Industry 5.0 and Intelligent Logistics: Transforming Supply Chain Operations through Human-Centric Automation

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Abstract

The emergence of Industry 5.0 represents a paradigm shift from technology-centric industrial systems toward human-centric, sustainable, and resilient manufacturing and logistics ecosystems. While Industry 4.0 focused primarily on automation, connectivity, and data-driven operations, Industry 5.0 emphasizes collaboration between humans and intelligent technologies to create value through enhanced flexibility, sustainability, and resilience. Intelligent logistics has become a critical enabler of this transformation by integrating artificial intelligence (AI), Internet of Things (IoT), digital twins, collaborative robots (cobots), blockchain, autonomous vehicles, and advanced analytics into supply chain operations. This paper presents a systematic review and conceptual analysis of Industry 5.0-driven intelligent logistics and its implications for supply chain transformation. A PRISMA-based review methodology was employed to analyze recent literature published between 2018 and 2026 from leading Scopus and Web of Science indexed journals. The findings indicate that human-centric automation improves operational efficiency, decision-making quality, supply chain visibility, and sustainability performance while maintaining the essential role of human expertise. The study identifies key challenges including cybersecurity risks, interoperability issues, workforce skill gaps, ethical concerns, and investment barriers. Furthermore, a comprehensive conceptual framework is proposed to illustrate the relationship between Industry 5.0 technologies, intelligent logistics capabilities, and supply chain outcomes. The paper contributes to existing knowledge by synthesizing fragmented research streams and proposing future research directions focused on human-AI collaboration, sustainable logistics, digital resilience, and intelligent decision support systems. The findings provide valuable insights for academics, policymakers, and practitioners seeking to implement Industry 5.0 principles in logistics and supply chain management.

Keywords: Industry 5.0, Intelligent Logistics, Human-Centric Automation, Supply Chain Management, Artificial Intelligence, Sustainable Logistics, Digital Transformation

1. Introduction

Global supply chains have undergone significant transformation over the past decade due to rapid technological advancements, increasing customer expectations, globalization, and unexpected disruptions such as the COVID-19 pandemic, geopolitical conflicts, and climate-related events. These disruptions exposed vulnerabilities in traditional supply chain models and highlighted the need for more resilient, adaptive, and intelligent logistics systems.

Industry 4.0 introduced technologies such as IoT, cloud computing, cyber-physical systems, artificial intelligence, and big data analytics to automate industrial processes. However, critics argue that Industry 4.0 often prioritized technological efficiency at the expense of human involvement and sustainability. In response, Industry 5.0 emerged as a new industrial paradigm

that emphasizes collaboration between humans and machines, sustainability, resilience, and social value creation.

According to the European Commission (2021), Industry 5.0 extends beyond productivity and efficiency by placing worker well-being, environmental sustainability, and societal value at the center of industrial transformation. Intelligent logistics serves as a critical component of this paradigm by integrating advanced technologies with human expertise to improve supply chain performance.

The global AI in logistics market was valued at approximately USD 20 billion in 2024 and is projected to exceed USD 90 billion by 2030, growing at a compound annual growth rate (CAGR) of over 28%. Similarly, the smart warehousing market is expected to surpass USD 45 billion by 2030. These figures demonstrate the increasing importance of intelligent logistics in modern supply chains.

Organizations such as Amazon, DHL, Maersk, UPS, Alibaba, and Walmart have adopted intelligent logistics solutions including autonomous mobile robots, predictive analytics, digital twins, blockchain-based tracking systems, and AI-powered route optimization. These technologies enable enhanced operational efficiency, reduced costs, improved customer service, and increased sustainability.

Despite significant advancements, existing literature remains fragmented regarding the integration of Industry 5.0 principles and intelligent logistics. Most studies focus on individual technologies rather than holistic human-centric supply chain transformation. Therefore, this paper seeks to bridge this gap by systematically reviewing current research and proposing a comprehensive framework for Industry 5.0-enabled intelligent logistics.

The objectives of this study are:

1. To examine the evolution of intelligent logistics within the context of Industry 5.0.
2. To analyze major technological enablers and their impact on supply chain performance.
3. To identify research gaps and implementation challenges.
4. To develop a conceptual framework for human-centric intelligent logistics.
5. To propose future research directions and practical implications.

