Cureus Journal of Business and Economics
https://doi.org/10.7759/s44404-026-00079-z

Review Article

Artificial Intelligence in Logistics 4.0: A Systematic Review of Process-Level Impacts

Eric Sucky [1] , Zhiyi Guan [2,]

1. *Chair of Operations Management and Logistics, Faculty of Social and Economic Sciences, University of Bamberg, Bamberg, DEU*
2. *Faculty of Economics, University of Göttingen, Göttingen, DEU*

Received: February 17, 2026 | Review began: February 18, 2026 | Review ended: April 29, 2026 | Published: May 21, 2026

Abstract

Artificial intelligence (AI) has emerged as a key technology for Logistics 4.0. AI enables the digital transformation of logistics processes through automation, data-driven decision-making, and real-time optimization. Although a growing body of research examines AI applications in logistics, the existing findings are fragmented across functional areas and technologies. This systematic literature review uses the PRISMA methodology to synthesize recent research and evaluate the impact of AI on modern-day logistics. The results demonstrate that AI significantly enhances seven core areas: cost, automation, route optimization, warehouse management, customer service, sustainability, and risk management. AI improves the efficiency, resilience, and responsiveness of logistics systems by enabling predictive analytics and real-time monitoring. This study provides a comprehensive, process-oriented framework of AI applications and highlights critical research gaps in scalability, data integration, energy efficiency, and workforce adaptation. These findings offer practical insights for practitioners and a strategic roadmap for future research on AI-driven logistics.

Categories: Logistics Management, Strategic Supply Chain Management

Keywords: artificial intelligence, logistics 4.0, systematic literature review, digital transformation, supply chain management

Introduction And Background

Global logistics systems are undergoing a profound transformation due to increasing market volatility, rising customer expectations, sustainability pressures, and rapid technological advancements. Traditional logistics models, which are characterized by linear processes and reactive decision-making, are unable to cope with the complexity, speed, and interconnectedness of contemporary supply chains. Consequently, logistics is evolving toward a digitally enabled, data-intensive, and highly integrated system, often referred to as Logistics 4.0 (Winkelhaus and Grosse, 2020). Building upon the principles of Industry 4.0, Logistics 4.0 emphasizes the integration of cyber-physical systems, real-time data exchange, automation, and intelligent decision support across logistics processes (Amr et al., 2019). Instead of focusing solely on technological innovation, Logistics 4.0 represents a comprehensive transformation of logistics systems that encompasses processes, organizational structures, and human-technology interaction. This transformation reflects a broader shift toward digital transformation, in which digital technologies fundamentally reshape how organizations create value, coordinate activities, and respond to environmental change.

In this context, artificial intelligence (AI) has emerged as a pivotal enabling technology. AI encompasses computational techniques, such as machine learning, deep learning, optimization algorithms, and intelligent agents, that allow systems to learn from data, recognize patterns, and adapt independently to changing conditions. In logistics, AI is increasingly applied in areas such as demand forecasting, transportation planning, warehouse automation, inventory optimization, predictive maintenance, and customer service (Zhang, 2019). AI's relevance in logistics is closely linked to the exponential growth of logistics-related data. Sensors, the Internet of Things (IoT) devices, enterprise systems, and digital platforms continuously generate large volumes of structured and unstructured data. AI technologies provide the analytical capabilities required to transform this data into actionable insights and operational decisions. Thus, AI is a core mechanism through which digital transformation occurs at the process level in logistics.

Despite its transformative potential, AI adoption in logistics remains uneven and challenging. Organizations face significant technical barriers, including data integration across heterogeneous systems, limited interoperability, cybersecurity risks, and high implementation costs. Organizational challenges, such as skill shortages, resistance to change, and uncertainty regarding return on investment, further complicate AI implementation (Al Suwaidi et al., 2022). Additionally, the growing automation of logistics processes raises concerns about workforce displacement, ethical responsibility, and governance.

From an academic perspective, research on AI in logistics has expanded rapidly over the past decade, with significant advancements being made in various fields, including machine learning, natural language processing, and robotics. However, existing studies often focus on isolated applications, specific algorithms, or narrow operational contexts. Consequently, the literature remains fragmented, lacking an integrative perspective that connects AI applications to broader theoretical frameworks, such as Logistics 4.0 and digital transformation. There is limited synthesis, in particular, of how AI contributes to the structural, organizational, and processual transformation of logistics systems.

Despite the growing number of studies, the current body of literature still exhibits several important limitations that justify further investigation. First, prior research predominantly analyzes AI applications within single functional domains, such as transportation or warehousing, without systematically addressing interdependencies across end-to-end logistics processes. Second, many contributions emphasize technological capabilities while neglecting the broader socio-technical implications of AI adoption within Logistics 4.0 systems. Third, existing reviews often lack a process-oriented perspective and do not explicitly link AI-driven applications to the overarching logic of digital transformation. As a result, there is still an insufficient understanding of how AI holistically reshapes logistics systems beyond isolated efficiency improvements. This creates a critical research gap, as both scholars and practitioners require a comprehensive and theory-informed synthesis that integrates AI applications across processes and connects them to the fundamental transformation of logistics systems. Therefore, this study is needed to provide a structured and integrative analysis of AI-driven process transformations and to identify overarching patterns, challenges, and future research directions within the Logistics 4.0 paradigm.

This study addresses this gap by conducting a systematic literature review of recent research on AI-driven logistics processes. By embedding AI applications within the theoretical frameworks of Logistics 4.0 and digital transformation, the study aims to deepen our understanding of the role of AI in reshaping logistics systems. The guiding research question is: How does AI enable and transform logistics processes within the Logistics 4.0 framework?

