



AI Adoption in Small-Scale Industries under Industry 4.0 with 5.0: A Critical and Brief Review

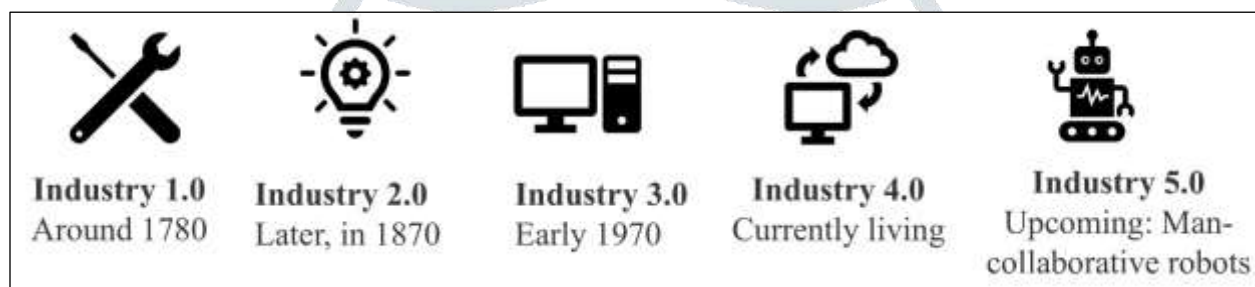
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GRAPHICAL ABSTRACT



Abstract: The rise of Industry 4.0 has reshaped global manufacturing, with Artificial Intelligence (AI) driving smart production and digital transformation. While large enterprises rapidly adopt AI to boost efficiency and decision-making, small-scale industries (SSIs) face barriers such as high costs, limited skills, weak infrastructure, and data security concerns. This review critically examines AI adoption in SSIs under Industry 4.0 and 5.0, outlining applications in predictive analytics, automation, supply chain management, and customer engagement. It highlights how Industry 5.0 shifts the focus from a rapid automation toward human-centric, sustainable, and resilient practices, where AI supports personalization, sustainability, and human-machine collaboration. The study concludes that although AI offers significant potential for SSIs, successful integration requires structured roadmaps emphasizing awareness, skill development, and ecosystem-level support.

Keywords: Artificial Intelligence, Industry 4.0, Industry 5.0, Digital Transformation, Automation.

1. INTRODUCTION

The industrial revolutions have unfolded in distinct phases over time. Industry 1.0, marked the use of water and steam power for mechanization. Industry 2.0 introduced electricity, assembly lines, and mass production. Industry 3.0, the digital revolution, leveraged electronics, computers, and automation. Industry 4.0, integrated AI, IoT, big data, and cyber-physical systems to create smart factories, also shown its evolution in graphical abstract. Now, Industry 5.0, onwards is emerging, focusing on human-machine collaboration, sustainability, resilience, and personalized production. The advent of Industry 4.0, or the Fourth Industrial Revolution, has brought about transformative changes in manufacturing by leveraging cyber-physical systems (CPS), Internet of Things (IoT), big data, and artificial intelligence (AI) to create smart, connected production systems (Liao et al., 2017; Strozzi et al., 2017; Frank et al., 2019). Among these technologies, AI plays a pivotal role in enabling predictive maintenance, quality control, real-time decision-making, supply chain optimization, and automation (Javaid et al., 2021).

Despite Industry 4.0's benefits being widely recognized, most research and implementation efforts are concentrated on large enterprises, with relatively little attention given to the unique circumstances of small-scale industries (SSIs) or SMEs. SSIs account for a substantial portion of global industrial output, employment, and innovation, yet they face distinct constraints in resources, technical capability, and digital readiness, hindering their adoption of Industry 4.0 and AI technologies (Mittal et al., 2018; Müller & Voigt, 2021; Iakovets et al., 2023). Moreover, SSIs often suffer from financial limitations, infrastructure challenges, skill shortages, and weak absorptive capacity, which further impede their ability to adopt and adapt AI-driven systems (Sharma et al., 2023; Jayashree et al., 2021; Dossou et al., 2022; Canhoto et al., 2021). A growing body of literature, however, addresses these gaps by exploring tailored strategies for AI integration in SMEs. Prescriptive frameworks propose stepwise approaches starting with awareness, leadership commitment, and low-cost AI implementations, progressing toward customized generative and discriminative models as a way to gradually build capacity. Surveys of AI and IoT use in manufacturing SMEs further highlight both the potential (e.g., predictive analytics, efficiency gains) and barriers (knowledge gaps, technology access).

Critically, integration of AI in Industry 4.0 contexts also raises data-related challenges, such as heterogeneous and low-quality data, lack of interpretability, and trust issues especially pertinent for SSIs with limited data infrastructure (Windmann et al., 2024; Wikipedia, 2025).

