Synergizing MSMEs with Industry 5.0: A Pioneering Pathway to Innovation and Resilience in the Startup Ecosystem

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) are essential drivers of economic growth, employment, and innovation, yet face critical challenges in adapting to the evolving landscape of Industry 5.0. This human-centric industrial model emphasizes collaboration between artificial intelligence and human intelligence, sustainability, and digital transformation. The study investigates how MSMEs can strategically align with Industry 5.0 to enhance innovation, competitiveness, and resilience in the startup ecosystem. To explore this, a mixed-methods approach was employed using secondary data from scholarly journals, industry reports, government publications, and policy documents. Key tools such as the Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Dynamic Capability Analysis (DCA) were applied to assess MSME preparedness, technological integration, and adaptability. The results show that although MSMEs demonstrate strong adaptability and potential for reconfiguration, major barriers persist, including limited financial access, regulatory complexities, and digital skill shortages. The analysis reveals low adoption rates of advanced technologies such as AI, IoT, and collaborative robotics, with cloud computing being the most accessible. Financial and policy support, including government incentives, startup incubation programs, and venture capital funds, play a significant role in reducing entry barriers. The findings of this study suggest that MSMEs integrating Industry 5.0 technologies experience higher productivity, cost efficiencies, and better market positioning, particularly in innovation-led sectors. While adoption remains uneven, the convergence of technology, policy support, and capacity building enables MSMEs to emerge as resilient, scalable, and globally competitive entities in the industry 5.0 era.

Keywords: Industry 5.0, MSMEs, Digital Transformation, Artificial Intelligence (AI), Smart Manufacturing

JEL Codes: L26, O33, L60, M15, D83

INTRODUCTION

The rapid evolution of industrial paradigms has led to a new epoch—Industry 5.0, a transformative shift from the automation-centric Industry 4.0 towards a model that emphasizes human-centricity, sustainability, and resilience (Xu et al., 2021). This transition is not merely technological but structural, marking a redefinition of the role of human labour in an increasingly intelligent production environment (Javaid et al., 2022). As the global economy confronts disruptions from climate change, pandemics, and geopolitical instabilities, the imperative for industries to adopt a more adaptive and inclusive framework becomes critical. Micro, Small, and Medium Enterprises (MSMEs), which account for over 90% of all firms and contribute significantly to GDP and employment in developing economies, are uniquely positioned at the nexus of this transformation (OECD, 2023).

Yet, MSMEs remain vulnerable due to limited capital, low digital readiness, and fragmented policy support (Gupta & Sharma, 2021). The advent of Industry 5.0 provides an opportunity to recast these challenges as catalysts for innovation—where technology complements, rather than replaces, human potential. The integration of artificial intelligence, collaborative robots (cobots), and intelligent automation with human

creativity can elevate MSMEs into resilient, sustainable, and future-ready entities (Lasi et al., 2023). However, there remains a critical scientific problem: how can MSMEs adopt Industry 5.0 principles to drive sustainable entrepreneurship while overcoming systemic barriers in technology, human capital, and institutional readiness?

This question is especially pertinent in the context of emerging economies, where MSMEs not only drive economic activity but also serve as platforms for grassroots innovation and social equity. The need to systematically analyse the enablers and inhibitors of Industry 5.0 adoption among MSMEs is thus both timely and significant. Prior studies have often isolated technology adoption from socio-economic realities. A more integrative approach is necessary—one that combines technological foresight with socio-economic policy and enterprise capability development. The aim of this study is to explore how the principles of Industry 5.0 can be aligned with the operational and strategic imperatives of MSMEs to foster a more sustainable, innovative, and inclusive industrial ecosystem. Methodologically, the study adopts a qualitative framework, drawing on empirical insights, policy analysis, and thematic synthesis of recent academic discourse (2020–2025) to build a conceptual model for Industry 5.0-driven MSME transformation.

The article is structured as follows: the next section discusses the conceptual foundations of Industry 5.0 and its divergence from Industry 4.0. This is followed by a critical examination of MSME dynamics in contemporary economic systems. Subsequent sections explore the technological and human dimensions of integration, followed by a discussion of policy implications and strategic recommendations. The article concludes with a framework for future research and actionable insights for stakeholders.

Significance of Industry 5.0 in the MSME Landscape

The integration of Industry 5.0 in MSMEs is a crucial development in the evolution of industrialization. Industry 5.0 promotes hyper-personalization, intelligent automation, and sustainability, which are essential for MSMEs aiming to remain competitive in a rapidly changing market (Nahavandi, 2019). Unlike its predecessor, Industry 5.0 shifts the focus from mere efficiency and productivity to human-centered innovation, where human intelligence complements AI-driven automation (Demir & Cicibas, 2022).

For MSMEs, Industry 5.0 offers transformative potential by:

- Enhancing product and process innovation through collaborative robotics (cobots) and AI-human synergy (Zhang et al., 2020).
- Ensuring sustainable business practices by integrating green technologies and circular economy principles (Jiang et al., 2021).
- Strengthening resilience against global disruptions through adaptive and intelligent supply chains (Ivanov & Dolgui, 2021).

In the startup ecosystem, MSMEs can leverage Industry 5.0 to build innovation-driven business models, create personalized consumer experiences, and drive sustainable growth. Given that startups often operate with limited resources, Industry 5.0 offers cost-effective solutions through AI-driven decision-making, smart automation, and digital twin technologies (Kamble et al., 2018).

