Proceedings of the 2nd World Congress on Industrial Engineering and Operations Management
Windsor, Canada, October 14-16, 2025

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/WC02.20250128
Published: October 14, 2025

Transforming the Manufacturing Workforce through AI and Digital Twins: Global Model Insights

Johnson Olaitan and Ahmad Elshennawy
Orlando, Florida, USA
jide.johnson@jjtechnologiesinc.com

Abstract

Industry 5.0 emphasizes human-centric, sustainable manufacturing where AI and digital twin technologies reshape workforce roles and collaboration. This study examines workforce transformation in AI-enabled manufacturing ecosystems, providing insights from Western and Asian models. Research integrates literature, policy frameworks, and case studies (2018-2025) to map workforce competencies and training models. Western approaches focus on adaptive frameworks and cross-functional innovation, while Asian models prioritize state-directed reskilling. A synthesis identifies hybrid pathways bridging scalability with resilience. The paper provides an analytical framework, comparative analysis, and implementation roadmap with recommendations. Findings show Industry 5.0 transitions require aligning technology with workforce readiness through skills development and AI-driven platforms.

Keywords
AI-enabled manufacturing, Digital twins, Workforce transformation, Industry 5.0, Comparative workforce models, Upskilling and reskilling

1. Introduction
Industry 5.0 signals a shift from the automation-centered paradigm of Industry 4.0 to one that emphasizes human–technology collaboration, sustainability, and resilience. Rather than displacing workers, advanced technologies such as artificial intelligence (AI) and digital twins position them as co-creators in production systems, enabling predictive maintenance, real-time optimization, and simulation-driven decision making (Nahavandi, 2019; Wang et al., 2023). These developments generate new demands for skills in data analytics, systems thinking, and AI supervision (Qi & Tao, 2018; Wang et al., 2023).

Yet, workforce transformation strategies vary significantly across regions. Western and European approaches often emphasize decentralized innovation, industry–academia partnerships, and modular upskilling frameworks. In contrast, Asian and Chinese models prioritize state-directed reskilling and vocational integration aligned with national policies (European Commission, 2021; Liu et al., 2023). While both strategies have strengths, research often treats technology adoption and workforce development as separate domains, leaving a gap in understanding how policies, industries, and skills interact in shaping the future of work (OECD, 2022; World Bank, 2021).

This paper addresses that gap by:
1. Developing an analytical framework linking AI and digital twin adoption to workforce readiness.
2. Providing a comparative analysis of Western/European and Asian/Chinese strategies.
3. Proposing a policy-driven implementation roadmap supported by multi-stakeholder collaboration.

Findings indicate that successful Industry 5.0 transitions depend on aligning technological integration with human-centered workforce development, ensuring both resilience and global competitiveness.

2. Literature Review & Analytical Foundations

2.1 Industry 5.0 Principles

Industry 5.0 has been described by Leon (2023) as a shift from the automation-driven paradigm of Industry 4.0 toward a human-centered model that prioritizes sustainability and resilience. Rather than displacing workers, Nahavandi (2019) and Xu et al. (2021) argue that it reframes them as adaptive collaborators within socio-technical systems. This viewpoint emphasizes inclusion, flexibility, and digital empowerment in manufacturing's future. In Industry 5.0, human-technology collaboration integrates into sustainability and resilience frameworks, with workers as adaptable co-creators rather than passive operators.

2.2 Technologies and Workforce Skills

Scholars have identified artificial intelligence (AI) and digital twins as the key enablers of this transition. Lv (2023) and Soldatos et al. (2024) show that AI supports predictive maintenance, defect detection, and process optimization, thereby creating new hybrid roles such as AI supervisors and data interpreters. Qi and Tao (2018) and Soori et al. (2023) emphasize that digital twins extend workforce capacity through process simulation and sustainability planning. Artificial intelligence enables predictive maintenance and optimization, creating hybrid workforce roles within Industry 5.0 ecosystems.