The remainder of this paper is structured as follows. First, the theoretical foundations of Logistics 4.0 and digital transformation are outlined to establish the conceptual framework for the analysis. Next, the research methodology is described, including the systematic literature review approach, search strategy, and selection criteria. This is followed by the presentation of the results, which are organized according to core logistics processes and key application areas of AI. Subsequently, the findings are discussed in light of existing theoretical perspectives, highlighting implications for both research and practice. Finally, the paper concludes with a summary of the main insights, identifies limitations, and proposes directions for future research.

Theoretical foundations

Logistics 4.0 as a Socio-technical System

Logistics 4.0 applies the principles of Industry 4.0 to logistics activities, emphasizing connectivity, automation, transparency, and intelligence throughout logistics systems. Instead of being a purely technological upgrade, Logistics 4.0 is a socio-technical system in which technological components, organizational structures, and human actors are deeply interrelated (Winkelhaus and Grosse, 2020). Technologically, Logistics 4.0 relies on the integration of IoT devices, cyber-physical systems, cloud and edge computing, and advanced analytics. These technologies enable real-time monitoring of logistics assets, continuous data exchange, and automated process execution. At the organizational level, Logistics 4.0 necessitates new forms of coordination, cross-functional integration, and process orientation (Dallasega et al., 2022). Human actors remain central to this system, particularly in roles involving supervision, exception handling, and strategic decision-making. A defining characteristic of Logistics 4.0 is the shift from reactive to proactive and predictive logistics management. Traditional logistics systems typically respond to disruptions after they occur. In contrast, Logistics 4.0 systems use predictive analytics and real-time data to anticipate demand fluctuations, equipment failures, and transportation disruptions. This enables pre-emptive action. AI plays a crucial role in enabling this shift by providing the analytical and decision-making capabilities required to process complex, dynamic data environments. Without AI, the volume, velocity, and variety of logistics data would exceed human cognitive capacity, thereby limiting the effectiveness of digitalization initiatives.

Digital Transformation in Logistics

Digital transformation refers to the process through which digital technologies fundamentally reshape organizational processes, structures, and value creation mechanisms (Vial, 2019) (Konopik et al., 2022). In logistics, digital transformation involves more than adopting individual technologies; it also requires reconfiguring end-to-end processes, decision-making authority, and performance measurement systems (Kern, 2021).

A key feature of digital transformation in logistics is process integration. Digital technologies enable the horizontal integration of logistics activities across organizational boundaries, as well as the vertical integration of strategic, tactical, and operational decision-making processes (Cichosz et al., 2020). While this integration increases transparency and coordination, it also introduces new complexities related to data governance and system interoperability. AI contributes to digital transformation by enabling higher levels of automation and intelligence within logistics processes. Rather than merely digitizing existing workflows, AI creates fundamentally new ways of organizing logistics activities. Examples include autonomous planning systems, self-optimizing warehouses, and predictive transportation networks.

Role of AI within Logistics 4.0

In the context of Logistics 4.0, AI can be viewed as a cognitive layer that converts data into decisions and actions. AI systems analyze real-time and historical data to identify patterns, generate predictions, and recommend or execute operational decisions. This capability is essential for navigating the complexity and uncertainty of ever-evolving logistics environments (Boute and Udenio, 2022). AI also supports the evolution of logistics systems toward higher levels of maturity. While early stages of digitalization focus on data collection and visibility, advanced stages involve predictive analytics, autonomous decision-making, and self-learning systems. AI enables this progression by continuously improving performance through learning and adaptation. From a theoretical perspective, AI can be viewed as a dynamic capability that allows logistics organizations to sense changes in their environment, seize opportunities through adaptive decision-making, and reconfigure resources in response to evolving conditions.

Review

This study uses the systematic literature review (SLR) methodology to examine the impact of AI on logistics processes within the Logistics 4.0 framework. The choice of an SLR is motivated by the fragmented and multidisciplinary nature of existing AI-driven logistics research. Studies in this field span logistics and supply chain management, operations research, information systems, and computer science. These studies often employ heterogeneous conceptualizations, methods, and analytical perspectives. An SLR allows for the structured synthesis of this diverse body of knowledge by applying transparent, replicable, and theory-informed procedures (Tranfield et al., 2003). Unlike narrative or integrative reviews, SLRs minimize subjective bias and facilitate the systematic identification of dominant research streams, methodological patterns, and knowledge gaps. This is particularly relevant in the context of Logistics 4.0, where rapid technological development risks outpacing conceptual consolidation. This review follows the methodological framework proposed by Denyer and Tranfield (Denyer and Tranfield, 2009). They conceptualize literature reviews as a structured research process consisting of five phases: (1) formulation of research questions, (2) identification of relevant studies, (3) selection and evaluation of studies, (4) analysis and synthesis of findings, and (5) reporting of results. Due to the exploratory nature of AI applications in logistics and the evolving theoretical foundations of Logistics 4.0, the review employs a scoping-oriented SLR design. This approach prioritizes comprehensive coverage and thematic mapping over narrow hypothesis testing. This design is particularly suitable for identifying emerging patterns, conceptual linkages, and future research directions in the context of digital transformation.

Search strategy and study selection

To ensure theoretical coherence, the review is explicitly framed by the concepts of Logistics 4.0 and digital transformation. Rather than treating AI applications as isolated technological solutions, the review focuses on their role in transforming logistics processes, organizational practices, and decision-making structures. Accordingly, the scope of the review is defined along three dimensions:

Process scope: The review covers core logistics processes, including transportation, warehousing, inventory management, customer service, and risk management.