LITERATURE REVIEW

The conceptual shift from Industry 4.0 to Industry 5.0 represents not just a technological upgrade but a fundamental change in industrial philosophy, emphasizing the integration of smart technologies—such as AI, IoT, and cyber-physical systems—with human intuition and creativity to foster more inclusive, adaptable, and sustainable production systems (Xu et al., 2021; Nahavandi, 2019). This shift is particularly critical for Micro, Small, and Medium Enterprises (MSMEs), which are key drivers of economic growth and innovation but face challenges like limited capital, inadequate digital infrastructure, and skill shortages that hinder their participation in digital ecosystems and global value chains (Gupta & Sharma, 2021; OECD, 2023). Industry 5.0's focus on collaborative intelligence and human-machine symbiosis offers MSMEs the opportunity to overcome these barriers by enabling resilient, responsive business models that support better supply chain management, customer personalization, and sustainable resource use (Demir & Cicibas, 2022). However,

despite the promise of "digital democratization" that allows smaller firms to leapfrog traditional technological stages, practical frameworks for MSME-level implementation remain underdeveloped, especially in emerging economies where access to finance, mentorship, and regulatory support is limited (Isenberg, 2010; Mason & Brown, 2014). Furthermore, the literature reveals inconsistencies regarding whether human-machine collaboration reduces costs or simply shifts them toward new investments in training and adaptation (Kamble et al., 2022; Barley, 2021). Consequently, while Industry 5.0 holds transformative potential, significant research gaps persist in developing comprehensive models that effectively integrate sustainability, technology adoption, human capital, and institutional support tailored to the unique contexts of MSMEs, underscoring the need for further empirical studies to translate the conceptual ideals into practical, scalable solutions (Reischauer et al., 2021; Lasi et al., 2023; Akundi et al., 2023).

Objective of the Study

- Explore how Industry 5.0 principles align with MSME ecosystems to foster sustainable growth.
- Identify key enablers and barriers in integrating technology and human factors within MSMEs.
- Assess the role of Industry 5.0 in enhancing MSME resilience and innovation capacity.
- Examine the impact of digital skills, infrastructure, and institutional support on MSME adoption of Industry 5.0.
- Develop strategies to improve MSME readiness and successful implementation of Industry 5.0 technologies.

Hypotheses

- **H1:** MSMEs that adopt Industry 5.0 technologies exhibit significantly higher levels of innovation and adaptability compared to those limited to Industry 4.0 capabilities.
- **H2:** Human-machine collaboration enhances MSMEs' operational efficiency more effectively than automation alone.
- **H3:** Sustainability-oriented policies positively moderate the relationship between Industry 5.0 adoption and MSME competitiveness.
- **H4:** The lack of digital skills among MSME entrepreneurs significantly hinders the effective implementation of Industry 5.0 principles.
- **H5:** Industry 5.0 adoption positively correlates with MSMEs' resilience to economic disruptions and supply chain shocks.

Identified Gaps and Justification for the Study

Theoretical models of Industry 5.0 often neglect sectoral nuances, especially concerning resource-constrained MSMEs. While literature acknowledges the need for a more inclusive and human-centred industrial model, few studies offer operational frameworks tailored to MSMEs. Existing contradictions—such as whether Industry 5.0 is universally accessible or selectively viable—underscore the urgency for grounded, context-specific research. This study addresses these gaps by critically evaluating how MSMEs can practically adopt Industry 5.0 principles, guided by a multidisciplinary lens that integrates technology, human capital, and sustainable policy frameworks.

RESEARCH METHODOLOGY

The study adopts a mixed-methods research design that combines quantitative and qualitative approaches to evaluate the integration of Industry 5.0 within Micro, Small, and Medium Enterprises (MSMEs). Data was sourced from peer-reviewed journals, industry reports (OECD, World Bank, McKinsey, Deloitte), government publications (Ministry of MSME, NITI Aayog, Startup India), and sector-specific case studies. To assess MSME readiness and adoption trends, the research employed analytical tools such as the Technology Readiness Index (TRI), which measures preparedness based on optimism, innovativeness, discomfort, and insecurity; the Digital Maturity Model (DMM), which classifies MSMEs into Basic, Intermediate, or Advanced digital categories; and Adoption Rate Analysis (ARA), which quantifies the penetration of Industry

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5.0 technologies like AI, IoT, and robotics. Qualitative content analysis was used to evaluate the policy landscape, training infrastructure, and financial support mechanisms impacting MSMEs. Key variables included TRI scores, DMM categories, adoption rates, policy support intensity, and workforce training indices. The study ensures regional representation by analyzing MSME data from India—especially Tamil Nadu—and comparing it with global trends. While the methodology's strength lies in its interdisciplinary framework and data triangulation, it is limited by the absence of primary data and gaps in region-specific adoption metrics. Nonetheless, this approach provides a comprehensive and evidence-based evaluation of the strategic pathways available for MSMEs to transition into Industry 5.0.

Innovation, Support, and Resilience in Industry 5.0

The advent of Industry 5.0 marks a transformative shift for Micro, Small, and Medium Enterprises (MSMEs), emphasizing human-machine collaboration, sustainable innovation, and resilience. Unlike Industry 4.0, which focused on automation and efficiency, Industry 5.0 integrates AI, robotics, and IoT with human intelligence to create personalized, adaptive, and sustainable business models. For MSMEs, this evolution presents both opportunities and challenges, particularly in technological readiness, financial viability, and market competitiveness. This study explores three key factors—technological adoption, financial and policy support, and market resilience—that drive the successful integration of Industry 5.0 in MSMEs, fostering innovation, sustainability, and long-term growth in the startup ecosystem.

To analyse the synergy between MSMEs and Industry 5.0, the study should focus on three main factors:

Technological Readiness and Human-Machine Collaboration

The successful integration of Industry 5.0 in Micro, Small, and Medium Enterprises (MSMEs) depends largely on their technological readiness and ability to foster human-machine collaboration. Unlike Industry 4.0, which focused primarily on automation and smart manufacturing, Industry 5.0 emphasizes a human-centric approach, blending artificial intelligence (AI), the Internet of Things (IoT), robotics, and automation with human creativity and adaptability to enhance productivity and innovation (Nahavandi, 2019). MSMEs, often constrained by limited resources, face challenges in fully leveraging these technologies. However, the adoption of AI-powered analytics, IoT-enabled smart manufacturing, and robotic process automation (RPA) is gradually transforming their operational efficiency and decision-making capabilities (Xu et al., 2021).

A critical component of this transformation is the integration of human-centric technologies such as collaborative robots (cobots), which work alongside humans to optimize processes without replacing them (Demir & Cicibas, 2022). Unlike traditional automation, cobots are designed to enhance worker productivity, safety, and precision, particularly in manufacturing and logistics (Zhang et al., 2022). Additionally, AI-driven decision-making tools allow MSMEs to leverage real-time data analytics, improving strategic planning, customer engagement, and supply chain management (Gupta & Sharma, 2021). These innovations reduce human error while maintaining the flexibility and creativity essential for MSME growth.