In addition to structural and technical hurdles, SSIs face economic and social sustainability imperatives. Sustainability-driven applications such as energy-efficient operations and waste reduction through AI could align with SSIs' critical role in employment and environmental. Meanwhile, AI's broader implications, including workforce displacement and regulatory concerns, underline the need for a socio-technical lens in adoption (Nelson et al., 2023).

This paper therefore undertakes a critical review of AI adoption in SSIs under the Industry 4.0 and 5.0 paradigm, with the following objectives:

- To synthesize current applications and benefits demonstrated across SSIs.
- To examine the unique barriers technological, organizational, economic, and data-related that inhibit AI integration.
- To assess and critique proposed frameworks and maturity models suited to SSIs.
- To outline a structured roadmap grounded in realistic strategies for sustainable adoption in these contexts.

By integrating insights from recent empirical studies, theoretical models, and sector-specific analyses, this review aims to contribute a nuanced understanding of how SSIs can meaningfully engage with AI within Industry 4.0 balancing ambition with pragmatism. factors.

1. Role of AI in Industry 4.0 and 5.0 for Small-Scale Industries



Figure 1. Role of AI in Industry 4.0 and 5.0

AI technologies are central to the realization of Industry 4.0 with 5.0, enabling smart factories, autonomous decision-making, and adaptive manufacturing systems. The role of AI is shown in the Figure 1. In the context of small-scale industries (SSIs), AI tools such as predictive analytics, virtual reality, reverse engineering, machine learning, natural language processing, and computer vision can support process optimization, reduce human error, and enhance competitiveness (Javaid et al., 2021; Frank et al., 2019).

- **Predictive maintenance** helps minimize downtime and cost by anticipating equipment failures.
- **Computer vision** enhances quality control in production lines with real-time defect detection.
- **AI-driven supply chain models** optimize inventory and logistics for resource-constrained SSIs.

Despite these opportunities, the application of AI in SSIs remains limited compared to large corporations due to gaps in awareness, expertise, and affordability.

2. Barriers to AI Adoption in SSIs Under Industry 4.0 with 5.0

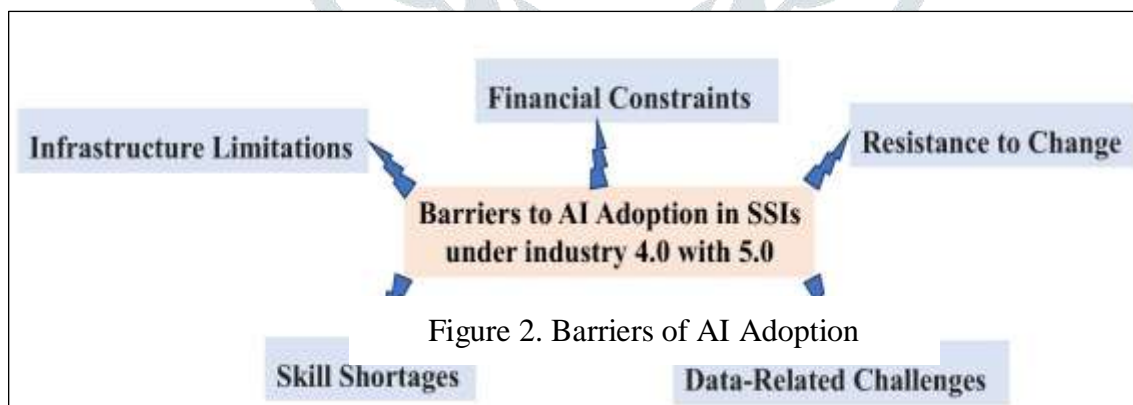


Figure 2. Barriers of AI Adoption

Numerous studies identify barriers shown in Figure 2, restrict AI adoption in SSIs under Industry 4.0. These include:

1. **Financial Constraints** – High costs of AI infrastructure, licensing, and skilled workforce hinder implementation (Mittal et al., 2018; Müller & Voigt, 2021).
2. **Skill Shortages** – Lack of technical expertise and training in AI tools limit operationalization (Sharma et al., 2023).
3. **Data-Related Challenges** – Insufficient data quality, volume, and integration with legacy systems create difficulties in applying AI effectively (Windmann et al., 2024).
4. **Resistance to Change** – Organizational inertia and cultural barriers reduce willingness to transition from traditional methods (Canhoto et al., 2021).
5. **Infrastructure Limitations** – Many SSIs operate in regions with limited internet connectivity and digital infrastructure, restricting adoption (Iakovets et al., 2023).

Together, these challenges suggest that AI adoption in SSIs requires context-specific frameworks and external support.

3. Frameworks and Strategies for Adoption of Industry 4.0 with 5.0

The successful adoption of Industry 4.0 and 5.0 in small-scale industries requires a balanced framework that integrates digital transformation with human-centric and sustainable approaches. While Industry 4.0 provides the technological foundation through automation, IoT, AI, and cyber-physical systems, Industry 5.0 emphasizes resilience, inclusivity, and sustainability. A combined adoption strategy enables SSIs to not only modernize operations but also ensure long-term competitiveness and responsible growth.