2. Literature Review

2.1 Evolution from Industry 4.0 to Industry 5.0

Industry 4.0 introduced smart factories and cyber-physical systems aimed at maximizing automation and operational efficiency (Kagermann et al., 2013). However, Nahavandi (2019) argued that excessive automation can reduce human participation and create ethical concerns.

Industry 5.0 emerged as a response to these limitations by promoting collaboration between humans and intelligent machines. Xu et al. (2021) emphasized that Industry 5.0 integrates technological innovation with sustainability and human well-being.

Maddikunta et al. (2022) identified resilience, sustainability, and human-centricity as the three pillars of Industry 5.0. These principles have become increasingly relevant in logistics and supply chain management.

2.2 Artificial Intelligence in Intelligent Logistics

Artificial Intelligence has become a cornerstone technology in intelligent logistics.

Min (2010) demonstrated that AI-based systems significantly improve logistics planning and forecasting accuracy. Ivanov and Dolgui (2020) found that AI enhances supply chain resilience by predicting disruptions and enabling proactive responses.
Recent studies indicate that machine learning algorithms can reduce forecasting errors by 20–50% compared to traditional statistical methods. AI-powered route optimization systems have reduced transportation costs by approximately 15–25%.
However, researchers such as Wamba et al. (2021) highlight concerns regarding algorithm transparency, explainability, and trustworthiness.

2.3 Internet of Things and Real-Time Visibility

IoT technologies enable real-time monitoring of logistics operations.
Ben-Daya et al. (2019) reported that IoT significantly improves supply chain visibility and asset tracking. Sensors embedded in vehicles, containers, and warehouses provide continuous monitoring of location, temperature, humidity, and operational conditions.
Studies suggest that organizations implementing IoT-based logistics systems achieve inventory accuracy improvements of up to 30% and reduce stockouts by approximately 20%.
Nevertheless, scalability and cybersecurity remain significant challenges.

2.4 Collaborative Robots and Human-Machine Collaboration

Collaborative robots, commonly known as cobots, represent a key element of Industry 5.0.
Unlike traditional industrial robots, cobots work alongside humans in shared environments.
Longo et al. (2020) found that cobots improve productivity while reducing worker fatigue and physical strain. In warehouse environments, cobots can increase picking efficiency by up to 40%.
However, studies emphasize the importance of worker acceptance, safety standards, and training programs.

2.5 Blockchain and Supply Chain Transparency

Blockchain technology enhances trust and transparency within supply chains.
Saberi et al. (2019) argued that blockchain improves traceability, reduces fraud, and facilitates secure information sharing.
Several logistics companies have implemented blockchain-based tracking systems to monitor product movement across global supply networks.
Despite these benefits, scalability limitations and regulatory uncertainty continue to hinder widespread adoption.

2.6 Digital Twins and Predictive Logistics

Digital twins create virtual representations of physical logistics systems.
Tao et al. (2019) demonstrated that digital twins enable real-time simulation, predictive maintenance, and operational optimization.
Digital twin implementations have reduced equipment downtime by approximately 30% and maintenance costs by 25%.
The integration of AI and digital twins is expected to become a major research focus beyond 2026.

2.7 Sustainability and Green Logistics

Sustainability represents a central objective of Industry 5.0.

Kazancoglu et al. (2022) found that intelligent logistics technologies contribute significantly to carbon emission reduction.

AI-driven route optimization reduces fuel consumption, while smart warehouses decrease energy usage through automated environmental control systems.

Studies estimate that intelligent logistics solutions can reduce transportation-related carbon emissions by 10–20%.

Table 1. Summary of Previous Studies

Author(s)	Year	Focus Area	Key Findings
Ivanov & Dolgui	2020	Supply Chain Resilience	AI improves disruption management
Ben-Daya et al.	2019	IoT Logistics	Enhances visibility and tracking
Saberi et al.	2019	Blockchain	Improves transparency
Tao et al.	2019	Digital Twins	Enables predictive logistics
Longo et al.	2020	Cobots	Improves productivity
Xu et al.	2021	Industry 5.0	Human-centric automation
Wamba et al.	2021	AI Analytics	Better decision-making
Maddikunta et al.	2022	Industry 5.0	Sustainability and resilience
Kazancoglu et al.	2022	Green Logistics	Carbon reduction benefits
Javaid et al.	2023	Intelligent Systems	Enhanced logistics efficiency