Technological scope: Only studies that explicitly employ AI-based techniques (e.g., machine learning, deep learning, intelligent optimization, predictive analytics) are included.

Temporal scope: The review focuses on recent literature published between 2020 and 2026 to reflect contemporary developments in AI and Logistics 4.0.

By applying these criteria, the review aims to capture AI applications that contribute to the digital transformation of logistics systems rather than incremental automation of isolated tasks. The literature search was conducted across three major academic databases: EBSCOhost, ScienceDirect, and Web of Science. To capture recent developments in AI-driven logistics, the search period was restricted to publications from January 2020 to January 2026.

Database	Keywords Used	Filters Applied	Results Obtained
EBSCOhost	"Industry 4.0" AND AI "Industry 4.0" AND "artificial intelligence" Logistics AND AI Logistics AND "artificial intelligence" Logistics AND "digital transformation"	Peer-reviewed articles Publication date: 2020/01/01 to 2024/12/31 Academic journals English language only	73
ScienceDirect	"Industry 4.0" AND AI "Industry 4.0" AND "artificial intelligence" Logistics AND AI Logistics AND "artificial intelligence" Logistics AND "digital transformation"	Reviewed and research articles Publication date: 2020/01/01 to 2024/12/31	43
Web of Science	"Industry 4.0" AND AI "Industry 4.0" AND "artificial intelligence" Logistics AND AI Logistics AND "artificial intelligence" Logistics AND "digital transformation"	Publication years: 2020–2024 Document types: Articles and review articles English language only Research areas: Engineering, Computer Science, Business Economics	137

TABLE 1: Search strategy query for each database

The search strings combined keywords related to AI, logistics, Logistics 4.0, and digital transformation (see Table *1*). Only peer-reviewed journal articles written in English were considered. After removing duplicates and screening titles and abstracts, 33 articles met the inclusion criteria and were included in the final dataset. The exclusion criteria adopted for the research are (1) papers unrelated to AI applications in logistics, (2) articles that were not peer-reviewed, and (3) non-AI in Logistics 4.0: A Systematic Review of Process-Level Impacts English language papers. Only papers addressing the impact of AI on logistics processes were included in the final review. The review process followed the PRISMA framework (Page et al., 2021) to ensure transparency, rigor, and replicability (see Figure *1*).