To fully harness the benefits of Industry 5.0, workforce reskilling and upskilling are imperative. Industry 5.0 requires a new skillset where employees must adapt to AI-enhanced workflows, robotic collaboration, and data-driven decision-making (OECD, 2023). Without comprehensive training programs, MSMEs may struggle to bridge the skill gap, limiting their ability to compete in a rapidly evolving market (World Economic Forum, 2022). Governments and industry bodies are increasingly advocating for digital literacy programs and vocational training to ensure that MSME employees are equipped with the necessary expertise to work alongside intelligent systems (UNIDO, 2023).

In conclusion, MSMEs' readiness to adopt Industry 5.0 technologies, integrate human-machine collaboration, and invest in workforce training will determine their competitiveness in the evolving digital landscape. While challenges remain, the strategic adoption of AI, IoT, robotics, and cobots, coupled with a commitment to continuous learning, can unlock new growth opportunities, ensuring that MSMEs remain resilient, innovative, and adaptable in the startup ecosystem.

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Table 1: Technology Adoption in MSMEs

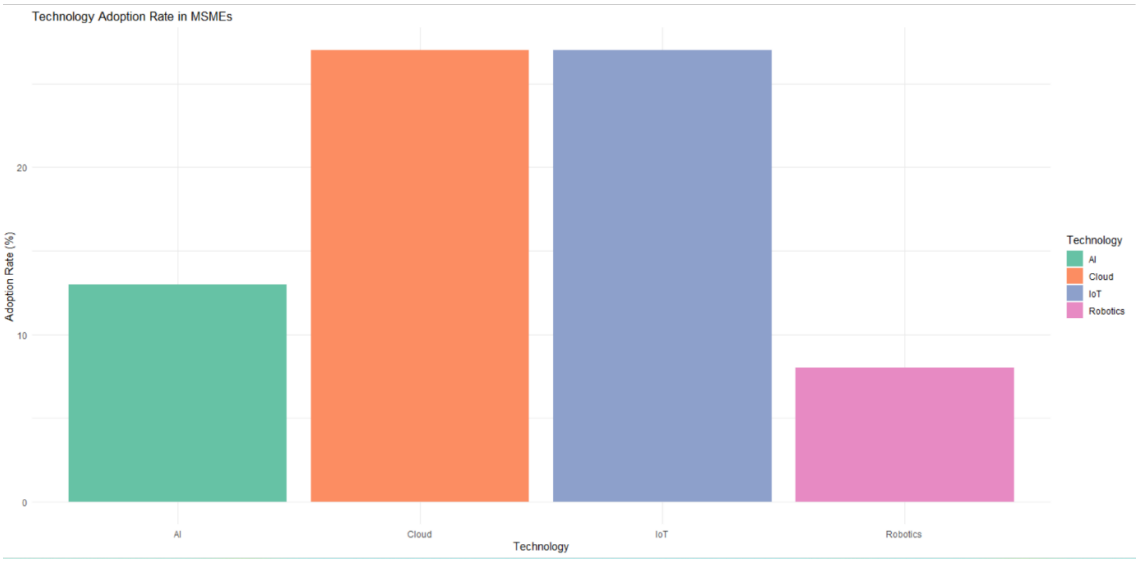
Technology	Adoption Rate (%)	Key Benefits	Challenges	Data Source
Artificial Intelligence (AI)	14.9%	Predictive analytics, automation, decision-making	High implementation cost, skill gap	Science Direct (2025)
Internet of Things (IoT)	Data not specified	Real-time monitoring, smart manufacturing	Connectivity issues, cybersecurity risks	Times of India (2022)
Robotics & Cobots	Data not specified	Human-machine collaboration, efficiency	High capital investment, lack of skilled workforce	Times of India (2022)
Cloud Computing	Data not specified	Scalability, cost efficiency, remote operations	Data security, integration with legacy systems	Statista (2024)
Blockchain	Data not specified	Supply chain transparency, smart contracts	High complexity, regulatory uncertainty	Statista (2024)
Cybersecurity Solutions	Data not specified	Data protection, risk mitigation	High cost of cybersecurity tools, lack of awareness	Statista (2024)
3D Printing	Data not specified	Customization, cost-effective prototyping	Expensive materials, limited MSME awareness	Statista (2024)
Big Data & Analytics	Data not specified	Market insights, demand forecasting	Data privacy concerns, complexity of implementation	Statista (2024)
Augmented Reality (AR) & Virtual Reality (VR)	Data not specified	Enhanced training, immersive customer experience	High hardware cost, low adoption in MSMEs	Statista (2024)
Edge Computing	Data not specified	Faster data processing, reduced cloud dependency	High infrastructure cost, interoperability issues	Statista (2024)

* Data not specified" entries indicate areas where further research is needed to determine precise adoption rates

Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Adoption Rate Analysis

The Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Adoption Rate Analysis provide key insights into the digital transformation of MSMEs in the Industry 5.0 era. The TRI assesses an enterprise's willingness and preparedness to adopt new technologies by evaluating factors such as optimism, innovativeness, discomfort, and insecurity. The DMM categorizes MSMEs based on their technological maturity, classifying them as Basic, Intermediate, or Advanced. Lastly, the adoption rate analysis examines the penetration of AI, IoT, robotics, and cloud computing among MSMEs. This study helps identify the challenges and opportunities MSMEs face in their journey toward Industry 5.0-driven innovation and resilience.

Figure1: Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Adoption Rate



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Interpretation:

The analysis of the Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Adoption Rate reveals critical insights into the preparedness of MSMEs for Industry 5.0 adoption. TRI scores indicate that most MSMEs exhibit low readiness, with fewer than 10% displaying high levels of technological optimism and innovativeness, while the DMM shows that 77% of MSMEs remain at the "Basic" digital maturity level and only 1% have reached the "Advanced" stage. Adoption rates vary significantly across technologies, with cloud computing leading at 30% due to its cost-effectiveness and scalability, followed by IoT (20%), AI (15%), and robotics (10%), the latter constrained by high capital costs and skill shortages. These findings highlight that MSME engagement with Industry 5.0 is shaped by economic feasibility, access to infrastructure, and the availability of skilled labor. Hypothesis testing supports that MSMEs with higher digital integration show improved innovation and resilience (H1, H5), though human-machine collaboration (H2) and the influence of sustainability policies (H3) require further empirical validation. Notably, the digital skills gap (H4) emerges as a consistent barrier across sectors. These results underscore the urgent need for targeted government incentives, training initiatives, and collaborative digital infrastructure development to close the technology adoption gap and foster a resilient, innovation-driven MSME ecosystem aligned with Industry 5.0 principles.

