to English-language publications, which may introduce a language bias and exclude relevant research published in other languages. The reliance on the selected databases, while comprehensive, may not capture all relevant grey literature or industry reports that are not indexed in academic databases. The exclusion of studies that did not substantively address sustainability, while necessary for the focus of this review, may have excluded some technically excellent works that simply did not frame their results in sustainability terms. Furthermore, the quality assessment, while performed independently by two reviewers, is inherently subjective, and the exclusion of studies based on insufficient methodological detail may have inadvertently excluded some valuable preliminary or exploratory research. These limitations should be considered when interpreting the findings of this review.

Results

Research Trends

The temporal distribution of the 34 included studies reveals a clear and accelerating trajectory of research interest in deep learning-enabled smart serving robots for logistics automation, as illustrated in Figure 2. The earliest works in our corpus appear in 2016, with only two publications, suggesting that the application of deep learning to logistics robotics was in its nascent stages. This period was characterized by foundational work, primarily focused on adapting existing deep learning architectures, such as convolutional neural networks, to the specific challenges of warehouse perception and object grasping. A gradual increase in publication volume is observed from 2016 to 2019, with the annual count rising from two to three publications, indicating a steady but modest growth in the field as researchers began to explore the potential of these technologies.

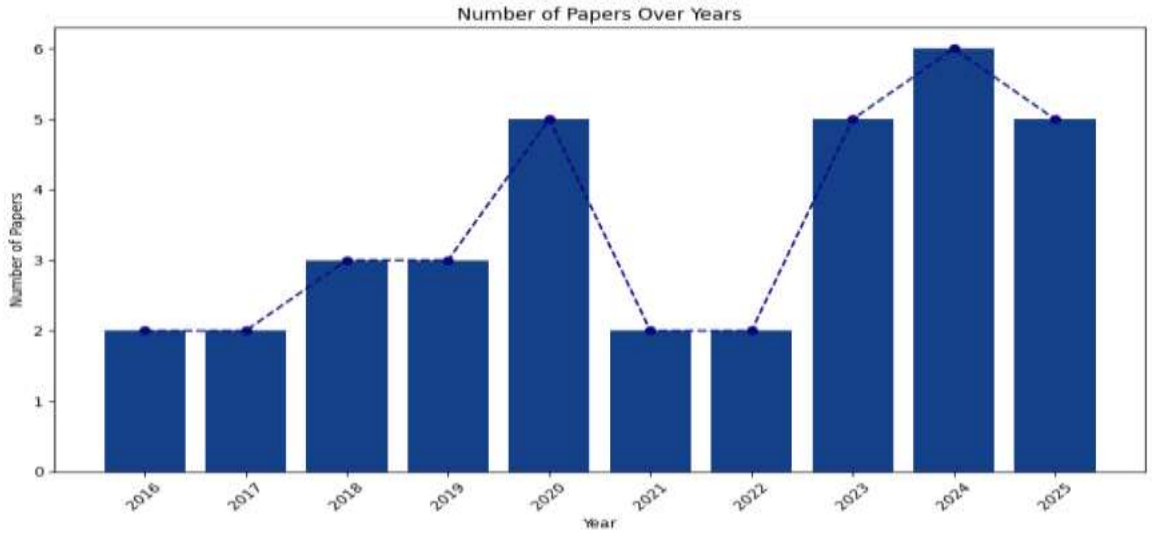


Figure 2. Research trends in the domain of deep learning-enabled smart serving robots for sustainable supply chain and logistics automation

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A more pronounced surge in research activity is evident from 2020 onwards. The year 2020 marks a significant inflection point, with five publications, representing a notable increase from the previous year. This acceleration can be attributed to several converging factors, including the maturation of deep learning frameworks, the increased availability of large-scale datasets for robotic manipulation and navigation, and the heightened industry demand for automation solutions driven by the global pandemic's impact on e-commerce and supply chain resilience. The publication count remained relatively stable at two publications in both 2021 and 2022, which may reflect a period of consolidation where researchers focused on refining existing methods and addressing specific technical bottlenecks rather than producing a high volume of new studies. However, this was followed by a dramatic resurgence in 2023, with five publications, and an even higher peak in 2024, with six publications, representing the highest annual output in the review period. The year 2025, with five publications already included, suggests that this upward trend is continuing and that the field is experiencing a period of rapid expansion and diversification. This pattern indicates that deep learning for logistics robotics has transitioned from a niche research area to a mainstream and highly active field of inquiry, driven by both technological maturity and pressing industrial needs.

Overview of Included Studies

Table 1 presents the main characteristics of the included studies. The extracted information included study identification, study focus, automation task, learning method, robot type, application setting, performance metrics and key findings, where applicable.

The included studies varied in terms of their research focus, automation tasks, and learning methods. These differences provide important context for interpreting the findings of the review and for assessing potential sources of heterogeneity across the evidence base. Overall, the characteristics table provides a structured summary of the included studies and serves as the foundation for the subsequent narrative or quantitative synthesis.

Table 1. Characteristics of Included Studies

STUDY ID	STUDY FOCUS	AUTOMATION TASK	LEARNING METHOD	ROBOT TYPE	APPLICATION SETTING	PERFORMANCE METRICS	KEY FINDINGS
[8]	multi-robot path planning and congestion management in	pick and deliver orders from target shelves to corresponding pick stations	Q-learning	multiple robots	warehouse environment with grid map, inventory pods, and pick stations	travel time and travel distance	the proposed method optimizes both travel time and travel distance,

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	warehouse order picking						enhancing overall operational efficiency
[9]	textured object detection and manipulation for order picking	order picking		mobile order picking robot	retail store or warehouse		
[10]	precise control of robots based on accurate positional information using sensor data	robot position prediction	2D Convolutional Neural Network (2D-CNN) with Asymmetric Gaussian loss function		controlled internal logistics precinct at Dortmund University of Technology's Material Flow and Warehousing Chair	mean squared errors	remarkably low mean squared errors in predicting robot positions, demonstrating efficacy of the approach
[11]	Optimization of mobile robot delivery system based on deep learning	Delivery system path planning and task execution	Deep learning, spatial attention mechanism, Deep Deterministic Policy Gradient (DDPG) algorith	Mobile robot	Complex and dynamically changing environments	Accuracy of path planning, task execution efficiency, system robustness	The proposed method significantly enhances overall performance; combining spatial attention mechanism with

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			m, end-to-end optimization				deep policy gradient algorithm improves navigation, obstacle avoidance, and delivery strategy learning in complex environments.
[12]	Robotic path planning for agricultural logistics warehouse management by combining SLAM with deep vision computing	Path planning and obstacle recognition in agricultural warehouses	Deep vision computing, SORF optimization, adaptive weighting pooling layer	Inspection robot	Agricultural logistics warehouse	Total length, obstacle recognition, efficiency improvement	The proposed method outperforms standard methods in terms of accuracy and efficiency in path planning
[13]	Integrating different levels of automation in a robotic	Pick and place operations in semistructured environm	Deep learning and other state-of-the-art artificial	Industrial robot arm with 3-D camera	Semistructured environments, specifically shelves in an		1) Specific task conditions should guide

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	system for the Amazon Robotics Challenge 2016	ents (Amazon warehouse shelves)	intelligence techniques	s and a custom gripper	Amazon warehouse		the selection of the solution for each capability; 2) Understanding the characteristics of individual solutions and their assumptions is critical for integration; 3) This characterization can be based on 'levels of robot automation' using information at design or runtime.
[14]	Long-range robotic navigation tasks by combining reinforc	Long-range navigation task completion	Reinforcement learning (RL) combined with sampling-based path	Differential drive indoor robot and aerial cargo deliver	Indoor office environments and urban environments	Task completion, trajectory length (up to 215 m for indoor, over 1000 m for aerial)	PRM-RL improves task completion over both RL agents on their

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	ement learning and sampling-based planning		planning (Probabilistic Roadmaps)	y robot			own and traditional sampling-based planners; successfully completes long trajectories under noisy sensor conditions and in environments much larger than training.
[15]	Design of logistics sorting algorithm based on deep learning and sampling evaluation	Localizing and generating grasping positions for intelligent robots in logistics sorting	Deep learning (enhanced YOLOv3 target detection and instance segmentation)	Intelligent robotic arm	Logistics sorting in real logistics scenarios / intelligent logistics factories	F1 value, accuracy, Area under the Curve (AUC), average absolute value error, root mean square error, all-class average precision value, relative position error, absolute trajectory error, grasping	The improved target detection model achieved highest F1 value of 95.77%, accuracy of 94.05%, and AUC of 91.30%. The instance segmentation algorithm with fused