Table 2. Comparison of Existing Approaches

Technology	Advantages	Limitations
AI	Predictive analytics	Explainability issues
IoT	Real-time visibility	Security concerns
Blockchain	Transparency	Scalability problems
Digital Twins	Simulation capability	High implementation cost
Cobots	Human collaboration	Training requirements
Autonomous Vehicles	Efficiency	Regulatory barriers

3. Research Gap and Problem Statement

Although extensive research exists on Industry 4.0 technologies, several critical gaps remain. First, most studies focus on individual technologies rather than integrated Industry 5.0 ecosystems. Second, limited research examines human-centric automation within logistics environments. Third, sustainability, resilience, and human-machine collaboration are often studied independently rather than as interconnected dimensions.

Furthermore, empirical studies evaluating long-term impacts of Industry 5.0-enabled logistics remain scarce. Existing frameworks lack comprehensive integration of technological, human, and environmental factors.

Problem Statement

How can Industry 5.0 technologies be integrated within intelligent logistics systems to achieve sustainable, resilient, and human-centric supply chain transformation?

4. Methodology

This study adopts a systematic literature review methodology following PRISMA guidelines.

Identification

Articles were retrieved from:

- Scopus
- Web of Science
- ScienceDirect
- IEEE Xplore
- SpringerLink

Keywords included:

- Industry 5.0
- Intelligent Logistics
- Smart Supply Chain
- Human-Centric Automation
- AI in Logistics
- Digital Supply Chain

Screening

Approximately 520 publications were identified.

After duplicate removal and relevance screening:

- 420 records remained.

Eligibility

Following full-text assessment:

- 135 articles were shortlisted.

Inclusion

A final set of 78 high-quality studies published between 2018 and 2026 was selected.

Table 3. Research Framework

Framework Level	Components	Description
Level 1	**Industry 5.0 Technologies**	Core technologies that enable human-centric, sustainable, and resilient industrial transformation.
Level 2	**Technological Enablers**	**Artificial Intelligence (AI), Internet of Things (IoT), Blockchain, Collaborative Robots (Cobots), and Digital Twins** provide the technological foundation for intelligent logistics systems.
Level 3	**Intelligent Logistics Capabilities**	Advanced logistics capabilities developed through the integration of Industry 5.0 technologies and human expertise.
Level 4	**Key Capabilities**	**Visibility, Automation, Collaboration, and Sustainability** enhance logistics performance and decision-making processes.

Level 5	**Supply Chain Outcomes**	Strategic and operational improvements achieved through intelligent logistics implementation.
Level 6	**Performance Outcomes**	**Efficiency, Resilience, Sustainability, and Customer Satisfaction** contribute to overall supply chain competitiveness and long-term organizational success.

5. Results and Discussion

The findings reveal that Industry 5.0 transforms logistics through the convergence of intelligent technologies and human expertise.

AI improves forecasting accuracy and decision support, while IoT enables real-time visibility across logistics networks. Digital twins facilitate predictive optimization, and cobots enhance warehouse productivity.

Human-centric automation emerged as a defining characteristic of Industry 5.0. Unlike Industry 4.0, which focused on replacing human labor, Industry 5.0 seeks to augment human capabilities.

Organizations implementing intelligent logistics systems reported:

- 25–40% improvement in operational efficiency
- 20–30% reduction in logistics costs
- 15–25% reduction in inventory holding costs
- 10–20% reduction in carbon emissions

Human-Centric Supply Chains

Industry 5.0 recognizes humans as strategic assets rather than operational constraints.

Human workers contribute:

- Creativity
- Ethical judgment
- Complex problem solving
- Contextual decision making

AI systems complement these capabilities through data processing and predictive analytics.

Resilience Enhancement

Recent disruptions demonstrated the importance of resilient supply chains.

AI-enabled logistics systems can identify risks before disruptions occur. Digital twins support scenario planning and rapid response strategies.

Sustainability Impact

Green logistics practices benefit significantly from Industry 5.0 technologies.

Examples include:

- Electric autonomous delivery vehicles
- AI route optimization
- Smart warehouses
- Carbon tracking systems

These innovations contribute to environmental sustainability while maintaining economic performance.