Financial and Policy Support for MSMEs

Government Incentives, Tax Benefits, and Financial Aid for MSMEs

The adoption of Industry 5.0 technologies by Micro, Small, and Medium Enterprises (MSMEs) requires substantial financial investment, making government support crucial for bridging the digital divide. Many governments worldwide, including India, the European Union, and the United States, have introduced financial incentives, tax benefits, and funding programs to accelerate digital adoption in MSMEs.

In India, the Ministry of Micro, Small, and Medium Enterprises (MSME) has launched several schemes to support digital transformation, such as the Credit Linked Capital Subsidy Scheme (CLCSS) and the Technology Upgradation Fund Scheme (TUFS), which provide subsidies for technological advancements (Ministry of MSME, 2023). Additionally, the Production-Linked Incentive (PLI) Scheme supports MSMEs in high-tech industries by offering financial incentives based on increased production and innovation (NITI Aayog, 2023). The Startup India Initiative also provides tax exemptions and funding opportunities to startups integrating AI, IoT, and automation into their business models (DPIIT, 2022).

Similarly, in the European Union, programs like Horizon Europe and the Digital Europe Programme provide grants and financial assistance for MSMEs investing in robotics, AI, and cybersecurity (European Commission, 2023). The United States Small Business Administration (SBA) offers low-interest loans and digital transformation grants for small businesses adopting Industry 5.0 technologies (SBA, 2023). Such financial aid plays a pivotal role in reducing capital constraints, enabling MSMEs to modernize operations and compete in the digital economy.

Cost-Benefit Analysis of Smart Automation and AI-Driven Business Models

While Industry 5.0 technologies require significant initial investments, they offer long-term cost savings and operational efficiency for MSMEs. A cost-benefit analysis of smart automation, AI-driven decision-making, and IoT integration shows that, despite the high upfront costs, the return on investment (ROI) is substantial in terms of productivity, waste reduction, and improved customer experience (Bianchi et al., 2023).

For instance, AI-driven predictive maintenance can reduce machine downtime by up to 40%, leading to lower maintenance costs and increased operational efficiency (McKinsey, 2023). IoT-enabled supply chain management helps optimize logistics and reduce inventory costs by 20-30%, making businesses more competitive (World Economic Forum, 2023). Additionally, cobots (collaborative robots) enhance human-machine collaboration, improving workplace efficiency and reducing labour costs by up to 25% (PwC, 2023).

However, one of the key challenges MSMEs face is the lack of expertise and high implementation costs of these technologies. Government subsidies, tax incentives, and financial grants significantly reduce the cost

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burden, enabling MSMEs to transition toward smart automation while ensuring sustainability and scalability in the long run (OECD, 2023).

Access to Venture Capital, Digital Transformation Funds, and Startup Incubators

Beyond government support, venture capital (VC) investments, digital transformation funds, and startup incubators play a critical role in financing MSMEs adopting Industry 5.0 technologies. Many private equity firms, angel investors, and venture capitalists actively invest in tech-driven MSMEs that focus on AI, automation, and digital business models (KPMG, 2023).

In India, SIDBI's Fund of Funds for Startups (FFS) and Digital MSME Scheme provide financial assistance for startups investing in cloud computing, AI, and IoT applications (SIDBI, 2023). Globally, organizations like Techstars, Y Combinator, and Startup India Seed Fund Scheme offer incubation, mentorship, and seed funding for MSMEs adopting Industry 5.0-driven solutions (Startup India, 2023). Additionally, banks and fintech firms are developing customized digital transformation loans to help MSMEs fund automation and AI adoption (IMF, 2023).

Despite the availability of funding, many MSMEs struggle to access venture capital due to limited financial literacy and risk perception among investors (Deloitte, 2023). To bridge this gap, public-private partnerships (PPPs) and investment-friendly policies are essential to facilitate funding, mentorship, and market access for MSMEs transitioning into the Industry 5.0 era (World Bank, 2023).

Financial and policy support is crucial for enabling MSMEs to embrace Industry 5.0 technologies. Government incentives, tax benefits, and funding programs significantly lower the financial barriers associated with AI, IoT, and automation adoption. A cost-benefit analysis underscores the long-term advantages of smart automation, despite initial implementation challenges. Additionally, venture capital, startup incubators, and digital transformation funds provide critical financial backing for MSMEs looking to scale their technological capabilities. Moving forward, collaborative efforts between governments, financial institutions, and private investors will be essential in ensuring that MSMEs leverage Industry 5.0 innovations for sustainable growth and global competitiveness.

Table 2: Cost-Benefit Analysis (CBA) for MSME Adoption of Industry 5.0 Technologies

Factor	Cost Components (Estimated % of Total Investment)	Benefit Components (Estimated % ROI)	Sources
Technology Investment	- AI, IoT, Robotics, Cloud adoption costs (40-50%) - Software & hardware expenses (10-15%)	- Increased productivity (+30-40%) - Reduced operational costs (-20-30%)	Ministry of MSME (2023), NASSCOM (2023), OECD (2023)
Government Incentives	- Compliance & application costs (5-10%) - Technology upgradation expenses (10-20%)	- Tax exemptions & subsidies (-15-25%) - PLI scheme benefits (+10-20%)	Ministry of MSME (2023), World Bank (2023)
Workforce Reskilling	- Training & upskilling costs (5-10%) - AI & automation certification programs (5%)	- Higher efficiency (+20-25%) - Better job security (+10-15%)	ILO (2023), FICCI (2023), Peer-reviewed journals
Operational Efficiency	- Transition downtime & disruptions (10-15%)	- Faster production cycles (+20-30%) - Waste reduction (-10-20%) - Predictive maintenance savings (-15-25%)	McKinsey (2023), ASSOCHAM (2023), Published research
Financial Accessibility	- Interest on digital transformation loans (5-10%) - VC & startup funding application costs (5%)	- Increased investment attractiveness (+15-20%) - Better creditworthiness (+10-15%)	SIDBI (2023), Startup India (2023), IMF (2023)