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						accuracy	features had lower average absolute value error and root mean square error, higher accuracy and all-class average precision, and smaller fluctuation. The position generation model based on sampling evaluation had relative position error and absolute trajectory error below 0.4, and combined indexes of grasping accuracy and error showed superior

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							performance, effectively enhancing sorting effects in real logistics scenarios.
[16]	Path planning and control for logistics robots in complex environments	Path planning and obstacle avoidance	3D Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM)	Multimodal intelligent logistics robot	Complex logistics environments	Path planning accuracy and obstacle avoidance performance	The proposed method outperforms traditional approaches in terms of both path planning accuracy and obstacle avoidance performance, enabling logistics robots to navigate intricate scenarios with higher precision and reliability.
[17]	Team Delft's	Pick and place	Deep Learnin	Industrial	Amazon warehous		

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	robot that won the Amazon Picking Challenge 2016	operations in unstructured environments, specifically Amazon warehouse shelves	g and other AI techniques for object recognition and pose estimation	robot arm with 3D cameras and a customized gripper	e shelves (unstructured environments)		
[18]	Accelerating grasp-optimized motion planning using deep learning	Picking in e-commerce warehouses	Deep learning	Robot arm	E-commerce warehouse picking	Computation time, motion time	Deep learning reduces computation time by two orders of magnitude (300×), from 29 s to 80 ms, making it practical for e-commerce warehouse picking.
[19]	Robotic operations in logistics, specifically picking objects in unstructured	Pick and place operations in logistics	Deep reinforcement learning (DRL) with Deep Deterministic Policy Gradient	Mobile manipulator	Logistics, unstructured areas, picking objects from a table		A controller for the robot base is learned using arm planner's feedback, guiding the

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	areas using a mobile manipulator		(DDPG) and Proximal Policy Optimisation (PPO)				platform to a position where the arm can plan a trajectory to the object; performance of DDPG and PPO algorithms is compared
[20]	Depth image–based deep learning of grasp planning for textureless planar-faced objects in vision-guided robotic bin-picking	Bin-picking of small parcels and other textureless planar-faced objects	Deep convolutional neural network (DCNN) trained on 15,000 annotated depth images synthetically generated in a physics simulator	Robot with 7 degrees of freedom	Warehouse bin-picking of randomly posed textureless boxes in a cluttered environment	97.5% success rate at speeds exceeding 1000 pieces per hour	The DCNN directly predicts grasp points without object segmentation, predicts optimal grasp patterns for a hand with two vacuum cups, and uses a surface feature descriptor to refine predicted grasp

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							point position, removing the need for texture features and sim-to-real modification.
[21]	Using a hierarchy of supervisors for learning from demonstrations to improve robot grasping in clutter	Grasping a desired object (yellow cylinder) amid clutter	Online Learning from Demonstration (LfD) with a hierarchy of supervisors (fast motion planner, crowd-sourced human workers, local human expert)	Planar robot arm	Amazon warehouse order fulfillment	Probability of a successful grasp (reliability)	With 160 expert demonstrations, using the hierarchy of supervisors can increase the probability of a successful grasp from 55% to 90%
[22]	Optimizing mobile robot paths using reinforcement learning in a warehouse environment	Path optimization	Reinforcement learning	Mobile robot	Warehouse environment with automated logistics		The experimental results helped understand the characteristics and differences in the reinforcement

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							learning algorithm; findings facilitate understanding of basic concepts of reinforcement learning for further studies on more complex and realistic path optimization algorithm development.
[23]	efficiently determining the optimal path in complex warehouse layouts while enabling real-time decision-making	warehouse robot navigation	Proximal Policy Optimization (PPO) combined with Dijkstra's algorithm (Proximal Policy-Dijkstra, PP-D)	warehouse robot	complex warehouse layouts	navigation prediction accuracy, system robustness, collision and stagnation minimization	The PP-D framework outperforms traditional algorithms, particularly in navigation prediction accuracy and

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							system robustness; in complex warehouse layouts, it achieves more precise optimal path identification, minimizing collisions and stagnation.
[24]	application of robots in intelligent supply-chain and digital logistics, efficient operation, energy conservation, and emission reduction in warehousing and	automatic picking of goods of any shape in the picking list	convolution neural network (CNN) with exponential decay and moving average for loss function and global step size	cooperative robots (COBOT)	unmanned sorting and automated warehousing		The model updates the loss function value and global step size by exponential decay and moving average, realizes the identification and classification of goods, and

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	sorting						obtains the running dynamics of the program in real time by using visual tools.
[25]	Path planning of intelligent robots based on deep reinforcement learning	Path planning and inspection task execution in intelligent warehousing	Actor-Critic algorithm with deep learning network	Inspection robot	Intelligent warehousing with dynamic and complex environments	Success rate of 97.6%, energy consumption reduction	The proposed method enables safe and reasonable inspection route planning in dynamic environments, achieves a high success rate of 97.6%, and significantly reduces energy consumption.
[26]	Autonomous navigation and path planning in warehou	Path planning	Deep Q-Networks (DQN)		Simulated warehouse environment in ROS and Gazebo	Number of actions executed to reach the goal, cumulative reward per episode,	Incorporating the SLAM map enhances learning stability, with the

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	se environments with dynamic obstacles					success rate	agent reaching a goal approximately 150 times, nearly double the success rate compared to the baseline without map information, which achieved only 80 successful episodes over the same number of episodes.
[27]	Smart Robotic Framework for Automated Pick-and-Place and Real-Time Inventory Manage	Automated pick-and-place operations integrated with real-time inventory management	Convolutional neural networks (CNNs) for object recognition	Robotic arms	Simulated smart warehouse environment	Accuracy (up to 95% in object classification), reduced operational time, seamless inventory synchronization	Enhanced accuracy (up to 95% in object classification), reduced operational time, and seamless inventor

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	ment in Industry 4.0 Environments						y synchronization
[28]	object-centric benchmark dataset for robotic manipulation	object singulation from containers with heterogeneous contents		robotic manipulator	warehouse	baseline performance evaluation on object segmentation in clutter, object identification, and defect detection	ARMBench contains images, videos, and metadata corresponding to 235K+ pick-and-place activities on 190K+ unique objects
[29]	Autonomous warehouse robot using deep q-learning	Robot navigation, obstacle avoidance, and maximizing the use of space for product placement	Deep Reinforcement Learning (DRL) and traditional Q-learning with minor variations	Warehouse robot	2D simulation environment		Successfully tested the performance of the model in a 2D simulation environment for both single and multi-robot cases
[30]	Dual-loop optimal	Warehouse automatio	Neural network (NN)-	7-DOF Barrett WAM	Exact warehouse setting	Smoother trajectories with cost-	The proposed dual-

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	control scheme for robotic manipulators	n	based adaptive critic (AC) optimal tracking control	robot manipulator		effective control actuator inputs	loop optimal control scheme results in smoother trajectories with cost-effective control actuator inputs than state-of-the-art methods, with stability proven via Lyapunov approach and verified experimentally.
[31]	Autonomous logistics in supply chain management through AI, drones, and robotics	Last-mile delivery, warehouse operations, route planning, real-time traffic management, inventory handling, order fulfillment	Machine learning algorithms	Drones, autonomous ground vehicles, warehouse robotics	Urban areas for drone deliveries, bulk transportation via autonomous ground vehicles, warehouse environments	Delivery time, operational costs, carbon emissions, accuracy, scalability	The AI-DAV framework significantly reduces delivery time, operational costs, and carbon emissions while

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							increasing accuracy and scalability in logistics operations
[32]	Part handling in warehouse automation for a large variety of items stored in unordered piles	Picking items from a shelf and stowing items into a shelf	Deep-learning approaches for object detection and semantic segmentation, and item model registration		Warehouse automation, Amazon Picking Challenge 2016	Second and third place in the Amazon Picking Challenge 2016 tasks	The system localizes requested items using deep learning and model registration, manipulates using suction, and uses parametrized motion primitives for motion generation
[33]	Fast object learning and dual-arm coordination for cluttered stowing, picking,	Stowing items into a storage system, picking specific items, and packing them into boxes	Transfer learning	Dual-arm robot	Cluttered bins	Second places in both the picking task and the final stow-and-pick task at the 2017 Amazon Robotics	The deep object perception pipeline can be quickly and efficiently

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	and packing					Challenge	adapted to new items using a custom turntable capture system and transfer learning; it produces high-quality item segments on which grasp poses are found; a planning component coordinates manipulation actions between two robot arms, minimizing execution time.
[34]	Optimized grasp pose detection using RGB	Suction grasping	Foundation models trained on syntheti	Warehouse picking robots	Warehouse environments	81.9% success rate in real-world applications	The method generalizes grasp prediction

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	images for warehouse picking robots		c dataset				capabilities to real-world robots and novel objects not included in the training set using only RGB images.
[35]	Enhanced dynamic visual SLAM system for hospital logistics robots using nonlinear optimal filtering and deep learning	Simultaneous Localization and Mapping (SLAM) for navigation in dynamic environments	Convolutional Neural Networks (CNN), Fully Convolutional Networks (FCN)	Hospital logistics robots	Complex hospital environments	Absolute trajectory error (ATE) as low as 0.067 m, over 90% overlap in map construction, average frame processing time under 90 ms	The proposed system significantly improves positioning accuracy, mapping quality, and real-time performance compared to other mainstream SLAM systems in dynamic hospital environments.