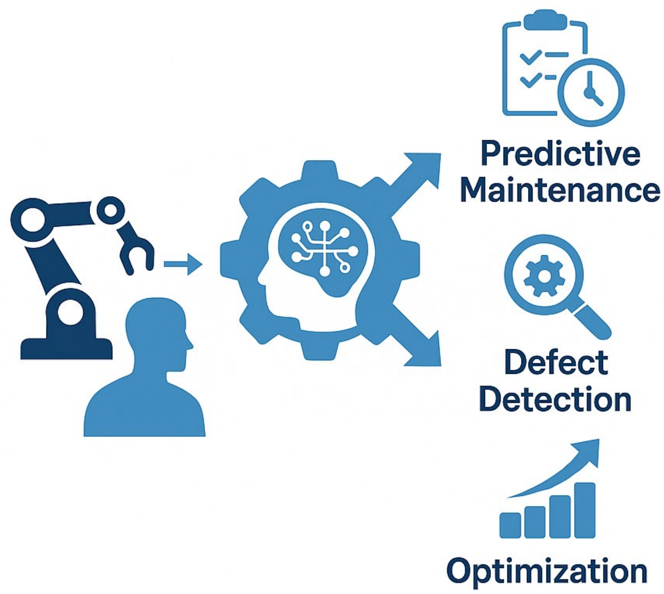

Figure 1. AI in Workforce Transformation

Figure 1 shows AI's role in predictive maintenance, defect detection, and optimization. AI transforms the Industry 5.0 workforce, creating hybrid roles like supervisors and interpreters. Digital twins enhance workforce capabilities through simulation and sustainability planning.

Hazrat et al. (2023) and Tay et al. (2023) argue that simulation-based training via digital twins reduces risks and costs, accelerating workforce adaptability. Collectively, these studies highlight that technical competencies must be coupled with data literacy, systems thinking, and collaborative decision-making, while also embedding sustainability as a skill dimension.

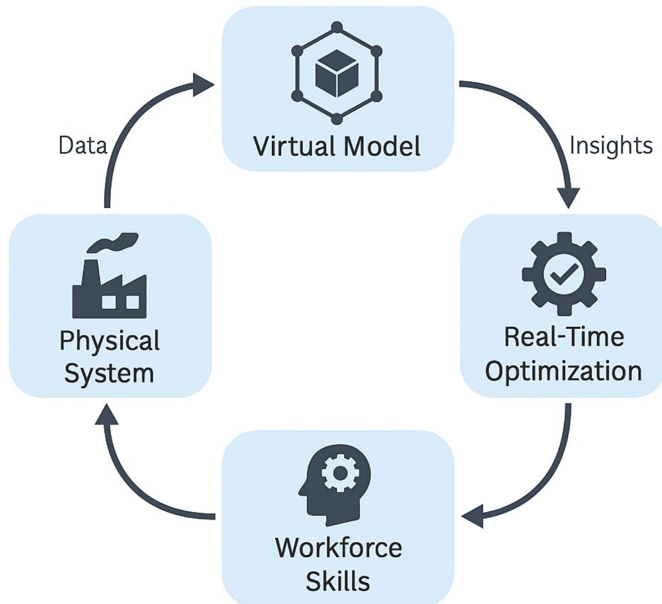

Figure 2. Digital Twin Ecosystem

Digital twin systems integrate physical processes, data, and virtual modeling into a feedback loop, with workforce skills crucial for insights. Figure 2 shows digital twin ecosystems in manufacturing. Digital twins create data-driven system replicas for simulation and process optimization, while developing workforce expertise in modeling and decision-making through cost-effective training.

2.3 Regional Workforce Models and Research Gap

Comparative studies reveal that workforce strategies vary considerably across regions. According to the Tan et al. (2022) and World Economic Forum (2023), Western and European models tend to prioritize decentralized innovation, lifelong learning, and standardized certification. In contrast, Krupas et al. (2024) and International Labour Organization (2021) show that Asian and particularly Chinese approaches rely on state-led acceleration, vocational-industrial integration, and large-scale retraining.

This divergence creates trade-offs: European approaches emphasize quality and global recognition, whereas Asian approaches stress speed and mobilization. OECD (2022) and the World Bank (2021) note that existing research often treats technology adoption and workforce development as separate domains, leaving gaps in understanding the interaction of policy, skills, and technology. To bridge this gap, this study employs a comparative framework built around six skill domains identified as critical for Industry 5.0 readiness (Table 1).