Key Frameworks and Strategies:

1. **Digital Readiness Assessment**
 - Conduct baseline evaluations of technological maturity, infrastructure, and workforce readiness.
 - Identify gaps in digital capabilities to prioritize investments in scalable AI and IoT solutions.
2. **Phased Implementation Model**
 - Begin with low-cost Industry 4.0 tools such as cloud-based AI, predictive maintenance, and digital monitoring.
 - Progressively integrate Industry 5.0 elements like human-AI collaboration and sustainable production models.
3. **Skill Development and Workforce Empowerment**
 - Establish training programs to reskill workers for digital tools (Industry 4.0) while fostering creativity, decision-making, and ethical AI literacy (Industry 5.0).
 - Encourage collaborative coordination between man and machines to leverage hybrid intelligence.
4. **Sustainability-Driven Adoption**
 - Align technology adoption with circular economy practices, renewable energy integration, and eco-friendly production methods.
 - Use AI for optimizing and enhancing energy use and efficiency, reducing waste, and minimizing environmental impact.
5. **Collaborative Ecosystems**
 - Foster partnerships among SSIs, technology providers, academic institutions, and government bodies to create accessible innovation hubs.
 - Encourage shared platforms for knowledge exchange, joint R&D, and cost-effective technology access.
6. **Policy and Governance Support**
 - Implement supportive policies such as subsidies, tax benefits, and digital innovation grants for SSIs.
 - Reestablish regulatory frameworks that ensure data security, ethical AI use, and inclusive adoption.
7. **Resilience and Risk Management**
 - Adopt AI-based forecasting and risk assessment tools (4.0) integrated with human-centered resilience planning (5.0).
 - Strengthen supply chains with flexible, adaptive, and community-focused strategies.

4. Opportunities and Benefits of Industry 4.0 with 5.0

The integration of Industry 4.0 and Industry 5.0 offers a complementary pathway for small-scale industries (SSIs) to transform their operations. While Industry 4.0 emphasizes automation together with 5.0, connectivity, and data-driven decision-making, Industry 5.0 brings in a human-centric, sustainable, and resilient dimension. Together, they create a balanced ecosystem where efficiency and productivity are coupled with personalization and social responsibility.

Key Opportunities and Benefits:

- **Enhanced Productivity and Efficiency:** Industry 4.0 technologies such as AI, IoT, and predictive analytics streamline operations, reduce downtime, and optimize resources, while Industry 5.0 ensures that these efficiencies are aligned with long-term sustainability goals.
- **Mass Customization and Personalization:** With Industry 4.0 enabling smart manufacturing and data-driven insights, Industry 5.0 enhances the value chain by integrating human creativity and AI for customized products that meet diverse customer needs.
- **Sustainability and Circular Economy:** Industry 5.0 extends the benefits of digitalization by embedding eco-friendly production models, waste reduction strategies, and energy optimization, offering SSIs opportunities to compete responsibly in global markets.
- **Human-Machine Collaboration:** Industry 4.0 reduces manual effort through automation, while Industry 5.0 ensures that workers remain central to innovation by leveraging AI and robotics as collaborative partners rather than replacements.
- **Resilience and Agility:** Together, 4.0 and 5.0 prepare SSIs to withstand disruptions—4.0 through predictive analytics and digital supply chains, and 5.0 through resilient, human-centric approaches to crisis management.
- **Inclusive Growth:** By combining digital skills (4.0) with ethical AI practices (5.0), SSIs can foster inclusive industrial growth that empowers both workforce and local communities.

5. CONCLUSION

The integration of Artificial Intelligence (AI) within the frameworks of Industry 4.0 and 5.0 presents both opportunities as well as challenges for small-scale industries (SSIs). AI-driven tools can enhance operational efficiency, predictive maintenance, quality assurance, blockchain in supply chain management, and sustainability practices. However, barriers such as limited financial resources, inadequate digital infrastructure, shortage of skilled workforce, and organizational resistance hinder widespread adoption.

While large enterprises have advanced considerably in leveraging Industry 4.0 technologies, SSIs require context-specific strategies that are affordable, scalable, and aligned with their operational realities. Phased adoption models, government incentives, collaborative ecosystems, and low-cost AI platforms can help bridge the technological divide. Importantly, in the transition toward Industry 5.0, AI adoption should not be seen merely as a technological upgrade but as a socio-technical transformation that emphasizes human-machine collaboration, inclusivity, resilience, and sustainable industrial practices. Overall, AI has the potential to transform SSIs into competitive, innovative, and sustainable contributors to the global value chain. Its success depends on structured roadmaps that address SSI-specific constraints while leveraging the combined opportunities of Industry 4.0 and 5.0. Future research and policy interventions should therefore focus on developing inclusive frameworks that enable small-scale industries to thrive in the emerging digital and human-centric industrial era.

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