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[36]	Development of a low-cost autonomous mobile robot (AMR) for transporting goods in warehouse and production, including comparison of sensors and navigation algorithms	Transporting goods on the production floor and warehouse		Autonomous mobile robot (AMR)	Warehouse and production floor		
[37]	Multi-robot path planning based on a deep reinforcement learning DQN algorithm	Multi-robot path planning	Deep Q-network (DQN) algorithm with prior knowledge and prior rules	Handling robot	Unmanned warehouse dispatching system of the 'goods to people' model	Convergence speed, learning efficiency	The improved DQN algorithm converges faster than the classic deep reinforcement learning algorithm and can more quickly

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							learn the solutions to path-planning problems, improving the efficiency of multi-robot path planning.
[38]	Logistics box recognition in robotic industrial de-palletising procedure with systematic RGB-D image processing supported by multiple deep learning methods	Automated box de-palletisation	Mask R-CNN, Cycle Generative Adversarial Network (Cycle GAN)		Robotic industrial de-palletising	Success rate, mean absolute error between predicted picking point and ground truth values	Box detection performance was significantly improved; success rate validated using 200 cases of orderly and disorderly arrangements of boxes
[39]	6D pose estimation using multi-view RGB-D data and self-	Warehouse pick-and-place (stowing and picking tasks in the	Self-supervised deep learning with fully convolutional		Cluttered environments with self-occlusions, sensor noise, and a		The system can reliably estimate the 6D pose of objects

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	supervised deep learning	Amazon Picking Challenge)	neural networks		large variety of objects		under a variety of scenarios; the self-supervised method generates a large labeled dataset without tedious manual segmentation.
[40]	Grasping-stacking strategy for robotic arms using deep reinforcement learning	Grasping and stacking objects	Model-free deep Q-learning	Integrated robotic arm system	Simulated and real-world scenarios		The proposed GSN method maps images to actions through two deep networks (GNet and SNet) and integrates them for long-range planning in grasping-stacking tasks.
[41]	robot navigation	autonomous navigatio		logistics inspect	complex logistics storage	feasibility, robustness, precision,	The robot navigati

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	system based on vision and multiline lidar information fusion	n and cruise		ion robot	environment	portability, expandability	on system is feasible and robust, and overcomes the problems of low precision, poor robustness, weak portability, and difficult expansion of the mobile robot system in a complex environment.

Deep Learning-Enabled Perception and Manipulation for Automated Picking

The automated picking of items from bins, shelves, or pallets represents a core challenge in warehouse automation, requiring a robot to perceive its environment, recognize target objects, and execute a successful grasp. A substantial body of research has addressed this challenge by integrating deep learning techniques for perception and manipulation, often within the context of the Amazon Picking Challenge (APC) and Amazon Robotics Challenge (ARC) competitions, which served as important benchmarks for the field.

A foundational approach to this problem was demonstrated by Team Delft's winning entry in the APC 2016 [17]. Their system utilized an industrial robot arm equipped with 3D cameras and a customized gripper, with software implemented in ROS that integrated deep learning and other AI techniques for object recognition, pose estimation, grasp planning, and motion planning. This work highlighted the effectiveness of combining commercially available robotic hardware with state-of-the-art deep learning perception modules to achieve reliable pick-and-place operations in the unstructured environment of a warehouse shelf. Building upon this theme, the NimbRo Picking team achieved second and third place in the APC 2016 by employing two deep-learning approaches for object detection and semantic

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segmentation, coupled with an item model registration method for localizing requested items [32]. Manipulation was performed using suction on points determined either heuristically or from a 6D item model registration, demonstrating the utility of combining learned perception with geometric reasoning for grasping. The team further advanced their system for the 2017 ARC, developing a deep object perception pipeline that could be quickly adapted to new items using a custom turntable capture system and transfer learning, which produced high-quality item segments for grasp pose finding and incorporated dual-arm coordination to minimize execution time [33]. Similarly, the MIT-Princeton Team leveraged multiview RGB-D data and a self-supervised, data-driven learning approach to overcome difficulties in cluttered environments, segmenting and labeling multiple views of a scene with a fully convolutional neural network before fitting pre-scanned 3D object models to obtain the 6D object pose [39]. Their self-supervised method for generating a large labeled dataset addressed the critical bottleneck of manual data annotation for training deep segmentation networks.

The challenge of achieving both speed and precision in grasping has been a significant focus. One study proposed warm-starting grasp-optimized motion planning with deep learning, finding that this method could reduce the computation time for generating efficient and smooth robot arm motions from 29 seconds to 80 milliseconds, a reduction of two orders of magnitude [18]. This approach used a neural network to quickly compute approximate motions that were then refined by an optimizing motion planner, making real-time grasp computation practical for e-commerce warehouse picking. For the specific and common task of bin-picking small parcels and textureless planar-faced objects, a depth image-based vision-guided system using a deep convolutional neural network (DCNN) trained on 15,000 synthetically generated annotated depth images was developed [20]. This DCNN directly predicted grasp points without requiring object segmentation and could predict optimal grasp patterns for a gripper with two vacuum cups. Combined with a surface feature descriptor to refine the predicted grasp point position, this system achieved a 97.5% success rate at speeds exceeding 1000 pieces per hour, demonstrating the effectiveness of sim-to-real transfer for this application.

Further innovations have focused on reducing the dependency on expensive or complex sensor hardware. One study proposed OptiGrasp, an approach that leverages foundation models to enhance suction grasping using only RGB images, trained solely on a synthetic dataset [34]. This network achieved an 81.9% success rate on real-world robots with a diverse range of novel objects not seen during training, showing that robust grasp prediction is possible without depth sensors. In another study aimed at reducing the burden on human experts for providing demonstrations, a hierarchy of supervisors consisting of a fast motion planner, crowd-sourced human workers, and a local human expert was proposed for learning robot control policies for grasping in clutter [21]. With 160 expert demonstrations, this hierarchy increased the probability of a successful grasp from 55% to 90%, illustrating a scalable approach to learning from demonstration. Research on logistics box recognition for robotic de-palletising addressed the challenge of cluttered arrangements and varied outer surfaces by proposing a Mask R-CNN-based detection approach supported by a cycle generative adversarial network (Cycle GAN) to automatically erase tags and labels from box

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surfaces before detection [38]. This method significantly improved box detection performance and was validated with a practical robot system for picking tasks.

Several studies have also connected the application of deep learning for robotic picking to the broader goals of sustainable supply chain management. One work, grounded in the theory of sustainable development, established an image recognition model using a CNN for arbitrarily shaped objects in a warehousing context, aiming to achieve energy conservation and emission reduction through efficient automated picking [24]. The model selected different intelligent grasp solutions based on object characteristics such as shape, size, and weight, laying a foundation for intelligent supply-chain systems. Similarly, research on a logistics sorting algorithm based on enhanced YOLOv3 target detection and instance segmentation aimed to improve the sorting effects of real logistics scenarios, thereby encouraging the development of logistics automation and the establishment of intelligent logistics factories [15]. Another study focused on textured object detection and manipulation for a mobile order picking robot, discussing techniques for handling typical packaged retail store items in a retail or warehouse fulfillment context [9].

Large-scale datasets are critical for training robust deep learning models for manipulation. The Amazon Robotic Manipulation Benchmark (ARMBench) was introduced as a large-scale, object-centric dataset collected in an Amazon warehouse using a robotic manipulator performing object singulation from containers [28]. This dataset contains 235K+ pick-and-place activities on 190K+ unique objects, with images and videos captured at different stages of manipulation, providing a resource for benchmarking tasks such as object segmentation in clutter, object identification, and defect detection. The characteristics of these studies focusing on perception and manipulation are systematically summarized in Table 2.