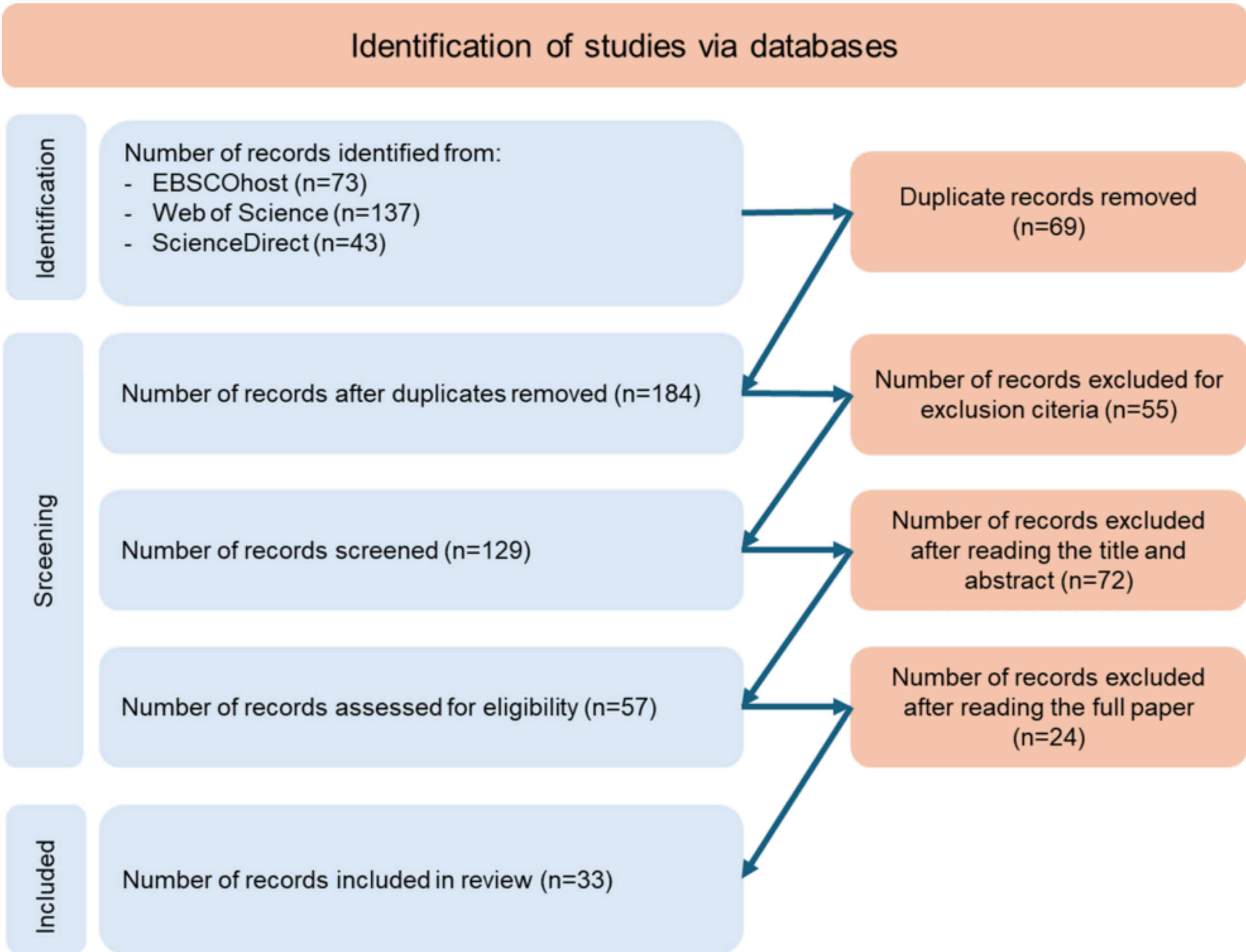

FIGURE 1: Flowchart of search and selection criteria, based on PRISMA

PRISMA, Preferred Reporting Items for Systematic reviews and Meta-Analyses

Nevertheless, the review is subject to limitations. Restricting the sample to English-language journal articles may exclude relevant research published in other languages. Furthermore, the rapidly evolving nature of AI technologies means that recent developments may not yet be fully reflected in academic literature. Despite these limitations, the methodological rigor of the review provides a robust foundation for synthesizing current knowledge on AI-driven logistics processes.

No.	Title	Author(s) and Year	Application Area
1	A survey paper in transportation logistics based on artificial intelligence	(Emam et al., 2021)	AI-driven cost optimization in logistics processes
2	Constructing rural e-commerce logistics model based on ant colony algorithm and artificial intelligence method	(Feng, 2020)	AI-driven cost optimization in logistics processes
3	AI-powered ensemble machine learning to optimize cost strategies in logistics business	(Yaiprasert and Hidayanto, 2024)	AI-driven cost optimization in logistics processes
4	Smart logistic system for enhancing the farmer-customer corridor in smart agriculture sector using artificial intelligence	(Ramirez-Asis et al., 2022)	AI-driven cost optimization in logistics processes
5	Artificial intelligence monitoring system using ZigBee wireless network technology in warehousing and logistics innovation and economic cost management	(Zhao and Xu, 2022)	AI-driven cost optimization in logistics processes
6	Document process automation with artificial intelligence for logistics sector	(Stoyanova, 2023)	AI-driven cost optimization in logistics processes
7	Artificial-intelligence-powered customer service management in the logistics industry	(Brzozowska et al., 2023)	AI-driven cost optimization in logistics processes; AI-enabled customer service in logistics
8	The AI revolution in industry: A review of its usage in reverse logistics returns prediction	(Alkhorasani and Alawag, 2025)	AI-driven cost optimization in logistics processes; AI-enabled customer service in logistics
9	AI-driven optimization for freight and logistics management using predictive analytics	(Royappa et al., 2024)	AI-driven cost optimization in logistics processes; Route optimization and transportation management
10	A single AI platform for the unification of railway transport logistics processes	(Rohovyi et al., 2025)	Route optimization and transportation management

How to cite this article:
Sucky E, Guan Z (May 21, 2026) Artificial Intelligence in Logistics 4.0: A Systematic Review of Process-Level Impacts. Cureus J Bus Econ 3 : es44404-026-00079-z. DOI https://doi.org/10.7759/s44404-026-00079-z

11	Metaverse in transportation and logistics operations: An AI-supported digital technological framework	(Kuo and Choi, 2024)	Automation and process efficiency enhancement; Security and risk management
12	Artificial intelligence for production, operations and logistics management in modular construction industry: A systematic literature review	(Liu et al., 2024)	Automation and process efficiency enhancement
13	Artificial intelligence-empowered logistic traffic management system using empirical intelligent XGBoost technique in vehicular edge networks	(Alkinani et al., 2023)	Automation and process efficiency enhancement
14	Human-AI collaboration in route planning: An empirical efficiency-based analysis in retail logistics	(Loske and Klumpp, 2021)	Route optimization and transportation management
15	Blockchain, IoT and AI in logistics and transportation: A systematic review	(Idrissi et al., 2024)	Route optimization and transportation management
16	Research on optimization of cross-border e-commerce logistics distribution network in the context of artificial intelligence	(Shi, 2022)	Route optimization and transportation management; Security and risk management
17	Modelling urban logistics processes using artificial intelligence (AI)	(Engelaitis et al., 2025)	Route optimization and transportation management
18	From layout to data: AI-driven route matrix generation for logistics optimization	(Francuz and Bányai, 2026)	Route optimization and transportation management
19	The effects of using artificial intelligence and robotic in logistics service production: An application in 3PLs and 4PLs	(Çağlar and Taşkın, 2023)	Warehouse and inventory management
20	Logistics 4.0–digital transformation with smart connected tracking and tracing devices	(Helo and Thai, 2024)	Warehouse and inventory management

21	Efficient edge AI based annotation and detection framework for logistics warehouses	(Mori et al., 2025)	Warehouse and inventory management
22	Intelligent port logistics: A spatiotemporal knowledge graph and AI-agent framework for berth allocation	(Wang et al., 2025)	Warehouse and inventory management
23	Enhancing last-mile logistics: AI-driven fleet optimization, mixed reality, and large language model assistants for warehouse operations	(Leva et al., 2025)	Warehouse and inventory management
24	AI-enhanced digital twin systems for warehouse logistics optimization: A review of challenges with solutions and future directions	(Alam et al., 2026)	Warehouse and inventory management
25	Elevating logistics performance: Harnessing the power of artificial intelligence in e-commerce	(Malhotra and Kharub, 2025)	AI-enabled customer service in logistics
26	Artificial intelligence in logistics optimization with sustainable criteria: A review	(Chen et al., 2024)	Sustainability and energy efficiency
27	Towards the smart and sustainable transformation of Reverse Logistics 4.0: A conceptualization and research agenda	(Sun et al., 2022)	Sustainability and energy efficiency
28	Reinforcement learning for EV fleet smart charging with on-site renewable energy sources	(Li et al., 2024)	Sustainability and energy efficiency
29	Green incremental learning-Energy efficient ramp-up for AI-enhanced part recognition in reverse logistics	(Schlüter et al., 2023)	Sustainability and energy efficiency
30	Convergence of distributed ledger technologies with digital twins, IoT, and AI for	(Vilas-Boas et al., 2023)	Sustainability and energy efficiency