Table 1. Core Skill Domains for Industry 5.0 Workforce Readiness

Skill Domain	Linked Technologies	Western/European Emphasis	Asian/Chinese Emphasis
Technical Expertise	AI integration, digital twin simulation	Modular certifications, interoperability standards	Vocational-industrial training, state-funded labs
Analytical Capability	Data analytics, defect detection	Strong focus on data literacy and system optimization	Applied analytics embedded in factory bootcamps
Systems Thinking	Cyber-physical systems, digital ecosystems	University–industry research labs, RAMI 4.0 frameworks	Policy-driven industrial park integration
Collaboration	Human–AI supervision, co-creation tools	Cross-functional teams, EU skills alliances	Team-based retraining in vocational centers
Sustainability Awareness	Digital twins for energy & waste optimization	Green manufacturing standards, circular economy policies	Rapid deployment aligned with national energy goals
Lifelong Learning	AI-driven adaptive learning platforms	Lifelong learning platforms, stackable micro-credentials	Continuous reskilling mandates, state-directed schemes

This literature review underscores that while prior studies provide rich insights into the technological and organizational aspects of Industry 5.0, there remains a clear need for integrated analyses that connect AI, digital twins, and workforce development within policy and regional contexts.

3. Methodology

3.1 Research Design and Data Sources

This study adopts a **comparative desk-based research design**, synthesizing academic literature, industry reports, and policy frameworks published between 2018 and 2025. Such an approach, as World Bank (2021) and World Economic Forum (2023) note, is well-suited for capturing the evolving intersections of technology and workforce transformation. Three categories of sources were triangulated to ensure multi-dimensional insights (Figure 3):

1. Peer-reviewed literature on Industry 5.0, AI, digital twins, and workforce adaptation.
2. Policy frameworks from organizations such as the European Commission, OECD, WEF, and World Bank.
3. Case studies documenting firm-level practices in Europe, Asia, and North America.

This mix of sources allows the analysis to balance technical, organizational, and policy considerations, a strategy consistent with prior comparative workforce studies (International Labour Organization, 2021; World Economic Forum, 2023).

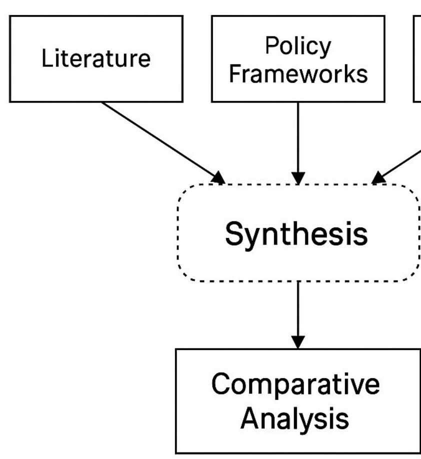

Figure 3. Comparative Framework: Sources and Data Flow

The research design integrates three inputs—literature, policy frameworks, and case studies—into a synthesis process that informs comparative analysis of Western/European and Asian/Chinese workforce strategies.

3.2 Analytical Framework

The analysis followed a three-step process, adapted from comparative policy evaluation methods as illustrated in Figure 5:

1. Theme extraction – identifying recurring patterns in workforce skills, governance models, and technology integration.
2. Comparative analysis – contrasting Western/European and Asian/Chinese strategies across training, governance, and scalability.
3. Synthesis – integrating findings into a unified Industry 5.0 workforce framework linking AI and digital twin adoption to policy-driven skills development.

This framework enables regional comparisons and global synthesis to uncover hybrid pathways through a three-step method: (1) Extracting themes from literature, policies, and case studies; (2) Comparing Western/European and Asian/Chinese models; (3) Integrating these into an Industry 5.0 workforce framework and roadmap. The process combines literature, policy frameworks, and case studies to develop a comprehensive Industry 5.0 workforce framework (Figure 4).