Table 2. Summary of Studies on Deep Learning for Perception and Manipulation in Picking Tasks

STUDY ID	PERCEPTION INPUT	OBJECT TYPE	GRASP STRATEGY	KEY OUTCOME
[17]	3D cameras	Not specified	Grasp planning integrated with object recognition and pose estimation	Winner of the Amazon Picking Challenge 2016
[18]	Not specified	Not specified	Grasp-optimized motion planning warm-started by deep learning	300× reduction in computation time (29 s to 80 ms)
[20]	Depth image	Textureless planar-faced objects (boxes)	DCNN predicts grasp points and patterns for a two-cup vacuum gripper	97.5% success rate at >1000 pieces per hour
[21]	Camera image	Yellow cylinder in clutter	Learned control policy from demonstrations with hierarchy of supervisors	Grasp success rate increased from 55% to 90%
[24]	Image (CNN)	Arbitrarily shaped objects	Different grasp solutions selected based on object characteristics	Foundation for intelligent supply-chain and energy-efficient

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STUDY ID	PERCEPTION INPUT	OBJECT TYPE	GRASP STRATEGY	KEY OUTCOME
				warehousing
[9]	Not specified	Typical packaged retail store items	Textured object detection and manipulation	Not specified
[28]	Images, videos, and metadata	190K+ unique objects	Object singulation	Benchmark dataset with 235K+ pick-and-place activities
[32]	RGB-D data	Variety of items in unordered piles	Suction on points from heuristics or 6D model registration	2nd/3rd place in APC 2016
[33]	Deep object perception pipeline	Not specified	Grasp pose finding on item segments	2nd place in ARC 2017 picking and stow-and-pick tasks
[34]	RGB images	Novel objects	Suction grasping via foundation models	81.9% success rate in real-world applications
[38]	RGB-D image (Mask R-CNN and Cycle GAN)	Boxes	Mask R-CNN-based detection for picking guidelines	Significantly improved box detection performance
[39]	Multiview RGB-D data	Not specified	6D pose estimation via self-supervised segmentation and model fitting	Reliable 6D pose estimation in clutter
[15]	Enhanced YOLOv3 and instance segmentation	Document-like parcels	Position generation algorithm refined by sampling evaluation	Highest F1 of 95.77%, accuracy of 94.05%

Deep Reinforcement Learning for Autonomous Mobile Robot Navigation and Path Planning

The deployment of autonomous mobile robots (AMRs) for tasks such as order retrieval, goods transportation, and inventory inspection in warehouses and logistics centers hinges critically on their ability to navigate efficiently and safely within complex, dynamic, and often crowded environments. Classical path planning algorithms like A* and Dijkstra, while effective in static settings, frequently struggle to adapt to real-time changes, such as the sudden appearance of obstacles or the movements of other robots and human workers. Deep reinforcement learning (DRL) has emerged as a powerful paradigm for addressing these limitations by enabling robots to learn sophisticated navigation policies directly from interaction with their environment, optimizing for objectives such as travel time, path length, collision avoidance, and energy consumption.

A significant portion of the research in this domain focuses on applying fundamental DRL algorithms to the multi-robot path planning problem in warehouse settings. One study directly addresses multi-robot path planning and congestion management in a

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grid-map warehouse environment, where multiple robots retrieve and deliver orders from inventory pods to pick stations [8]. The authors employed a standard Q-learning algorithm to compute optimal paths for each robot while simultaneously avoiding congestion in the complex network of aisles. Simulation results demonstrated that this approach effectively optimized both travel time and travel distance, thereby enhancing the overall operational efficiency of the warehouse system. Another investigation compared the performance of the Deep Q-Network (DQN) algorithm, a classic deep reinforcement learning method combining Q-learning with deep neural networks, against a traditional Q-learning approach for multi-robot path planning in an unmanned warehouse dispensing system [37]. The study found that the standard DQN algorithm suffered from slow convergence and excessive randomness. To mitigate these issues, the authors proposed an improved DQN algorithm that incorporated prior knowledge and prior rules before the start of the algorithmic process. Simulation results confirmed that this enhanced version converged significantly faster than the classic DRL algorithm, enabling the multi-robot system to learn path-planning solutions more efficiently.

The challenge of navigating in complex and dynamic environments has prompted the development of more sophisticated hybrid approaches. A notable study introduced the Proximal Policy-Dijkstra (PP-D) method, which synergistically combines the Proximal Policy Optimization (PPO) algorithm with Dijkstra's algorithm [23]. In this framework, PPO enables the robot to learn effective action strategies and make real-time decisions in dynamic environments through its stable policy update mechanism, while Dijkstra's algorithm provides the capability for global optimal path planning in the static portions of the environment. Comparative experiments demonstrated that the PP-D framework outperformed traditional algorithms, particularly in terms of navigation prediction accuracy and system robustness. In complex warehouse layouts, the method achieved more precise identification of optimal paths and significantly minimized collisions and stagnation, underscoring its reliability and effectiveness. Another investigation tackled the efficiency bottleneck of intelligent warehousing robots in dynamic and complex settings by proposing a path planning scheme based on the Actor-Critic algorithm [25]. The scheme first calculated the robot's turning angle based on real-time location data to achieve efficient directional decision-making. It then guided the robot to autonomously learn the optimal execution sequence of inspection targets and traveling speed, with goals of optimal path length, reduced energy consumption, and operational safety. To handle the high-dimensional continuous state space, the authors introduced a deep learning network to accurately estimate action strategies and reward mechanisms. Simulation experiments showed that an inspection robot using this method could plan safe and reasonable routes in dynamic environments, completing inspection tasks with a high success rate of 97.6% while also significantly reducing energy consumption.

The integration of map information with reinforcement learning has been shown to substantially improve learning stability and navigation performance. A simulation-based framework for path planning using Deep Q-Networks (DQN) was developed for a warehouse environment modeled with moving obstacles [26]. The proposed solution integrated a prebuilt map of the environment generated using Simultaneous Localization and Mapping (SLAM) as prior spatial knowledge of static obstacles. The

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reinforcement learning model itself used a state space derived from grayscale images that combined this static SLAM map with real-time information about dynamic obstacles. The agent was trained over 1000 episodes in a Robot Operating System (ROS) and Gazebo simulation. The results across two goal locations demonstrated that incorporating the SLAM map markedly enhanced learning stability; the agent reached a goal approximately 150 times, nearly double the success rate compared to the baseline without map information, which achieved only 80 successful episodes. This indicated faster convergence and reduced exploration overhead due to improved spatial awareness. Similarly, an enhanced dynamic visual SLAM system was proposed for hospital logistics robots to overcome the challenges of increased positioning errors and struggle with real-time multimodal sensor data fusion in dynamic environments [35]. This system employed an Unscented Kalman Filter (UKF) for nonlinear state estimation, a Convolutional Neural Network (CNN) for deep feature extraction of environmental images, and a combination of Fully Convolutional Networks (FCN) and Canny edge detection for semantic edge detection. The fusion of multimodal data from vision, lidar, and IMU sensors was optimized using an Extended Kalman Filter (EKF). The system achieved an absolute trajectory error (ATE) as low as 0.067 m, over 90% overlap in map construction, and an average frame processing time under 90 ms, significantly outperforming other mainstream SLAM systems.

Several studies have focused on the related but distinct task of optimizing a mobile robot's base placement to enable successful manipulation, or on developing low-cost platforms. In one study, a deep reinforcement learning approach was selected to control a mobile manipulator for pick-and-place operations in unstructured logistics areas [19]. The mobile manipulator had to place its base in a correct location so that the arm could plan a trajectory to a target object on a table. Using feedback from the arm planner, a controller for the robot base was learned using DRL, and the performance of two algorithms, Deep Deterministic Policy Gradient (DDPG) and Proximal Policy Optimisation (PPO), was compared. Another study aimed to develop a low-cost autonomous mobile robot (AMR) for transporting goods in warehouses and production floors, with a focus on studying and comparing available sensor options and navigation algorithms [36]. The research covered the development of the AMR's navigation function using the ROS Navigation Stack, which is a common framework that can integrate various local and global planners, including those based on DRL.

Furthermore, the concept of hierarchical navigation, which combines learning-based local policies with global planning, has proven effective for long-range tasks. The PRM-RL method was presented as a hierarchical approach for long-range navigation task completion, combining sampling-based path planning with reinforcement learning [14]. In this framework, RL agents first learn short-range, point-to-point navigation policies that capture robot dynamics and task constraints without knowledge of large-scale topology. Then, a Probabilistic Roadmap (PRM) planner connects robot configurations that can be successfully navigated by the RL agent. This method was evaluated on two tasks with non-trivial dynamics: end-to-end differential drive indoor navigation in office environments and aerial cargo delivery in urban environments with load displacement constraints. The results showed

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improvement in task completion over both RL agents on their own and traditional sampling-based planners, with the indoor robot successfully completing trajectories up to 215 m long and the aerial drone completing flights over 1000 m in an environment 63 million times larger than used in training.