	fresh food logistics: Challenges and opportunities		
31	AI-driven energy optimization in urban logistics: Implications for smart SCM in Dubai	(Mohsen and Mohsen, 2025)	Sustainability and energy efficiency
32	Digital Twin for managed transportation - Transforming logistics with AI-driven supply chain optimization	(Bhalerao, 2025)	AI-driven cost savings, efficiency, and sustainability
33	A framework for digital twins solutions for 5PL operators	(Nicoletti and Appolloni, 2024)	Security and risk management

TABLE 2: Overview of selected papers on AI and Logistics 4.0

Results

This section presents the results of the systematic literature review. Following the analytical framework outlined in the methodology, the findings are structured along core logistics processes and interpreted within the broader context of Logistics 4.0. The results are organized into a bibliometric overview and a detailed thematic synthesis of AI applications across logistics functions.

Bibliometric and Descriptive Results

An analysis of the 33 selected studies reveals a clear increase in scholarly attention to AI-driven logistics since 2020, particularly in terms of publications, which have risen since 2024. This trend reflects the maturation of AI technologies and their growing relevance to logistics practices. The surge in research activity coincides with the widespread adoption of digital transformation initiatives and the increased availability of logistics-related data.

Geographically, the literature exhibits a global orientation. A significant proportion of studies originate from China and European countries, indicating robust industrial and academic involvement in smart logistics and digital supply chains in these regions. Contributions from North America and emerging economies further underscore the worldwide relevance of AI in logistics.

In terms of research design, the reviewed studies employ diverse methodologies, such as optimization models, simulation-based analyses, empirical case studies, surveys, and conceptual frameworks. While this methodological diversity illustrates the interdisciplinary nature of AI research in logistics, it also contributes to fragmentation across literature.

Regarding logistics domains, transportation and warehouse management are the most prevalent, followed by inventory management, customer service, sustainability-related logistics, and risk management (see Table *2*). This distribution suggests that AI adoption is most advanced in operationally intensive logistics processes where data availability and automation potential are high.

AI-driven Cost Optimization in Logistics Processes

Cost optimization is one of the most frequently addressed objectives of AI applications in logistics (Alkhorasani and Alawag, 2025). Across the reviewed studies, AI-driven systems are consistently associated with reductions in transportation, inventory holding, labor, and administrative overhead costs (Royappa et al., 2024).

In transportation logistics, AI-enabled route optimization algorithms play a central role. Studies using genetic algorithms, ant colony optimization, and hybrid machine learning models have shown improvements in route efficiency, fuel consumption, and vehicle utilization (Emam et al., 2021), (Feng, 2020), and (Yaiprasert and Hidayanto, 2024). These algorithms dynamically integrate real-time data on traffic conditions, delivery constraints, and demand fluctuations, enabling the continuous adaptation of transportation plans. Beyond reducing direct costs, AI-driven transportation optimization improves asset utilization and reduces idle times. This is particularly relevant in complex logistics networks characterized by high variability and time-sensitive deliveries. AI systems can process large volumes of data and evaluate multiple scenarios simultaneously, enabling decision-making at a scale and speed beyond human capabilities.

In warehouse and inventory management, predictive analytics improve the accuracy of demand forecasting, enabling organizations to reduce safety stock levels and avoid the costs associated with overstocking or stockouts (Ramirez-Asis et al., 2022). AI-controlled robotics and automation systems further reduce labor costs while increasing throughput and accuracy (Zhao and Xu, 2022) (Stoyanova, 2023).

Administrative cost savings are also reported in logistics-related customer service processes. AI-powered chatbots and virtual assistants automate routine inquiries, reduce response times, and lower service costs while maintaining or improving service quality (Brzozowska et al., 2023).

Automation and Process Efficiency Enhancement

A second major subject in literature is automation and process efficiency. AI allows logistics organizations to transition from rule-based automation to adaptive, self-learning systems that continually enhance performance.

AI-driven scheduling systems optimize the allocation of resources across warehouses, transportation fleets, and distribution centers. These systems analyze historical and real-time data to dynamically adjust schedules to accommodate demand variability, equipment availability, and operational constraints (Kuo and Choi, 2024).

Another important application of AI in logistics automation is predictive maintenance. Machine learning models identify patterns in equipment performance data to predict failures before they occur, thereby reducing downtime and maintenance costs. This capability enhances process reliability and supports the transition from reactive to proactive logistics management (Mori et al., 2025).

Digital twins further extend the automation potential of AI by enabling simulation-based experimentation. By creating virtual representations of logistics systems, organizations can test alternative configurations, evaluate process changes, and identify performance bottlenecks without disrupting real-world operations (Liu et al., 2024). Digital twins thus support continuous process optimization and learning.

Integrating AI with IoT and edge computing technologies enables decentralized decision-making in logistics processes. Processing data closer to the point of action reduces latency and improves responsiveness, which is crucial in time-critical logistics environments, such as last-mile delivery (Engelaitis et al., 2025) (Alkinani et al., 2023).