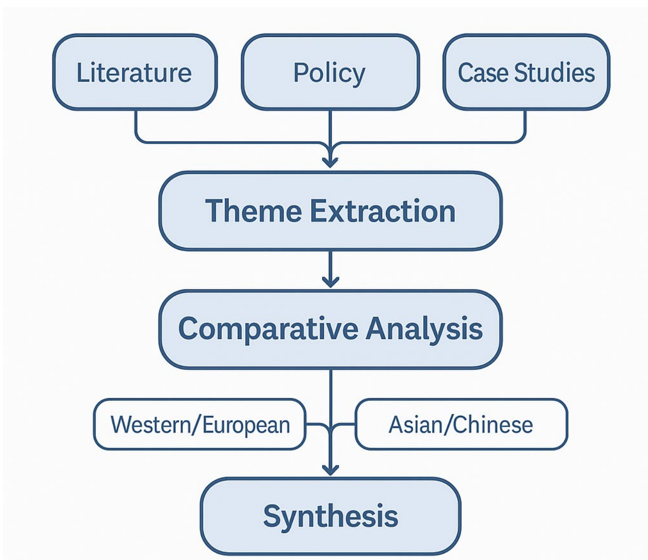

Figure 4. Analytical Framework

4. Comparative Workforce Pathways

4.1 Western and European Approaches

Western and European strategies emphasize **gradual integration and standardization**. Frameworks such as RAMI 4.0 and the EU's Industry 5.0 agenda promote interoperability, worker well-being, and socio-technical balance (European Commission, 2021; Xu et al., 2021). Universities co-develop curricula and research labs with industry partners (Rudolph, 2022; Toprak, 2024), ensuring global recognition of certifications, though often at the cost of slower workforce mobilization.

Figure 5 illustrates the Western/European model emphasizes gradual integration through higher education, technical skills training, modular certification, and lifelong learning, ensuring quality and global recognition but often slowing large-scale mobilization.

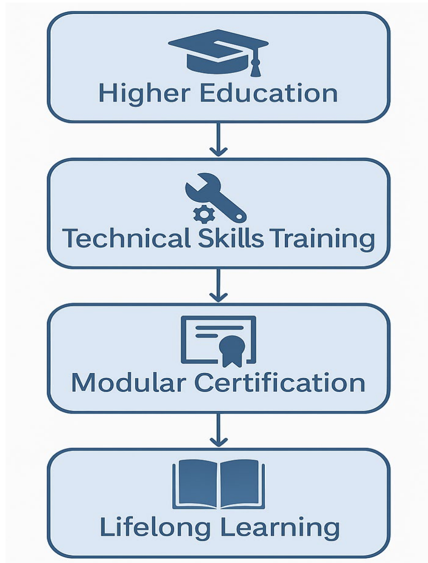

Figure 5. Western Workforce Pathway

4.2 Asian and Chinese Approaches

Asian models, especially China's, focus on state-directed acceleration. Policies like Made in China 2025 integrate vocational schools into industrial parks, expand retraining, and fund digital twin labs (Liu et al., 2023; Qi & Tao, 2018). This speeds workforce deployment but risks uneven skill depth and weaker international recognition (Zhang et al., 2022). Figure 6 highlights state-led acceleration through technical education, vocational-industrial integration, and rapid workforce deployment, enabling speed and scale but raising concerns about depth and recognition.

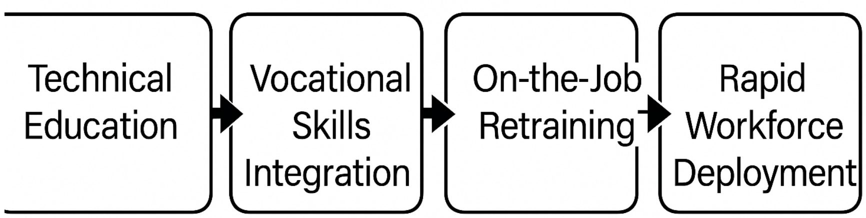

Figure 6. Asian Workforce Pathway

4.3 Hybrid Convergence

Evidence suggests growing convergence between the two models. OECD (2022) notes that Western systems increasingly adopt bootcamp-style training and labs, while International Labour Organization (2021) highlights Asian systems adopting international certifications and lifelong learning.