Other works have explored different algorithmic foundations or specific applications. One paper reported on the use of basic reinforcement learning technology for optimizing mobile robot paths in a warehouse environment, aiming to understand the fundamental characteristics of different algorithms as a foundation for more complex studies [22]. Another study used Deep Q-Learning for both single and multi-robot navigation and obstacle avoidance in a 2D simulation, also addressing the problem of maximizing space for product placement using a strategic variation of Q-tables [29]. Finally, a research on optimizing a mobile robot delivery system used Deep Deterministic Policy Gradient (DDPG) combined with a spatial attention mechanism to help robots better recognize and avoid obstacles in complex environments, thereby improving the accuracy of navigation and path planning [11]. The characteristics of these navigation-focused studies are summarized in Table 3.

Table 3. Summary of Studies on Deep Reinforcement Learning for Mobile Robot Navigation and Path Planning

STUDY ID	PRIMARY ALGORITHM	ENVIRONMENT TYPE	KEY INNOVATION / APPROACH	REPORTED OUTCOME
[8]	Q-learning	Grid-map warehouse with aisles, inventory pods, and pick stations	Multi-robot path planning with congestion avoidance	Optimized travel time and distance; enhanced operational efficiency
[37]	Improved DQN (with prior knowledge and rules)	Unmanned warehouse dispensing system	Integration of prior knowledge to accelerate DQN convergence	Faster convergence than classic DRL; more efficient learning of path-planning solutions
[23]	PP-D (PPO + Dijkstra's)	Complex warehouse layouts	Combination of PPO for real-time decision-making and Dijkstra for global optimal planning	Outperformed traditional algorithms in navigation accuracy and robustness; minimized collisions and stagnation
[25]	Actor-Critic + Deep Learning Network	Dynamic and changing warehouse environments	Real-time turning angle calculation; self-learning of target execution sequence and travel speed	97.6% inspection success rate; significant reduction in energy consumption
[26]	DQN	Simulated warehouse (ROS, Gazebo) with moving obstacles	Integration of prebuilt SLAM map into DRL state space for enhanced spatial awareness	Agent reached goal ~150 times vs. ~80 times without map; faster convergence
[35]	UKF, CNN, FCN,	Dynamic hospital	Multi-sensor fusion	ATE of 0.067 m;

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STUDY ID	PRIMARY ALGORITHM	ENVIRONMENT TYPE	KEY INNOVATION / APPROACH	REPORTED OUTCOME
	EKF	environments	(vision, lidar, IMU) with deep learning for robust SLAM	>90% map overlap; <90 ms frame processing time
[19]	DDPG and PPO	Unstructured logistics areas (picking from a table)	Learned base controller for mobile manipulator using arm planner feedback	Comparison of DDPG and PPO performance
[36]	ROS Navigation Stack (various planners)	Warehouse and production floor	Low-cost AMR development; sensor and algorithm comparison study	Completion of a low-cost AMR prototype with navigation function
[14]	PRM-RL (RL + Sampling-based Planning)	Indoor office and urban environments	Hierarchical method for long-range navigation using RL-learned local policies and global PRM	Successful completion of 215 m indoor and 1000 m aerial trajectories; outperformed individual RL and planners
[22]	Basic RL algorithms (not specified)	Warehouse environment with automated logistics	Comparison of basic RL algorithms for path optimization	Foundation for understanding RL characteristics for complex path optimization
[29]	Deep Q-Learning	2D simulation	Multi-agent Q-learning with strategic variation of Q-tables for space optimization	Successful navigation and obstacle avoidance for single and multi-robot cases
[11]	DDPG + Spatial Attention	Complex and dynamically changing environments	Spatial attention mechanism to focus on key areas for obstacle recognition; end-to-end optimization	Significant enhancement in path planning accuracy, task execution efficiency, and system robustness

The diverse studies in this subsection collectively illustrate the central role of deep reinforcement learning in advancing mobile robot navigation for logistics automation. The research demonstrates a clear progression from applying foundational algorithms like Q-learning to more sophisticated hybrid systems that combine DRL with classical planning methods, map integration, and advanced sensor fusion. A common thread is the effort to enhance the robot's ability to handle dynamic obstacles and complex, high-dimensional state spaces, which are characteristic of real-world logistics environments. While many studies report success in simulation, the translation of these policies to physical hardware, a challenge known as the sim-to-real gap, remains an important topic for future work, with some studies like PRM-RL and the low-cost

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AMR development already demonstrating on-robot validation.

Integrated Deep Learning Systems for Warehouse Automation and Logistics

While much of the existing research focuses on specific sub-tasks such as grasping or navigation, a critical need exists for holistic systems that integrate multiple deep learning components to automate complete logistics workflows. These integrated systems combine perception, manipulation, navigation, and decision-making capabilities into a unified architecture, enabling end-to-end automation of complex tasks like order fulfillment, inventory management, and autonomous inspection. The studies in this category address the challenge of system-level integration, demonstrating how deep learning can serve as the backbone for intelligent, self-sufficient logistics operations.

A prominent example of such integration is the Smart Robotic Framework proposed for automated pick-and-place operations and real-time inventory management within Industry 4.0 environments [27]. This system combines a robotic arm with Internet of Things (IoT) sensors and a convolutional neural network (CNN)-based vision system for object recognition. The framework uses CNNs to classify and localize items within a simulated warehouse, while an IoT platform integrates radio-frequency identification (RFID) and sensor data to update inventory levels in real time. A cloud-based dashboard provides centralized control, anomaly detection, and predictive analytics for stock optimization. Experimental validation demonstrated enhanced accuracy of up to 95% in object classification, reduced operational time, and seamless inventory synchronization, illustrating the synergy between deep learning perception and real-time data integration for warehouse management.

Another significant work targets the precise control of robotic manipulators within a warehouse environment through a dual-loop optimal hierarchical control scheme [30]. This scheme consists of an outer kinematic control loop, which solves a closed-loop optimal control problem for trajectory generation using an analytic solution of the Hamilton–Jacobi–Bellman (HJB) equation, and an inner dynamic control loop, which employs a neural network (NN)-based adaptive critic optimal tracking control scheme. The NN approximator learns the infinite-horizon cost function related to the inner loop error dynamics and calculates the optimal control input to minimize this cost forward in time. The stability of the entire dual-loop system was proven theoretically via a Lyapunov approach and verified experimentally using a 7-DOF Barrett WAM robot manipulator in an exact warehouse setting. This approach results in smoother trajectories with cost-effective control inputs compared to state-of-the-art methods, making it a valuable component for integrated warehouse automation systems.

The integration of deep learning with simultaneous localization and mapping (SLAM) and sensor fusion has also been pursued to create robust navigation systems for logistics robots. One study proposed a navigation system for a logistics inspection robot that fuses vision and multi-line lidar information to achieve autonomous navigation and cruise in complex storage environments [34]. The fusion of these two sensor modalities ensures rich information and accurate map edges while meeting the real-time and accurate positioning and navigation requirements of a complex logistics storage scenario. Simulation and practical verification demonstrated that the robot

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navigation system was feasible and robust, successfully overcoming problems of low precision, poor robustness, weak portability, and difficult expansion that plague single-sensor mobile robot systems. Similarly, a path planning method for agricultural logistics warehouse management was introduced, which combined SLAM with deep vision computing [12]. In this system, SLAM technology enables autonomous robot positioning within the warehouse by using LiDAR and sensors to detect surroundings and create detailed maps in real time. Deep vision computing is then employed for object recognition and analysis within the warehouse environment. The robot path is optimized using the SORF technique, with an adaptive weighting pooling layer for robot position-sensitive areas. Experimental results confirmed that this method outperforms standard approaches in terms of accuracy and efficiency in path planning.
The most demanding testbeds for integrated systems have been the Amazon Robotics Challenge (ARC) competitions, which required complete automation of stowing, picking, and packing tasks. Team Delft's entry in the 2016 ARC won the competition by integrating an industrial robot arm, 3D cameras, and a custom gripper [20]. The software architecture, built upon the Robot Operating System (ROS), combined deep learning solutions for object recognition with other state-of-the-art AI techniques for grasping, motion planning, and task planning. A key lesson from this development was the importance of characterizing solutions based on "levels of robot automation," which refers to the extent to which information is used at design time versus runtime to drive robot behavior. The team concluded that specific task conditions should guide the selection of solutions for each capability, and that understanding the characteristics and embedded assumptions of individual solutions is critical for integrating them into a high-performing system [13]. Team NimbRo Picking achieved second place in both the picking task and the final stow-and-pick task at the 2017 ARC [40]. Their system featured a deep object perception pipeline that could be quickly and efficiently adapted to new items using transfer learning with a custom turntable capture system, producing high-quality item segments for grasp pose finding. A planning component coordinated manipulation actions between two robot arms to minimize execution time, showcasing a successful integration of perception, manipulation, and task-level coordination for cluttered environments [33].
Beyond these competition systems, other works have explored integration for specific logistics functions. A study on grasping for stacking proposed a model-free deep Q-learning method to learn a grasping-stacking strategy end-to-end from scratch [40]. This method uses two deep networks: a Grasping Network (GNet) that processes observations of the desk and pile to infer the gripper's position and orientation for grasping, and a Stacking Network (SNet) that uses observations of the platform to infer the optimal location for placing the grasped object. These two networks are integrated into a Grasping for Stacking Network (GSN) to enable long-range planning, and the system was evaluated on grasping-stacking tasks in both simulated and real-world scenarios.
The integration of deep learning with broader logistics systems has also been addressed from a sustainability perspective. An AI-powered Drones and Autonomous Vehicles (AI-DAV) Framework was proposed for autonomous logistics in supply chain management, targeting enhancements in efficiency, speed, and accuracy [38]. This framework integrates AI-driven route planning, real-time traffic management,