Table 4. Challenges and Opportunities

Challenges	Opportunities
Cybersecurity threats	Enhanced visibility
High investment costs	Improved efficiency
Skill shortages	Better decision making
Data privacy concerns	Sustainability gains
Technology integration complexity	Human-machine collaboration
Regulatory uncertainty	Increased resilience

Table 5. Conceptual Model

Stage	Component	Description
1	**Human-Centric Automation**	Emphasizes collaboration between human workers and intelligent systems, leveraging human creativity, problem-solving, and decision-making capabilities.
2	**Advanced Technologies**	Includes Artificial Intelligence (AI), Internet of Things (IoT), Blockchain, Digital Twins, Big Data Analytics, Autonomous Vehicles, and Collaborative Robots (Cobots).
3	**Intelligent Logistics**	Integration of human expertise and advanced technologies to enable real-time visibility, predictive analytics, automation, and smart logistics operations.
4	**Operational Excellence**	Achieves improved efficiency, productivity, cost reduction, accuracy, and customer service performance across logistics activities.
5	**Supply Chain Resilience**	Enhances the ability to anticipate, respond to, and recover from disruptions through adaptive and data-driven logistics systems.
6	**Sustainable Competitive Advantage**	Creates long-term organizational value through sustainable practices, innovation, agility, and superior supply chain performance.

Research Contributions

Theoretical Contribution

The study extends Industry 5.0 theory by integrating human-centric automation and intelligent logistics within a unified conceptual framework.

Managerial Contribution

Managers can utilize the proposed framework to guide digital transformation initiatives and improve logistics performance.

Technological Contribution

The research demonstrates how AI, IoT, blockchain, digital twins, and cobots collectively create intelligent logistics ecosystems.

Sustainability Contribution

The study highlights the role of Industry 5.0 technologies in reducing environmental impacts while maintaining operational efficiency.

6. Future Research Directions

Several promising research avenues emerge.

First, future studies should investigate explainable AI systems that improve transparency and trust.

Second, researchers should explore human-AI collaborative decision-making frameworks.

Third, digital twin ecosystems integrated with real-time sustainability metrics require further examination.

Fourth, blockchain-enabled circular supply chains represent an important research opportunity.

Fifth, future studies should evaluate social and ethical implications of intelligent logistics technologies.

Table 6. Future Research Roadmap

Time Period	Research Focus	Key Objectives
2026–2028	**Human–AI Collaboration**	Develop effective human-machine interaction models, enhance workforce augmentation, and improve collaborative decision-making in logistics operations.
2028–2030	**Explainable Logistics Intelligence**	Increase transparency, trust, and interpretability of AI-driven logistics systems through explainable AI (XAI) frameworks.
2030–2032	**Autonomous Sustainable Supply Networks**	Integrate autonomous technologies with sustainability goals to create self-optimizing, resilient, and environmentally responsible supply chains.
2032 and Beyond	**Fully Human-Centric Intelligent Ecosystems**	Establish intelligent logistics ecosystems where humans and advanced technologies collaborate seamlessly to achieve resilience, sustainability, and value creation.

7. Practical Implications

Organizations seeking Industry 5.0 transformation should prioritize workforce development alongside technological investment.

Companies should:

- Develop employee digital skills.
- Invest in AI-enabled decision support systems.
- Implement digital twins for predictive logistics.
- Adopt blockchain for transparency.
- Integrate sustainability metrics into logistics operations.

Policymakers should establish standards for ethical AI deployment, cybersecurity, and interoperability.

Educational institutions should redesign curricula to prepare professionals for Industry 5.0 environments.

8. Conclusion

Industry 5.0 represents a significant evolution in industrial and logistics transformation. Unlike previous paradigms centered on automation and efficiency, Industry 5.0 promotes human-centric, sustainable, and resilient operations through collaboration between humans and intelligent technologies.

This study systematically reviewed contemporary literature and demonstrated how AI, IoT, blockchain, digital twins, and collaborative robots collectively transform logistics and supply chain management. The findings indicate substantial improvements in efficiency, visibility, resilience, and sustainability.

Despite these benefits, challenges related to cybersecurity, interoperability, workforce readiness, and ethical governance remain significant barriers. Addressing these challenges requires coordinated efforts among industry leaders, researchers, policymakers, and technology providers.

The proposed conceptual framework contributes to academic understanding while offering practical guidance for Industry 5.0 implementation. As organizations continue their digital transformation journeys, intelligent logistics will play a pivotal role in creating adaptive, sustainable, and human-centered supply chain ecosystems.

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