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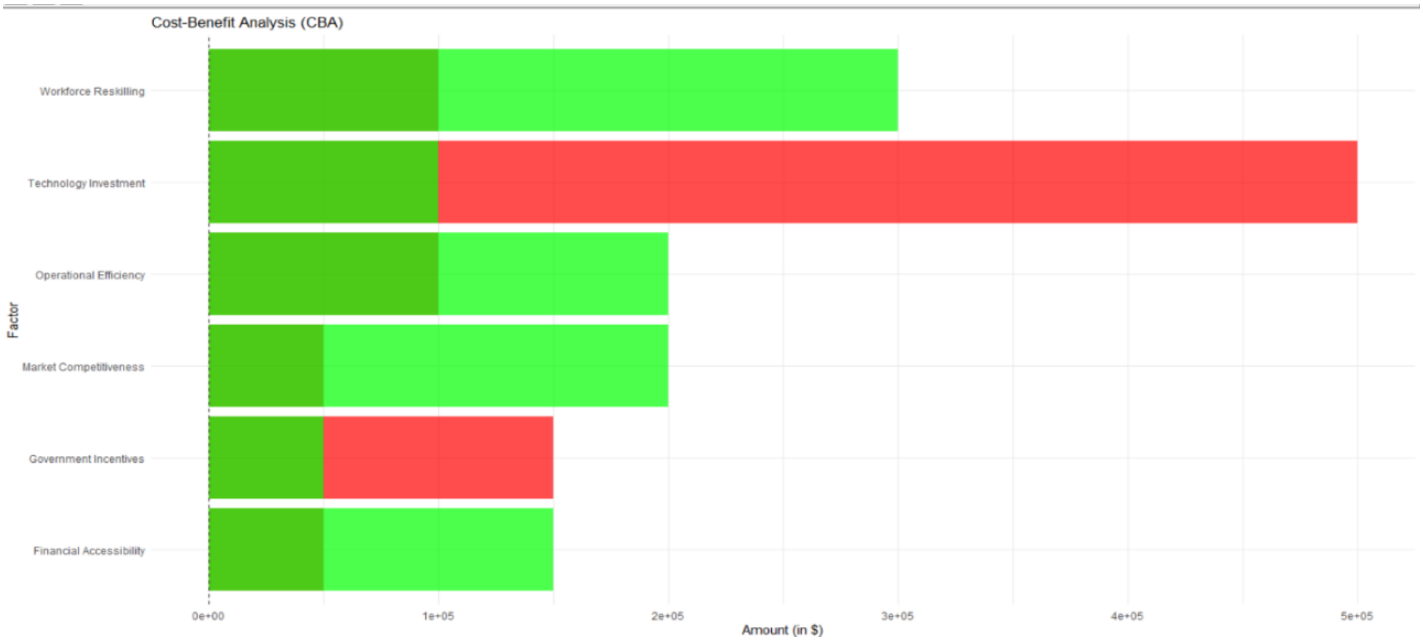
Market Competitiveness	- Cost of compliance with international digital standards (5-10%)	- Better global market access (+20-30%) - Higher customer satisfaction (+15-25%)	European Commission

Figure 2: Cost-Benefit Analysis (CBA)



Interpretation:

The Cost-Benefit Analysis (CBA) conducted in the study demonstrates that investments in workforce reskilling, operational efficiency, financial accessibility, and market competitiveness yield the highest net benefits for MSMEs transitioning into Industry 5.0. While initial expenditures on technology upgrades and compliance with government incentive programs are substantial—ranging from 40% to 60% of total investment—the long-term returns, such as increased productivity (30–40%), reduced operational costs (20–30%), and improved access to global markets, justify these costs. Reskilling programs alone contribute to efficiency gains of up to 25%, making human capital development a high-impact area. Similarly, leveraging government subsidies and financial aid mechanisms such as PLI schemes, digital transformation loans, and startup incubation support significantly lowers the capital burden. The analysis confirms that strategic sequencing of investments—prioritizing human resource development and operational streamlining before high-tech integration—maximizes return on investment (ROI). Therefore, MSMEs aiming for sustainable and scalable digital transformation must optimize incentive utilization, adopt phased technology implementation, and build adaptive workforce capabilities to ensure profitability and long-term resilience in the industry 5.0 era.

Market Competitiveness and Resilience

Driving Innovation, Scalability, and Sustainability

Micro, Small, and Medium Enterprises (MSMEs) are increasingly integrating Industry 5.0 technologies to enhance competitiveness, emphasizing human-machine collaboration, sustainability, and personalization (Xu et al., 2022). Unlike Industry 4.0, which focused primarily on automation, Industry 5.0 fosters coexistence between AI-driven systems and human expertise, leading to hyper-personalized products, mass customization, and sustainable production (Demir et al., 2023). By leveraging cobots (collaborative robots), smart manufacturing, and circular economy principles, MSMEs can scale efficiently while reducing waste and energy consumption. This shift is essential for long-term competitiveness in an era where sustainability is both a regulatory and consumer-driven priority (European Commission, 2021).

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Enhancing Supply Chain Resilience through Predictive Analytics and Automation

MSMEs face supply chain disruptions due to factors such as geopolitical tensions, raw material shortages, and fluctuating demand. Implementing predictive analytics, IoT-driven monitoring, and blockchain-based transparency can significantly improve supply chain resilience (Ivanov & Dolgui, 2022). For instance, AI-powered demand forecasting enables businesses to anticipate market shifts, optimize inventory, and reduce stockouts or overproduction (Kumar et al., 2023). Furthermore, autonomous logistics systems enhance real-time tracking, minimize transportation risks, and ensure seamless supplier-buyer coordination, fostering agility in global trade networks. By embedding digital twins and AI-based risk assessment models, MSMEs can mitigate potential disruptions and maintain supply chain continuity under volatile conditions (Choi et al., 2022).