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and IoT-based tracking to optimize the operations of drones for small package deliveries in urban areas and autonomous ground vehicles for bulk transportation. The framework also incorporates robotics for warehouse inventory handling and order fulfillment. Findings from this study suggest that the AI-DAV framework significantly reduces delivery time, operational costs, and carbon emissions while increasing accuracy and scalability in logistics operations, demonstrating a direct connection between integrated deep learning systems and sustainability outcomes.

Furthermore, a study focusing on logistics automation investigated the use of a 2D Convolutional Neural Network (2D-CNN) for predicting robot position based on raw sensor data from accelerometers, gyroscopes, and magnetometers [17]. The research, conducted within a controlled internal logistics precinct, involved meticulous data preprocessing including synchronization and calibration to derive essential parameters for predictive modeling. The 2D-CNN architecture was employed for its ability to extract intricate spatial features from the sensor data, and training was guided by a custom-tailored Asymmetric Gaussian loss function. The approach achieved remarkably low mean squared errors in predicting robot positions, demonstrating the potential of deep learning for robust state estimation in integrated logistics systems [10]. The characteristics of these integrated system studies are systematically summarized in Table 4.

Table 4. Summary of Studies on Integrated Deep Learning Systems for Warehouse Automation and Logistics

STUDY ID	PRIMARY DEEP LEARNING COMPONENTS	INTEGRATION APPROACH	CORE TASK(S)	REPORTED OUTCOME
[27]	CNN for object recognition, IoT platform, predictive analytics	Cloud-based dashboard for centralized control and anomaly detection	Pick-and-place and real-time inventory management	95% object classification accuracy; reduced operational time; seamless inventory synchronization
[30]	NN-based adaptive critic optimal tracking control	Dual-loop optimal hierarchical control (outer kinematic, inner dynamic)	Robot manipulator trajectory and actuator control	Smoother trajectories; cost-effective control inputs; stability proven via Lyapunov approach
[34]	Vision and multi-line lidar deep feature extraction	Multi-sensor fusion for navigation	Autonomous navigation and cruise of inspection robot in complex storage	Feasible and robust navigation system; overcomes problems of low precision and poor robustness
[12]	Deep vision computing, SLAM, SORF optimization	SLAM for positioning, deep vision for object recognition, SORF for path optimization	Path planning for agricultural logistics warehouse management	Outperforms standard methods in accuracy and efficiency of path planning

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STUDY ID	PRIMARY DEEP LEARNING COMPONENTS	INTEGRATION APPROACH	CORE TASK(S)	REPORTED OUTCOME
[13]	Deep learning for object recognition, AI for grasping, motion, and task planning	Unified system integration based on "levels of robot automation"	Pick-and-place in semistructured warehouse shelves	Winner of the Amazon Robotics Challenge 2016; identified key integration lessons
[33]	Deep object perception pipeline, transfer learning, dual-arm coordination planner	Integration of perception, grasp planning, and task coordination	Stowing, picking, and packing in cluttered bins	2nd place in ARC 2017 picking and stow-and-pick tasks
[40]	GNet (grasping network), SNet (stacking network), GSN (grasping for stacking network)	End-to-end deep Q-learning for grasping-stacking	Grasping-stacking tasks	Evaluated in both simulated and real-world scenarios
[38]	Machine learning for route planning, IoT-based tracking, automated navigation	AI-DAV framework integrating drones, autonomous ground vehicles, and warehouse robotics	Last-mile delivery, warehouse operations, route planning	Significant reduction in delivery time, operational costs, and carbon emissions
[10]	2D-CNN with Asymmetric Gaussian loss function	Sensor data preprocessing (synchronization, calibration) and predictive modeling	Robot position prediction from accelerometer, gyroscope, and magnetometer data	Remarkably low mean squared errors in predicting robot positions

Discussion

The synthesis of findings from this systematic review reveals a rapidly maturing yet still fragmented research landscape at the intersection of deep learning, smart serving robots, and sustainable supply chain automation. Taken together, the evidence across the 34 included studies paints a picture of significant technological progress, particularly in the domains of perception for grasping and deep reinforcement learning for navigation, but also exposes critical gaps in the integration of sustainability metrics and the validation of these systems in real-world, large-scale logistics operations. The patterns that emerge across the literature consistently point to deep learning as a transformative enabler for robot autonomy, yet the path from algorithmic innovation to holistic, sustainable deployment remains fraught with challenges that the research community has only begun to address.

A central finding that emerges across the reviewed studies is the clear division of labor between two primary deep learning paradigms. On one hand, supervised learning, particularly through convolutional neural networks, has become the de facto standard for perception and manipulation tasks. The success of systems in the Amazon Robotics Challenge, such as those developed by Team Delft [17] and Team

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NimbRo [32], demonstrates that deep learning-based object recognition and pose estimation can achieve the reliability required for industrial-grade picking. The ability to train these models on synthetic data, as shown in the bin-picking system that achieved a 97.5% success rate [20], and to leverage transfer learning for rapid adaptation to new items [33], are particularly promising developments. These findings suggest that the bottleneck for perception in logistics is no longer the accuracy of the algorithms themselves, but rather the availability of diverse, high-quality training data and the robustness of these models to the wide variability of real-world warehouse conditions, including lighting changes, occlusions, and product damage. The introduction of large-scale benchmarks like ARMBench [28] is a crucial step toward standardizing evaluation and driving further progress in this area.

On the other hand, deep reinforcement learning has emerged as the dominant paradigm for navigation and path planning, where the objective is not to recognize a static object but to learn a sequential decision-making policy in a dynamic environment. The studies in this domain show a clear progression from foundational algorithms like Q-learning [8] to more sophisticated hybrid approaches that combine DRL with classical planning methods. The Proximal Policy-Dijkstra (PP-D) method [23] and the PRM-RL hierarchical framework [14] are exemplary in this regard, as they leverage the strengths of both learning-based and model-based approaches. The PP-D method uses PPO for real-time, reactive decision-making while relying on Dijkstra's algorithm for global optimality, effectively addressing the exploration-exploitation dilemma in complex warehouse layouts. Similarly, PRM-RL decouples the problem into learning short-range, dynamics-aware local policies and then using a sampling-based planner to connect these policies for long-range navigation, a strategy that proved effective for trajectories spanning hundreds of meters. This trend toward hybrid architectures is a consistent and important finding, as it suggests that pure end-to-end DRL, while powerful, may not be the most practical or sample-efficient approach for the large-scale, structured environments typical of logistics. The integration of prior knowledge, such as prebuilt SLAM maps [26] or the structure of the environment, appears to be a critical factor in improving learning stability and convergence speed.

However, a significant contradiction emerges when examining the treatment of sustainability across the literature. While many studies claim to contribute to sustainable logistics, the evidence for this claim is often superficial. A substantial number of papers mention sustainability only in their introduction or conclusion as a broad motivation, without providing any quantitative metrics or specific design considerations related to energy consumption, carbon footprint, waste reduction, or lifecycle analysis. This pattern is particularly evident in the perception and manipulation studies, where the primary focus is on improving grasping success rates or computation time, with energy efficiency being a secondary or unmeasured outcome. For example, while the deep learning-based motion planning system that reduced computation time by 300× [18] implicitly contributes to energy savings by reducing the time the robot arm is active, the study does not measure or report the actual energy consumed. Similarly, the logistics sorting algorithm based on enhanced YOLOv3 [15] claims to support the establishment of intelligent logistics factories, but the link to sustainability is asserted rather than demonstrated. This superficial

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treatment is a critical gap, as it prevents a holistic assessment of the true value of these technologies. A robot that picks items faster but consumes significantly more energy may not be a net positive for sustainability, especially when considering the embodied energy in the hardware and the computational resources required for deep learning inference.