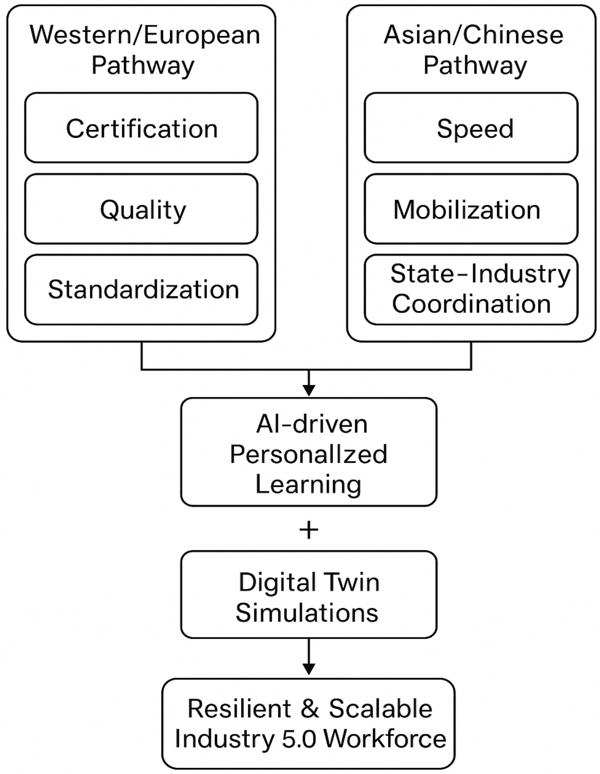

Figure 7. Hybrid Workforce Convergence Model

Hybrid pathways blend:

- Western rigor in certification and quality.
- Asian speed in mobilization and scaling.
- AI-driven personalization and digital twin simulations as bridging technologies.

The Figure 7 shows Western and Asian models converging into a hybrid combining certification and adaptive training. This hybrid merges Western strengths in certification and standardization with Asian advantages in speed and coordination. AI-driven learning and digital twins enable convergence, creating resilient Industry 5.0 workforce systems.

5. Policy & Organizational Enablers

Transforming the manufacturing workforce under Industry 5.0 requires alignment across multiple stakeholders. Prior studies (European Commission, 2021; OECD, 2022) emphasize that no single institution can achieve this transition alone; it depends on a **policy–industry–education nexus** where governance, training, and advocacy intersect.

5.1 Government and Standards

Governments play a catalytic role by funding digital skills programs, incentivizing reskilling through subsidies and tax credits, and setting national strategies. The EU's *Pact for Skills* and China's *Made in China 2025* illustrate contrasting approaches to mobilization (Leon, 2023; OECD, 2022). Standards bodies complement these efforts by harmonizing certification in areas such as AI, cybersecurity, and digital twin applications, ensuring workforce mobility and avoiding fragmented training (International Labour Organization, 2021).

5.2 Industry and Academia

Employers directly shape workforce demand by investing in corporate academies, apprenticeships, and digital twin labs. Siemens and Huawei, for instance, operate simulation-driven training hubs to prepare workers for AI-enabled production (Liu et al., 2020; Liu et al., 2024). Academia reinforces these efforts by embedding digital twin and AI modules into curricula, establishing joint research centers, and expanding lifelong learning platforms (Bauer & Herder, 2009). Together, these partnerships balance theoretical depth with applied practice.

5.3 Labor and Professional Bodies

Unions and professional associations advocate for equitable access to training and help set ethical frameworks for human–AI collaboration. According to (International Labour Organization, 2021), their involvement is critical in negotiating training standards, promoting peer-learning, and safeguarding worker rights in rapidly evolving industrial contexts.

5.4 Synthesis

These actors collectively enable a **multi-level governance system** in which government policy, industrial investment, academic training, and labor advocacy converge. Successful workforce transformation depends on coordinated action across these domains rather than isolated initiatives.

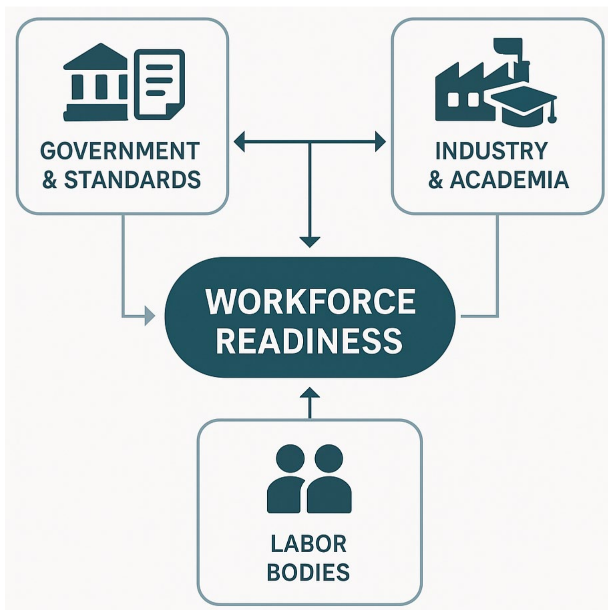

Figure 8. Policy & Organizational Ecosystem for Industry 5.0 Workforce Transformation

Figure 8 shows the Policy & Organizational Ecosystem for Industry 5.0 Workforce Transformation, featuring three interconnected clusters—Government & Standards, Industry & Academia, and Labor Bodies—whose interactions drive workforce readiness through coordinated governance, training, and advocacy.