Route Optimization and Transportation Management

Route optimization is one of the most mature and extensively researched applications of AI in logistics. Reviewed studies consistently demonstrate that AI-powered transportation management systems outperform traditional planning approaches in terms of efficiency, reliability, and adaptability. These systems dynamically incorporate real-time data on traffic congestion, weather conditions, vehicle status, and delivery priorities. This allows for continuous route adjustments and proactive disruption management (Loske and Klumpp, 2021) (Shi, 2022). Furthermore, predictive analytics enhance transportation planning by anticipating demand surges and potential delays.

Several studies emphasize the importance of human-AI collaboration in transportation management (Idrissi et al., 2024). Hybrid approaches that combine algorithmic recommendations with human expertise produce better results than fully automated or purely manual planning systems. Human decision-makers play a critical role in interpreting AI outputs, managing exceptions, and incorporating contextual knowledge that may not be captured in data. From a Logistics 4.0 perspective, AI-enabled route optimization integrates transportation processes into digitally connected logistics systems. Real-time visibility and adaptive planning enhance coordination and resilience across logistics networks.

Warehouse and Inventory Management

AI-driven automation has had a significant impact on warehouse and inventory management, two of the most affected logistics domains. Reviewed studies highlight the significant improvements in efficiency, accuracy, and responsiveness that result from AI-enabled warehouse systems (Alam et al., 2026).

Autonomous robots and AI-controlled picking and sorting systems increase throughput while reducing error rates and labor intensity (Çağlar and Taşkın, 2023). These systems are particularly effective in high-volume, highly dynamic logistics environments where manual operations struggle to maintain performance levels.

Predictive analytics enhance inventory management by enabling more accurate demand forecasting and stock optimization. Machine learning models identify patterns in historical sales data, seasonal trends, and external factors to support data-driven inventory decisions (Helo and Thai, 2024).

Real-time inventory visibility, enabled by AI and IoT integration, improves coordination across logistics processes. Organizations can respond more quickly to changes in demand, reduce lead times, and improve service levels. From a digital transformation perspective, AI-driven warehouse systems represent a shift toward autonomous, self-optimizing logistics operations (Kembro and Norrman, 2022)

AI-enabled Customer Service in Logistics

Customer service is an increasingly important aspect of logistics performance, especially in customer-centric and time-sensitive markets. AI applications in logistics-related customer service focus on automation, personalization, and transparency.

Chatbots, virtual assistants, and AI-driven notification systems offer customers real-time updates on order status, delivery schedules, and potential disruptions (Brzozowska et al., 2023). These systems reduce response times, improve customer satisfaction, and lower operational costs. AI-enabled personalization enhances service quality further by tailoring communication and delivery options to individual customer preferences (Malhotra and Kharub, 2025). AI systems analyze customer behavior and interaction data to support more proactive and responsive service models.

From a Logistics 4.0 perspective, AI-enabled customer service integrates logistics processes with customer-facing activities, thereby enhancing transparency and trust.

Sustainability and Energy Efficiency

Sustainability has become an increasingly prominent theme in the literature on AI-driven logistics. Recent research demonstrates that AI can make a substantial contribution to the decarbonization of logistics systems. Specifically, AI enhances routing efficiency, optimizes multimodal transport networks, improves energy management in warehouses, and enables more accurate demand forecasting (Chen et al., 2024). Across the analyzed studies, three recurring sustainability pathways can be identified: (1) energy and emissions optimization through AI-supported routing, predictive maintenance, and warehouse energy forecasting; (2) increased resource efficiency and waste reduction, particularly in reverse logistics enabled by deep learning-based material identification (Sun et al., 2022); and (3) the promotion of sustainable transport and green mobility through reinforcement learning approaches (Li et al., 2024).

Incremental learning models further contribute to sustainability by reducing the energy consumption associated with the training and deployment of AI systems, thereby addressing concerns regarding the environmental footprint of data-intensive technologies (Schlüter et al., 2023). In addition, digital twins support environmentally informed decision-making by allowing organizations to assess sustainability impacts prior to implementing operational changes (Vilas-Boas et al., 2023).

Beyond improving operational efficiency, AI also holds the potential to drive structural transformation within logistics systems. In the context of circular logistics, AI facilitates the identification, sorting, and reintegration of returned or discarded products. Deep learning-based computer vision systems enhance the accuracy of material recognition in sorting facilities, while machine learning models predict return flows and optimize reverse logistics networks, thereby reducing empty miles and minimizing resource waste. Empirical studies confirm that the application of AI in reverse logistics improves recovery rates and mitigates the environmental impacts associated with the production of new goods (Sun et al., 2022).

Overall, AI has emerged as one of the most powerful enablers of sustainable logistics. AI-driven sustainability initiatives are closely aligned with the broader objectives of Logistics 4.0, as they integrate economic and environmental performance considerations into logistics decision-making processes.

Risk Management

Risk management is a critical application area for AI in logistics, especially in complex and volatile environments. AI-driven predictive analytics and real-time monitoring allow for the early detection of disruptions, security threats, and operational anomalies.

Digital twins and simulation-based approaches support proactive risk mitigation by enabling organizations to test contingency plans and evaluate the resilience of logistics systems in various scenarios (Kuo and Choi, 2024) (Shi, 2022). AI-enabled digital twins allow logistics operators to simulate the effects of routing, fleet allocation, and warehouse configurations prior to implementation. This capability reduces operational risk and supports more informed and strategic planning and decision-making processes (Nicoletti and Appolloni, 2024).

AI reduces human error and enhances monitoring capabilities, contributing to safer and more reliable logistics operations. From a Logistics 4.0 perspective, AI-enabled risk management facilitates the transition to resilient and adaptive logistics systems.