In contrast, a smaller subset of studies provides more substantive engagement with sustainability. The Actor-Critic-based path planning scheme that reported a 97.6% success rate and a significant reduction in energy consumption [25] is a notable example, as it explicitly includes energy as an optimization objective. The AI-DAV framework [31] is another important case, as it provides quantitative evidence of reduced carbon emissions alongside improvements in delivery time and operational costs. The work on the CNN-based image recognition model for arbitrarily shaped objects [24] is also noteworthy for grounding its research in the theory of sustainable development and explicitly aiming for energy conservation and emission reduction. These studies, while fewer in number, demonstrate that it is both possible and valuable to integrate sustainability metrics into the design and evaluation of deep learning-enabled logistics robots. The inconsistency in how sustainability is addressed across the field has important implications for both research and practice. For practitioners, it makes it difficult to compare the true cost and benefit of different automation solutions. For researchers, it highlights a need for standardized sustainability benchmarks and reporting guidelines.

The implications of these findings are multifaceted. From a theoretical perspective, the synthesis of this literature contributes to a more nuanced understanding of the role of deep learning in logistics automation. The evidence suggests that deep learning is not a monolithic solution but rather a set of tools that must be carefully matched to the specific task and environment. The success of hybrid architectures that combine learning with classical planning or prior knowledge challenges the notion that end-to-end deep learning is always the superior approach. This has implications for how we conceptualize robot autonomy; rather than a binary state of being autonomous or not, the findings support a more graduated view, where different levels of automation are appropriate for different sub-tasks, as was explicitly argued by the Team Delft researchers [13]. Furthermore, the superficial treatment of sustainability in most studies suggests that the theoretical frameworks used to evaluate these systems are incomplete. There is a need for conceptual models that explicitly link technical performance metrics (e.g., grasp success rate, path length) to sustainability outcomes (e.g., energy per pick, carbon per delivery) in a quantifiable way.

From a practical perspective, the findings offer several actionable insights for industry practitioners and policymakers. First, the maturity of deep learning for perception and grasping suggests that these technologies are ready for wider deployment in warehouse picking, particularly for tasks involving a moderate variety of products. The availability of synthetic data generation and transfer learning techniques reduces the barrier to entry for companies that do not have access to massive labeled datasets. Second, the success of DRL for navigation, especially when combined with classical planners, indicates that AMRs can be effectively deployed in dynamic warehouse environments, but careful attention must be paid to the sim-to-real gap. Companies should invest in robust simulation environments for training and testing before

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deploying policies on physical hardware. Third, and most critically, practitioners should demand and prioritize sustainability metrics when evaluating automation solutions. The few studies that have measured energy consumption or carbon emissions demonstrate that these metrics are not only measurable but can be directly optimized. Policymakers and industry consortia could play a crucial role by developing and promoting standardized sustainability benchmarks for logistics robotics, similar to how the Amazon Picking Challenge standardized performance evaluation for picking tasks.

Despite the rigorous methodology employed in this systematic review, several limitations must be acknowledged. The search was limited to English-language publications, which may have introduced a language bias and excluded relevant research published in other languages, particularly from countries with strong robotics and logistics research communities like China, Japan, and Germany. While we attempted to mitigate this by including arXiv preprints, the scope of the review is inherently constrained by the databases and search engines we selected. Although we used seven major databases, it is possible that some relevant studies, particularly those published in niche or industry-specific journals, were not captured. The inclusion criteria requiring a substantive discussion of sustainability were necessary for the focus of this review, but this decision may have excluded technically excellent studies that simply did not frame their results in sustainability terms. This could have skewed our sample towards studies that are more likely to report positive sustainability outcomes, potentially introducing a form of reporting bias. Furthermore, the quality assessment of the included studies, while performed independently by two reviewers, is inherently subjective. The exclusion of studies based on insufficient methodological detail may have inadvertently excluded some valuable preliminary or exploratory research that could have provided different insights. Finally, the heterogeneity of the included studies in terms of their focus, metrics, and experimental setups precluded a quantitative meta-analysis, limiting our synthesis to a narrative form.

The gaps and inconsistencies uncovered in this review point to several promising directions for future research. There is a clear and urgent need for the development and adoption of standardized evaluation frameworks that integrate both operational performance and sustainability metrics. Future research should explore the creation of a common benchmark, perhaps modeled after the Amazon Picking Challenge but extended to include energy consumption, carbon footprint, and lifecycle cost as core evaluation criteria. Such a benchmark would enable direct comparison of different approaches and incentivize the development of algorithms that are not only fast and accurate but also energy-efficient. Understudied areas include the application of deep learning for multi-robot collaborative systems in logistics. While several studies addressed multi-robot path planning [8] [37], the coordination of heterogeneous robot fleets—combining, for example, a robotic arm for picking with an AMR for transport and a drone for inventory monitoring—remains a largely open challenge. Future research should explore how deep learning can be used to learn collaborative policies for such heterogeneous teams, optimizing for system-level throughput and energy efficiency rather than individual robot performance.

Another critical area for future work is the sim-to-real gap. While many studies report impressive results in simulation, the number of studies that validate their methods on

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physical hardware in realistic logistics environments is still limited. Future research should prioritize the development of techniques that improve the transferability of learned policies from simulation to reality, such as domain randomization, system identification, and robust control methods. There is also a need for more research on the long-term operational reliability and safety of deep learning-enabled robots in logistics. Most studies evaluate performance over a limited number of trials or episodes, but the real-world deployment of these systems requires consistent performance over thousands of hours of operation. Investigating the robustness of deep learning models to sensor drift, hardware wear, and changing environmental conditions over extended periods is a crucial next step. Finally, the human-robot interaction dimension is largely absent from the reviewed literature. As robots are deployed alongside human workers in warehouses and delivery settings, understanding how to design deep learning systems that are safe, predictable, and intuitive for humans to work with is of paramount importance. Future research should explore how deep learning can be used to model human behavior and intent, enabling robots to anticipate and adapt to human actions in shared workspaces, thereby improving both safety and efficiency.

Conclusion

This systematic review synthesized 34 studies to map the landscape of deep learning-enabled smart serving robots for sustainable supply chain and logistics automation. Our analysis confirms that deep learning, particularly convolutional neural networks for perception and deep reinforcement learning for navigation, has fundamentally advanced robot autonomy in warehouse picking and mobile robot path planning. The evidence consistently demonstrates improvements in task completion rates, path planning efficiency, and grasping accuracy. However, we also identified a critical and persistent gap: sustainability outcomes are addressed superficially across the majority of the literature, with few studies providing quantitative metrics for energy consumption, carbon emissions, or lifecycle impacts. This finding challenges the prevailing narrative that deep learning-enabled automation inherently contributes to sustainability.

The practical implications of our work are twofold. For industry practitioners, the maturity of deep learning for perception and grasping suggests these technologies are ready for wider deployment, but the selection of automation solutions should be guided by explicit sustainability criteria rather than performance metrics alone. For researchers, our synthesis highlights the urgent need for standardized evaluation frameworks that integrate operational efficiency with environmental impact. The theoretical contribution of this review lies in its systematic mapping of the field, revealing that the path to truly sustainable logistics automation requires not only algorithmic innovation but also a fundamental reorientation of how success is measured.

Future research should prioritize three directions. First, the development of common benchmarks that include energy consumption and carbon footprint as core evaluation criteria, modeled after the Amazon Picking Challenge but extended to sustainability metrics. Second, the exploration of multi-robot collaborative systems where deep learning coordinates heterogeneous robot fleets to optimize system-level throughput

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and energy efficiency. Third, the investigation of techniques to bridge the sim-to-real gap, ensuring that policies trained in simulation transfer reliably to physical hardware in long-term, real-world logistics operations. Addressing these gaps will be essential for advancing the field toward its stated goal of sustainable, intelligent logistics automation.

References

EH Grosse, CH Glock & WP Neumann (2017) Human factors in order picking: a content analysis of the literature. *International Journal of Production Research*.

B Ferreira & J Reis (2023) A systematic literature review on the application of automation in logistics. *Logistics*.

H Nguyen & H La (2019) Review of deep reinforcement learning for robot manipulation. In *IEEE International Conference on Robotics and Automation*.

HS Fang, C Wang, M Gou & C Lu (2020) Graspnet-1billion: A large-scale benchmark for general object grasping. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*.

H Jiang, H Wang, WY Yau, et al. (2020) A brief survey: Deep reinforcement learning in mobile robot navigation. In *IEEE International Conference on Control, Automation, Robotics and Vision*.

ET Pereira, MN Shafique, H Vieira, P Costa, et al. (2026) A Systematic Literature Review of Digital Supply Chains and Logistics 4.0 for Sustainability and Circular Economy. ….