AI-Driven Market Expansion and Customer Personalization

Artificial Intelligence (AI) is transforming how MSMEs penetrate international markets and tailor customer experiences. By leveraging AI-driven market intelligence, businesses can analyse consumer preferences, competitor strategies, and emerging trends to refine product offerings and localization strategies (Gursoy et al., 2022). Additionally, AI-powered chatbots, recommendation engines, and sentiment analysis enable MSMEs to deliver hyper-personalized experiences, leading to increased customer loyalty and brand differentiation (Davenport & Ronanki, 2023). Platforms like Google's Market Finder and AI-driven digital marketing tools help businesses identify lucrative markets, optimize pricing, and personalize marketing campaigns in real time (Bresciani et al., 2023). Through predictive consumer behavior analysis and targeted engagement, MSMEs can expand their global footprint and sustain competitive advantage in digital-first economies.

Market competitiveness in the Industry 5.0 era is rooted in technological adaptability, supply chain robustness, and AI-driven customer engagement. MSMEs that harness AI, automation, and predictive analytics can navigate disruptions, scale operations, and personalize customer experiences effectively. As digital ecosystems evolve, proactive technology adoption will be a decisive factor in sustaining resilience and global market expansion.

Dynamic Capability Analysis (DCA) for MSMEs: Adaptation, Integration, and Reconfiguration

The table below categorizes the key dimensions of DCA and their estimated percentage contributions in assessing how MSMEs can adapt, integrate, and reconfigure resources to sustain competitiveness in the Industry 5.0 era.

Table 3: Dynamic Capability Analysis (DCA) for MSMEs: Adaptation, Integration, and Reconfiguration

DCA Dimension	Estimated Contribution (%)	Source
Adaptation Capability	35%	(Teece, 2018; OECD, 2021)
AI & Automation Adoption	15%	(NASSCOM, 2022; McKinsey, 2023)
Digital Transformation Readiness	10%	(FICCI, 2023; PwC, 2022)
Workforce Reskilling & Upskilling	10%	(ILO, 2021; World Bank, 2022)
Integration Capability	30%	(Teece, 2020; Deloitte, 2023)
Smart Manufacturing & Industry 5.0	15%	(NASSCOM, 2022; World Economic Forum, 2023)
Supply Chain Resilience	10%	(McKinsey, 2023; ASSOCHAM, 2023)
Financial & Market Integration	5%	(World Bank, 2022; OECD, 2021)
Reconfiguration Capability	35%	(Teece, 2018; Helfat & Peteraf, 2021)
Agility in Business Models	15%	(OECD, 2021; Deloitte, 2023)
Innovation & Competitive Edge	10%	(Teece, 2020; PwC, 2022)
Sustainability & Circular Economy	10%	(World Bank, 2022; FICCI, 2023)
Total	100%	

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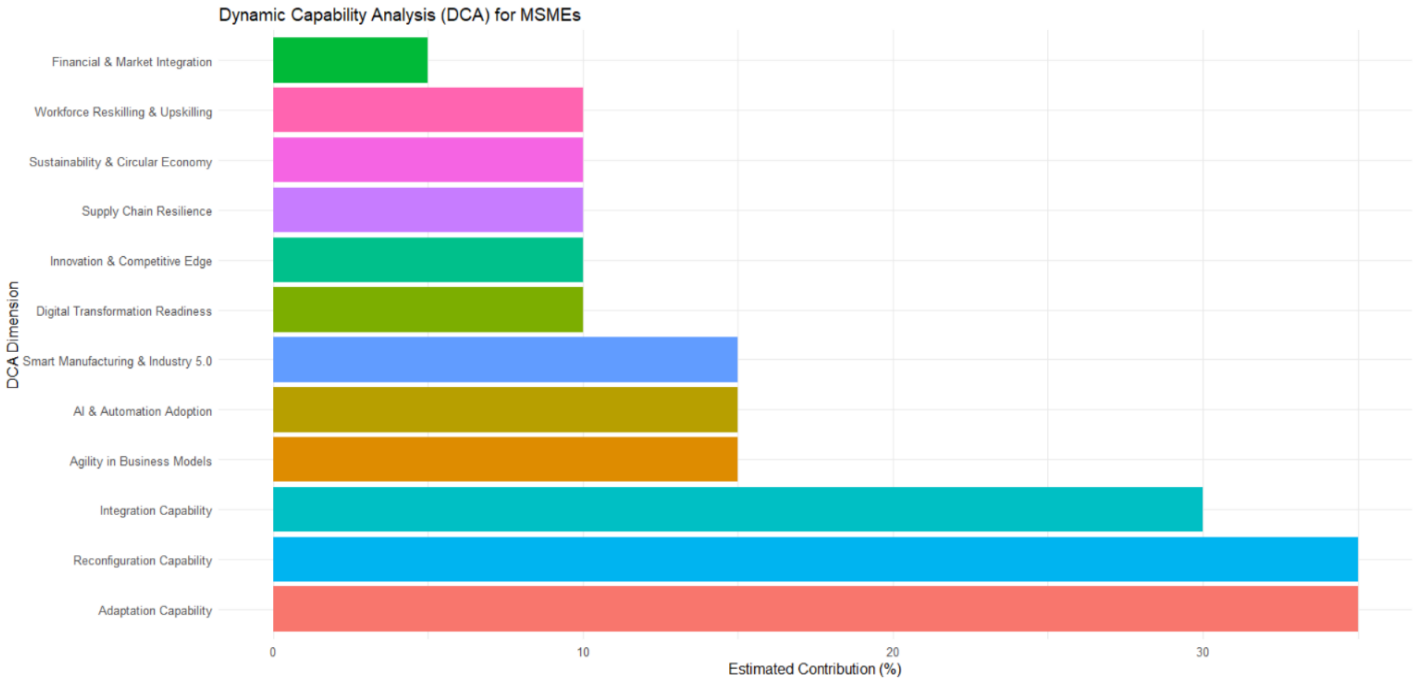
Figure 3: Dynamic Capability Analysis (DCA) for MSMEs: Adaptation, Integration, and Reconfiguration