Discussion

Introduction and Scope

This systematic literature review was undertaken to critically examine the mechanisms through which AI facilitates and fundamentally alters logistical processes within the conceptual framework of Logistics 4.0. The synthesized findings indicate that AI-driven applications exert influence on logistics systems across multiple, highly interdependent dimensions: operational efficiency, systemic process integration, organizational capacity building, and strategic agility. In the following section, these results are interpreted and contextualized within the broader theoretical discourse surrounding Logistics 4.0 and digital transformation.

AI as a Core Enabler of Logistics 4.0

The empirical evidence underscores that AI represents a pivotal enabling technology for the realization of Logistics 4.0. Across the entire spectrum of reviewed logistics processes, AI catalyzes a paradigm shift from reactive, experience-based decision-making toward predictive, data-centric, and increasingly autonomous architectures. This transition corroborates the conceptualization of Logistics 4.0 not merely as a fragmented collection of technological innovations but as a holistically integrated and intelligent logistical ecosystem.

At the operational level, AI-driven interventions enhance performance through sophisticated automation, algorithmic optimization, and real-time adaptability. However, the scope of this review illustrates that the utility of AI transcends mere operational refinements. By operationalizing predictive analytics, self-correcting systems, and digital twins, AI fosters anticipatory decision-making and iterative process optimization - capabilities that are indispensable for navigating the inherent complexity and volatility of contemporary supply chain environments.

How to cite this article:
Sucky E, Guan Z (May 21, 2026) Artificial Intelligence in Logistics 4.0: A Systematic Review of Process-Level Impacts.
Cureus J Bus Econ 3 : es44404-026-00079-z. DOI https://doi.org/10.7759/s44404-026-00079-z

From a socio-technical perspective, AI functions as a cognitive layer that bridges the gap between data acquisition, sophisticated analysis, and strategic execution. In the absence of AI, the vast volumes of data generated by IoT devices, enterprise resource planning systems, and digital platforms would remain largely latent. Consequently, AI serves as the critical transformative mechanism that converts data-driven visibility into actionable intelligence, thereby operationalizing the theoretical tenets of Logistics 4.0.

AI and the Digital Transformation of Logistics Processes

The findings accentuate that AI is a cornerstone of the digital transformation within the logistics sector. Digital transformation in this context extends beyond the mere digitization of legacy workflows; it necessitates a fundamental reconfiguration of the organizational, coordinative, and supervisory structures of logistics activities.

AI facilitates this metamorphosis by enabling unprecedented levels of cross-functional process integration. For instance, AI-enhanced demand forecasting and inventory optimization exert a direct, cascading influence on transportation scheduling and warehouse management, thereby tightening the interdependencies between historically siloed operations. While this integration promotes end-to-end optimization, it concurrently escalates the structural complexity of the system.

Furthermore, the review suggests a transition from fragmented process optimization toward holistic systemic management. Digital twins epitomize this evolution, empowering organizations to simulate and optimize entire logistical networks rather than isolated components. This macro-level perspective aligns seamlessly with the core objectives of Logistics 4.0, highlighting a transformative potential that far exceeds incremental efficiency gains.

AI as a Dynamic Capability in Logistics

From a theoretical vantage point, the findings suggest that AI can be conceptualized as a dynamic capability within logistics organizations. Dynamic capabilities allow firms to sense environmental shifts, seize emerging opportunities, and reconfigure their resource base in response to fluctuating market conditions.

- Sensing: AI bolsters the sensing function by continuously monitoring heterogeneous data streams to identify latent patterns and early warning signals, such as demand surges or supply chain disruptions.

- Seizing: The seizing function is operationalized through predictive analytics and prescriptive algorithms that facilitate rapid, evidence-based decision-making.

- Reconfiguring: AI contributes to organizational reconfiguration by enabling self-adaptive process adjustments and institutionalized learning.

This perspective elucidates why AI adoption is correlated not only with heightened efficiency but also with superior resilience and adaptability. Organizations leveraged by AI-driven capabilities are strategically positioned to mitigate the uncertainty and volatility that characterize today's fast-evolving global trade.

Process Maturity and the Evolutionary Trajectory of AI

The results further delineate varying degrees of maturity in AI-enabled logistics systems. While certain applications remain confined to discrete tasks - such as route optimization - others facilitate fully integrated, autonomous workflows. This variance suggests that AI implementation follows an evolutionary trajectory congruent with established digital maturity models.

- Foundational Stages: Initial digitalization efforts focus on data transparency and descriptive analytics.

- Intermediate Stages: As maturity increases, the focus shifts toward predictive and prescriptive analytics, fostering proactive management.

- Advanced Stages: At the highest levels of maturity, AI underpins autonomous systems capable of self-optimization and continuous, decentralized learning.

Understanding this maturity continuum is paramount for both academia and industry. It emphasizes that AI integration is not a discrete technological acquisition but a continuous process of transformation requiring organizational learning, robust governance, and specialized capability development.

Human-AI Interaction and Workforce Implications

Notwithstanding the trend toward increasing automation, the reviewed literature consistently highlights the enduring necessity of human agency. Hybrid human-AI decision-making models frequently demonstrate superior performance compared to fully autonomous systems, particularly in scenarios characterized by high ambiguity and non-routine exceptions.

This finding reinforces the socio-technical essence of Logistics 4.0: AI systems augment rather than render human cognition obsolete. While AI manages large-scale data processing, human actors provide the necessary contextual interpretation and ethical oversight. Consequently, the profile of the logistics workforce is evolving from manual execution toward roles centered on supervision, orchestration, and strategic governance.

However, this transition introduces significant challenges regarding human capital. There is an intensifying demand for data literacy, computational thinking, and AI-system management. Addressing these gaps necessitates comprehensive reskilling initiatives to ensure the workforce can interact synergistically with intelligent systems.