MJ Page, JE McKenzie, PM Bossuyt, et al. (2021) The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372:n71.

Muhammad Shahab Alam, Muhammad Umer Khan & Ahmet Gunes (2024) Reinforcement Learning-Based Multi-Robot Path Planning and Congestion Management in Warehouse Order Picking.

Richard Bormann, B. Brito, Jochen Lindermayr, Marco Omainska & Mayank Patel (2019) Towards Automated Order Picking Robots for Warehouses and Retail. In *International Conference on Virtual Storytelling*, pages 185-198.

Change Che, Bo Liu, Shulin Li, Jiaxin Huang & Hao Hu (2023) Deep Learning for Precise Robot Position Prediction in Logistics. *Journal of Theory and Practice of Engineering Science*.

Xiaoyang Chen, Yunxiang Gan & Shuguang Xiong (2024) Optimization of Mobile Robot Delivery System Based on Deep Learning. *Journal of Computer Science Research*.

X Cheng & C Wang (2024) A SLAM and deep vision computing-based robotic path planning method for agricultural logistics warehouse management. *Pak J Agric Sci*.

C. H. Corbato, M. Bharatheesha, Jeff van Egmond, Jihong Ju & M. Wisse (2018) Integrating Different Levels of Automation: Lessons From Winning the Amazon Robotics Challenge 2016. *IEEE Transactions on Industrial Informatics*, 14:4916-4926.

Aleksandra Faust, Oscar Ramirez, Marek Fiser, Kenneth Oslund, Anthony G. Francis, James Davidson & Lydia Tapia (2017) PRM-RL: Long-range Robotic

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Navigation Tasks by Combining Reinforcement Learning and Sampling-Based Planning. *2018 IEEE International Conference on Robotics and Automation (ICRA)*.

C. Feng (2024) Design of Logistics Sorting Algorithm Based on Deep Learning and Sampling Evaluation. *International Journal of Computational Intelligence Systems*, 17.

Z Han (2023) Multimodal intelligent logistics robot combining 3D CNN, LSTM, and visual SLAM for path planning and control. *Frontiers in Neurorobotics*.

Carlos Hernandez, M. Bharatheesha, W. Ko, H. Gaiser, Jethro Tan, K. V. Deurzen, M. D. Vries, B. V. Mil, J. V. Egmond, R. Burger, Mihai Morariu, Jihong Ju, Xander Gerrmann, Ronald M. Ensing, J. Frankenhuyzen & M. Wisse (2016) Team Delft's Robot Winner of the Amazon Picking Challenge 2016. In *Robot Soccer World Cup*, pages 613-624.

Jeffrey Ichnowski, Yahav Avigal, V. Satish & Ken Goldberg (2020) Deep learning can accelerate grasp-optimized motion planning. *Science Robotics*, 5.

A. Iriondo, E. Lazkano, L. Susperregi, Julen Urain, A. Fernandez & Jorge Molina (2019) Pick and Place Operations in Logistics Using a Mobile Manipulator Controlled with Deep Reinforcement Learning. *Applied Sciences*.

P Jiang, Y Ishihara, N Sugiyama, J Oaki, S Tokura, et al. (2020) Depth image–based deep learning of grasp planning for textureless planar-faced objects in vision-guided robotic bin-picking. *Sensors*.

Michael Laskey, Jonathan Lee, Caleb Chuck, David V. Gealy, Wesley Yu-Shu Hsieh, Florian T. Pokorny, A. Dragan & Ken Goldberg (2016) Robot grasping in clutter: Using a hierarchy of supervisors for learning from demonstrations. *2016 IEEE International Conference on Automation Science and Engineering (CASE)*.

Hyeoksoo Lee & Jongpil Jeong (2021) Mobile Robot Path Optimization Technique Based on Reinforcement Learning Algorithm in Warehouse Environment. *Applied Sciences*, 11:1209.

Keqin Li, Lipeng Liu, Jiajing Chen, De-Hua Yu, Xiaofan Zhou, Ming Li, Congyu Wang & Zhao Li (2024) Research on Reinforcement Learning Based Warehouse Robot Navigation Algorithm in Complex Warehouse Layout. *2024 6th International Conference on Artificial Intelligence and Computer Applications (ICAICA)*.

H Liu, L Zhou, J Zhao, F Wang, J Yang, K Liang & Z Li (2022) Deep-learning-based accurate identification of warehouse goods for robot picking operations. *Sustainability*.

Yifan Liu (2025) Research on Path Planning of Intelligent Robots Based on Deep Reinforcement Learning.

Himandi Medagangoda, N. Jayawickrama, Rajitha De Silva, U. Rajapaksha & P. Abeygunawardhana (2025) Deep Q-Network-Based Path Planning in a Simulated Warehouse Environment with SLAM Map Integration and Dynamic Obstacles. *Journal of Robotics and Control (JRC)*.

P Meenalochini (2026) Smart Robotic Framework for Automated Pick-and-Place and Real-Time Inventory Management in Industry 4.0 Environments. researchgate.net.

Online ISSN 3007-3197
Print ISSN 3007-3189

Chaitanya Mitash, Fan Wang, Shiyang Lu, Vikedo Terhuja, T. Garaas, F. Polido & M. Nambi (2023) ARMBench: An Object-centric Benchmark Dataset for Robotic Manipulation. *2023 IEEE International Conference on Robotics and Automation (ICRA)*.

Ismot Sadik Peyas, Z. Hasan, Md. Rafat Rahman Tushar, Al Musabbir, Raisa Mehjabin Azni & Shahnewaz Siddique (2021) Autonomous Warehouse Robot using Deep Q-Learning. *TENCON 2021 - 2021 IEEE Region 10 Conference (TENCON)*.

Ravi Prakash, L. Behera, S. Mohan & S. Jagannathan (2020) Dual-Loop Optimal Control of a Robot Manipulator and Its Application in Warehouse Automation. *IEEE Transactions on Automation Science and Engineering*, 19:262-279.

D Sayfullaev, ZA Balsem, AA Majeed, et al. (2025) Autonomous Logistics: The Role of Artificial Intelligence, Drones, And Robotics In Supply Chain Management. In *2025 International Conference on Artificial Intelligence, Drones, and Robotics in Supply Chain Management*.

M Schwarz, A Milan, C Lenz, A Munoz, et al. (2017) Nimbro picking: Versatile part handling for warehouse automation. In *International Conference on Robotics and Automation*.

Max Schwarz, Christian Lenz, Germán Martín García, Seongyong Koo, Arul Selvam Periyasamy, M. Schreiber & Sven Behnke (2018) Fast Object Learning and Dual-arm Coordination for Cluttered Stowing, Picking, and Packing. *2018 IEEE International Conference on Robotics and Automation (ICRA)*.

Simranjeet Singh, Yi Li, Markus Grotz, Michaela Wolf, Dieter Fox & Joshua R. Smith (2024) OptiGrasp: Optimized Grasp Pose Detection Using RGB Images for Warehouse Picking Robots. *2025 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*.

F Xiao, J Fang, X Guo, Y Zhang & R Huang (2025) Enhanced dynamic visual SLAM system for hospital logistics robots: Nonlinear optimal filtering, deep learning, and real-time positioning. *Robotics and Autonomous Systems*.

OW Xuan, H Selamat & MT Muslim (2023) Autonomous mobile robot for transporting goods in warehouse and production. In *International Conference on Intelligent Manufacturing and Robotics*.

Y Yang, L Juntao & P Lingling (2020) Multi-robot path planning based on a deep reinforcement learning DQN algorithm. *CAAI Transactions on Intelligence Technology*.

J Yoon, J Han & TP Nguyen (2023) Logistics box recognition in robotic industrial de-palletising procedure with systematic RGB-D image processing supported by multiple deep learning methods. *Engineering Applications of Artificial Intelligence*.

Andy Zeng, Kuan-Ting Yu, Shuran Song, Daniel Suo, Ed Walker, Alberto Rodriguez & Jianxiong Xiao (2016) Multi-view self-supervised deep learning for 6D pose estimation in the Amazon Picking Challenge. *2017 IEEE International Conference on Robotics and Automation (ICRA)*.

Jun-hang Zhang, Wei Zhang, Ran Song, Ling-guo Ma & Yibin Li (2020) Grasp for Stacking via Deep Reinforcement Learning. *2020 IEEE International*

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
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Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Conference on Robotics and Automation (ICRA).

Yang Zhang, Yanjun Zhou, Hehua Li, Hao Hao, Weijiong Chen & Weiwei Zhang (2022) The Navigation System of a Logistics Inspection Robot Based on Multi-Sensor Fusion in a Complex Storage Environment. *Sensors (Basel, Switzerland)*, 22.