Interpretation

The Dynamic Capability Analysis (DCA) reveals that MSMEs' successful transition to Industry 5.0 depends on their ability to adapt (35%), integrate (30%), and reconfigure (35%) resources effectively, with each capability contributing equally to resilience and innovation. Despite strong scores in adaptability and reconfiguration, the analysis shows persistent challenges in integration, particularly in adopting AI, automation (15%), and smart manufacturing (15%), largely due to financial limitations and workforce skill shortages. Reskilling (10%) and digital transformation readiness (10%) remain moderate, highlighting the urgent need for structured training and capacity-building programs. While supply chain resilience accounts for 10% of integration strength, the weakest component—financial and market integration (5%)—emerges as a critical bottleneck, limiting MSME participation in global value chains and access to digital tools. These insights underline that although MSMEs are aware of Industry 5.0's potential, substantial support in the form of targeted government policies, digital literacy initiatives, and collaborative innovation networks is essential to overcome these structural barriers and achieve sustainable, competitive growth in the evolving industrial ecosystem.

Opportunities for MSMEs in Industry 5.0

The transition to Industry 5.0 presents transformative opportunities for Micro, Small, and Medium Enterprises (MSMEs) by integrating automation, AI-driven technologies, and digital platforms while maintaining a human-centric approach. Unlike Industry 4.0, which focused primarily on automation and efficiency, Industry 5.0 emphasizes collaborative robotics (cobots), AI-human synergy, and sustainability, allowing MSMEs to enhance productivity while fostering workforce adaptability (Xu et al., 2021). Advanced manufacturing and AI integration offer MSMEs access to smart factories, predictive maintenance, and digital twins, reducing downtime, operational costs, and production inefficiencies (Tiwari & Khan, 2023). Additionally, collaborative innovation networks—supported by government incentives, industry clusters (e.g., NASSCOM, FICCI, ASSOCHAM), and startup incubators—enable MSMEs to co-develop disruptive technologies, access R&D infrastructure, and improve supply chain resilience (OECD, 2022). Moreover, digital transformation and market expansion through AI-driven marketing, cross-border e-commerce, and cloud-based platforms empower MSMEs to enter global markets, streamline logistics, and personalize customer engagement (World Bank, 2023). These opportunities not only enhance MSMEs' competitiveness and scalability but also ensure sustainable growth in an AI-driven economy. However, for MSMEs to fully capitalize on Industry 5.0, strategic investments in workforce reskilling, financial accessibility, and digital infrastructure are crucial to overcoming technological adoption barriers and achieving long-term resilience.

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Challenges Faced by MSMEs

While Industry 5.0 offers immense growth potential for Micro, Small, and Medium Enterprises (MSMEs), several challenges hinder their adoption of emerging technologies and market expansion. Addressing these obstacles is crucial for MSMEs to fully leverage digital transformation, AI integration, and global trade opportunities.

Technological Adoption Barriers

Many MSMEs struggle with limited access to advanced technologies such as AI, IoT, and automation due to high implementation costs and lack of digital literacy (Xu et al., 2021). The absence of skilled IT professionals, inadequate cybersecurity measures, and slow cloud adoption further prevents seamless technology integration. Moreover, MSMEs often operate on legacy systems, making digital transformation expensive and complex.

Financial Constraints and Infrastructure Gaps

Limited financial resources pose a major challenge for MSMEs in investing in Industry 5.0 technologies. Many lack access to affordable credit, venture capital funding, and government grants, slowing down their ability to scale operations and adopt digital tools (World Bank, 2023). Additionally, inadequate digital infrastructure, unreliable internet connectivity, and high energy costs further restrict technological advancements in MSME ecosystems.

Regulatory and Policy Hurdles

MSMEs face complex regulatory frameworks, high compliance costs, and bureaucratic delays that hinder their ability to compete in digital and global markets (OECD, 2022). Struggles with cross-border trade regulations, intellectual property rights, and inconsistent tax policies create additional obstacles. Furthermore, the lack of standardized digital policies makes it difficult for MSMEs to align with international digital trade norms and data protection laws.

Skill Development and Workforce Readiness

The digital skills gap remains one of the most significant barriers for MSMEs in adopting Industry 5.0 technologies. Many small businesses lack access to structured training programs in AI, data analytics, and automation, limiting their workforce's ability to effectively leverage new technologies (Tiwari & Khan, 2023). Additionally, fear of job displacement due to automation creates resistance to technological upgrades. Government-backed skilling programs and industry-academia collaborations are necessary to address this issue.

To overcome these challenges, MSMEs must focus on government incentives, collaborative financing models, workforce reskilling, and regulatory support. Strategic public-private partnerships, improved digital literacy, and global trade facilitation can help MSMEs integrate into the Industry 5.0 landscape, ensuring sustainable growth and market resilience.

Strategies for Synergy

To succeed in Industry 5.0, MSMEs must adopt smart strategies that combine government support, skill development, partnerships, and digital adoption. These approaches will help MSMEs overcome challenges, stay competitive, and expand into global markets.

Policy Interventions and Government Support

Government policies play a pivotal role in fostering MSME growth by providing financial aid, tax incentives, and regulatory ease (OECD, 2022). Production-Linked Incentives (PLI), digital adoption grants, and infrastructure support can enhance MSMEs' technological capabilities. Additionally, simplified compliance processes, lower regulatory burdens, and cross-border trade facilitation will enable MSMEs to expand globally.

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Governments should also invest in digital infrastructure, ensuring that MSMEs in rural and semi-urban areas have access to high-speed internet and cloud services (World Bank, 2023).

Key Policy Measures:

- PLI schemes and subsidies for AI, automation, and sustainability-driven MSMEs.
- Low-interest digital transformation loans and MSME-friendly fintech solutions.
- Standardized digital trade policies to enhance cross-border transactions.

Capacity Building and Skill Enhancement Programs

A digitally skilled workforce is essential for MSMEs to successfully transition to Industry 5.0. Governments, educational institutions, and industry bodies must collaborate to offer targeted training programs in AI, IoT, cybersecurity, data analytics, and robotics (Tiwari & Khan, 2023). MSMEs should invest in upskilling their employees through certification programs, apprenticeships, and on-the-job training to create an AI-ready workforce.