Governance, Scalability, and Organizational Barriers

Despite the documented advantages, the review identifies persistent impediments to universal AI adoption. Data fragmentation across heterogeneous systems remains a formidable barrier, especially within multi-stakeholder logistics networks where interoperability is often lacking.

Furthermore, scalability remains a critical bottleneck. Many AI applications exhibit high efficacy in pilot environments but encounter significant friction when deployed across large-scale, diverse logistical ecosystems. These difficulties are intrinsically linked to data quality, system silos, and a lack of organizational readiness.

Governance and ethics - encompassing data security, transparency, and algorithmic accountability - further complicate the landscape. As AI systems assume greater control over operational decisions, the establishment of robust governance frameworks becomes imperative to ensure trustworthy and responsible utilization, particularly in safety-critical sectors such as hazardous materials logistics.

Conclusions

This study sets out to examine how AI enables and transforms logistics processes within the framework of Logistics 4.0. By conducting a systematic literature review of recent peer-reviewed research, the study provides a comprehensive and theory-informed synthesis of AI-driven applications across core logistics functions. The findings demonstrate that AI plays a decisive role in reshaping logistics systems by enhancing efficiency, adaptability, sustainability, and resilience.

At the process level, the review shows that AI significantly improves cost optimization, automation, transportation management, warehouse and inventory operations, customer service, sustainability performance, and risk management. AI-driven predictive analytics, optimization algorithms, and autonomous systems enable logistics organizations to move beyond reactive decision-making toward proactive and adaptive process management. These capabilities are particularly valuable in increasingly complex and volatile logistics environments characterized by high uncertainty and dynamic demand patterns.

At the system level, the findings highlight that AI is a core enabling technology of Logistics 4.0. Rather than functioning as an isolated optimization tool, AI acts as a cognitive layer that connects data generation, analysis, and action across digitally integrated logistics systems. By transforming data into actionable intelligence, AI enables the realization of key Logistics 4.0 principles, such as real-time visibility, end-to-end integration, and continuous process optimization.

From a digital transformation perspective, the review underscores that AI adoption involves more than technological implementation. AI-driven logistics transformation requires organizational learning, capability development, and changes in decision-making structures. The reviewed studies illustrate that successful AI adoption depends on the alignment of technological capabilities with organizational processes, governance mechanisms, and workforce competencies. This reinforces the view of Logistics 4.0 as a socio-technical transformation rather than a purely technical evolution.

The study also contributes to theory by conceptualizing AI as a dynamic capability in logistics. AI enables organizations to sense environmental changes through continuous data monitoring, seize opportunities through predictive and prescriptive analytics, and reconfigure logistics processes through adaptive and self-learning systems. This perspective helps explain why AI adoption is associated not only with efficiency gains but also with enhanced resilience and strategic flexibility.

Despite these contributions, the review reveals several persistent challenges that constrain the widespread adoption of AI in logistics. Data integration and interoperability remain major barriers, particularly in complex logistics systems involving multiple stakeholders and heterogeneous IT infrastructures. Scalability issues limit the transfer of AI applications from pilot projects to large-scale operational deployment. Governance concerns related to data security, transparency, and accountability further complicate AI implementation, especially in safety-critical logistics contexts.

The findings also highlight important implications for the logistics workforce. While AI enables higher levels of automation, human expertise remains essential for supervision, exception handling, and strategic decision-making. The role of logistics professionals is shifting toward analytical, coordinative, and decision-oriented tasks, increasing the demand for digital and data-related skills. Addressing these workforce implications is critical for ensuring the long-term success of AI-enabled logistics systems.

Based on the findings of this review, several avenues for future research can be identified. First, there is a need for more longitudinal and empirical studies examining the long-term performance impacts of AI adoption in logistics. Many existing studies focus on short-term efficiency gains or isolated applications, leaving questions about sustained value creation and organizational learning unanswered. Second, future research should further investigate the interaction between AI technologies and organizational capabilities. In particular, studies examining how governance structures, leadership approaches, and cultural factors influence AI adoption would provide valuable insights into the socio-technical dynamics of Logistics 4.0. Third, greater attention should be paid to the challenges and opportunities of AI adoption in small and medium-sized logistics organizations. These organizations often face higher barriers related to investment capacity, skills availability, and data access, yet they play a crucial role in logistics systems. Fourth, future research should explore the ethical and governance implications of AI-driven logistics systems. Issues such as algorithmic transparency, accountability, and data privacy are becoming increasingly important as AI systems gain greater influence over operational and strategic decisions. Finally, there is significant potential for research examining the integration of AI with complementary digital technologies such as digital twins, IoT, and energy-efficient computing. Understanding how these technologies jointly contribute to sustainable and resilient logistics systems represents a promising direction for advancing both theory and practice.

In conclusion, this study demonstrates that AI is a central driver of transformation in increasingly complex logistics systems. By embedding AI applications within the theoretical frameworks of Logistics 4.0 and digital transformation, the study provides a structured and comprehensive understanding of AI's role in shaping the future of logistics. Addressing the identified challenges and research gaps will be critical for realizing the full potential of AI-enabled logistics systems in an increasingly complex and dynamic global environment.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Eric Sucky, Zhiyi Guan

Acquisition, analysis, or interpretation of data: Eric Sucky, Zhiyi Guan

Drafting of the manuscript: Eric Sucky, Zhiyi Guan

Critical review of the manuscript for important intellectual content: Eric Sucky, Zhiyi Guan

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

All data generated or analyzed during this study are included in this published article and/or its appendices.

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