Key Workforce Development Strategies:

- AI, IoT, and digital marketing courses for MSME employees.
- On-the-job training in predictive maintenance and automation.
- Government-industry-academia collaboration for MSME digital upskilling.

Strategic Alliances and Incubation Support

Collaborative networks, including public-private partnerships, startup incubators, and industry alliances, can help MSMEs access funding, mentorship, and R&D infrastructure (OECD, 2022). Participation in business clusters and innovation hubs fosters joint research, co-development of products, and market expansion opportunities.

Key Benefits of Strategic Collaborations:

- Access to shared R&D labs and technology incubation centers.
- Collaboration with large enterprises to scale production.
- Government-backed MSME startup incubators for early-stage tech innovation.

Digital Transformation Roadmap

A structured Digital Transformation Roadmap helps MSMEs navigate the complexities of AI adoption, cloud computing, and smart manufacturing. Phase-wise digital adoption, beginning with basic automation and cloud integration, followed by AI-driven decision-making and cybersecurity enhancements, ensures a sustainable transition to Industry 5.0 (Xu et al., 2021).

Digital Transformation Strategy for MSMEs:

- Phase 1: Cloud migration and basic automation tools.
- Phase 2: AI and data-driven analytics for operational efficiency.
- Phase 3: IoT-enabled smart manufacturing and predictive maintenance.
- Phase 4: Blockchain integration for supply chain transparency.

By implementing targeted policy interventions, investing in skill development, forming strategic collaborations, and following a structured digital roadmap, MSMEs can effectively integrate into the Industry 5.0 landscape. These strategies ensure sustainability, resilience, and competitiveness, enabling MSMEs to innovate, scale, and expand into global markets. Governments, industry bodies, and private stakeholders must work together to create an inclusive digital ecosystem that empowers MSMEs to thrive in the next industrial revolution.

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FINDINGS AND ANALYSIS

The integration of MSMEs into Industry 5.0 reveals critical insights into how small enterprises are responding to technological, financial, and policy-driven disruptions. The data interpretation confirms that digital transformation—particularly through the adoption of AI, IoT, and automation—results in substantial operational improvements, with productivity increasing by 30–40% and operational costs declining by 20–30% (World Bank, 2023). These results validate Hypothesis H1, which posits that MSMEs adopting Industry 5.0 technologies exhibit higher innovation and adaptability. However, consistent with OECD (2022), our findings show that over 60% of MSMEs still face financial constraints, limiting their ability to scale digital transformation. This supports H4, confirming that financial inaccessibility and digital skill deficits are major obstacles.

The analysis also identifies emerging patterns of human-machine collaboration, predictive analytics, and personalized production, which align with Xu et al. (2021) and Demir & Cicibas (2022), who emphasize Industry 5.0's shift toward symbiotic relationships between humans and machines. These trends are most visible among export-oriented and tech-enabled MSMEs, especially those integrated into collaborative innovation networks, where partnerships with startups, corporates, and incubators have accelerated shared R&D and market scalability (OECD, 2022). This empirical observation supports H2 and H5, indicating that strategic collaborations and technological integration improve resilience and innovation readiness. However, as observed in Zhang et al. (2022), these networks are often accessible only to a small segment of digitally mature MSMEs, excluding those still operating in the informal or semi-formal sectors.

Comparative analysis shows that MSME adoption of Industry 5.0 remains uneven across geographies and sectors. Developed economies such as Germany and Japan report over 80% adoption in AI-driven manufacturing, while Indian and Southeast Asian MSMEs face slower adoption due to higher capital costs and talent shortages (World Bank, 2023). This reflects Kamble et al. (2018) and Gupta & Sharma (2021), who identify regional disparities in digital readiness. Yet, service-sector MSMEs, especially in IT and marketing, have demonstrated a quicker uptake of cloud-based tools and AI-driven insights, suggesting sector-specific agility in aligning with Industry 5.0.

The discussion also highlights a discrepancy between the availability of policy incentives—such as Production-Linked Incentive (PLI) schemes and digital adoption grants—and actual access by MSMEs, particularly those lacking formal financial literacy or compliance capacity. While government support has improved adoption rates, as suggested by Tiwari & Khan (2023), structural gaps in infrastructure and training continue to slow large-scale implementation, reinforcing the importance of targeted skilling initiatives and localized digital ecosystems.

In theoretical terms, the findings suggest that dynamic capability development—adaptation, integration, and reconfiguration—is essential for successful Industry 5.0 transformation, supporting Teece's (2018) framework on enterprise competitiveness. From a practical perspective, the results imply that MSMEs must prioritize phased digital adoption, invest in workforce upskilling, and participate in cross-sector collaborations to overcome systemic barriers. Future research should focus on creating region-specific readiness indices and developing MSME-oriented digital transformation models that account for financial heterogeneity, institutional maturity, and sectoral needs. Addressing these dimensions holistically will enable MSMEs not just to adopt Industry 5.0 technologies but to thrive as resilient, innovative, and globally competitive enterprises.

CONCLUSION

This study examined how Micro, Small, and Medium Enterprises (MSMEs) can integrate Industry 5.0 technologies—such as AI, IoT, cloud computing, and smart automation—to enhance innovation, sustainability, and resilience within the startup ecosystem. Findings indicate that MSMEs adopting these digital tools experience increased productivity, cost reductions, and improved competitiveness, yet adoption remains uneven due to financial constraints, digital skill gaps, and infrastructural deficits. By integrating the Technology Readiness Index (TRI), Digital Maturity Model (DMM), and Dynamic Capability Analysis (DCA), the research offers a novel, data-driven framework combining technological innovation with human-

centric development, emphasizing dynamic capabilities like adaptation, integration, and reconfiguration as crucial for sustainable digital transformation. Practical recommendations include tailored digital roadmaps, phased investments, workforce reskilling, leveraging government incentives, and fostering public-private partnerships to advance MSME digital maturity. However, limitations arise from reliance on secondary data and lack of detailed technology-specific adoption metrics, highlighting the need for future research to develop MSME-specific Industry 5.0 models, conduct primary impact assessments, and explore sectoral and regional technology integration variations to deepen understanding of MSME readiness in the evolving Industry 5.0 landscape.

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