6. Implementation Roadmap

Industry 5.0 workforce transformation requires a phased roadmap that balances **speed with resilience**. Following OECD (2022) and World Economic Forum (2023), this study outlines a four-stage approach linking assessment, piloting, scaling, and global alignment.

Table 2. Phased Roadmap for Industry 5.0 Workforce Transformation

Phase	Time Frame	Main Actors	Focus & Activities
1. Assessment & Planning	0–6 months	Governments, industry, training institutions	Skills audits, policy alignment, establish partnerships, prioritize workforce gaps
2. Pilot Programs	6–18 months	Universities, firms, certification bodies	Launch digital twin labs, test AI-supervised projects, pilot international certifications
3. Scaling & Integration	18–36 months	Industry, academia, vocational centers	Expand pilots into curricula, embed AI & digital twin modules in retraining pipelines, strengthen apprenticeships
4. Consolidation & Globalization	36+ months	Governments, international bodies (ISO, ILO, AfCFTA, EU)	Align with international standards, establish lifelong learning ecosystems, promote cross-border collaboration

6.5 Synthesis
The roadmap demonstrates that workforce transformation is a **continuous cycle** rather than a linear process. By sequencing reforms, countries can avoid rushed reskilling while still achieving competitive readiness in global Industry 5.0 ecosystems.

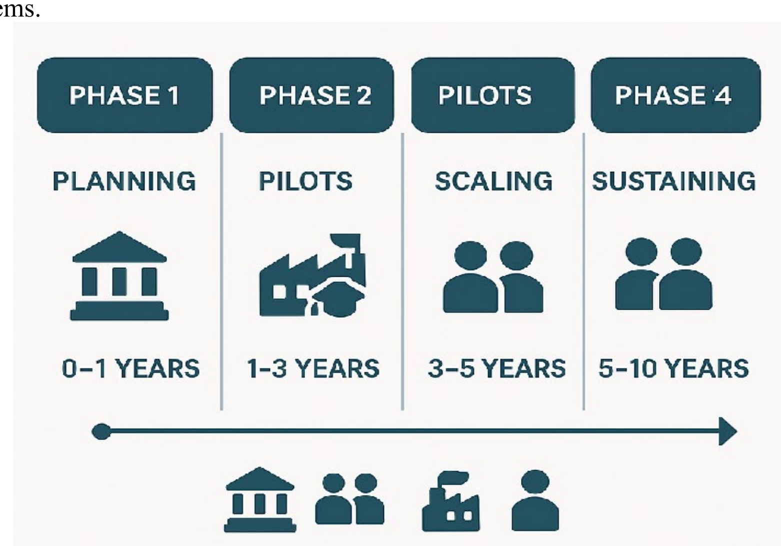

Figure 9. Phased Roadmap Timeline

Figure 9 outlines four sequential phases for workforce transformation: Phase 1 (Planning, 0–1 years), Phase 2 (Pilots, 1–3 years), Phase 3 (Scaling, 3–5 years), and Phase 4 (Sustaining/Globalization, 5–10 years). Icons for government, industry, academia, and labor highlight the main actors engaged at each stage.

7. Discussion
7.1 Lessons from Regional Models
The comparative pathways (Figures 6a–6c) highlight distinct strengths. Western/European models demonstrate the value of gradual adoption, certification credibility, and worker safety, supported by strong industry–academia partnerships. Asian/Chinese strategies illustrate the effectiveness of state-led acceleration and vocational integration for mobilizing large labor forces quickly. Each approach reveals trade-offs between quality and speed, suggesting neither model is sufficient in isolation.

7.2 Shared Challenges Across Regions

Despite distinct trajectories, Western/European and Asian/Chinese models face common challenges that constrain workforce transformation under Industry 5.0:

1. Data Interoperability – Fragmented platforms and siloed data architectures limit seamless AI and digital twin integration across factories and regions (Rasheed et al., 2020).
2. Cybersecurity Vulnerabilities – AI- and IoT-enabled environments increase exposure to cyberattacks, requiring harmonized international standards (OECD, 2022).
3. Change Management in Legacy Workforces – Reskilling older or traditionally trained workers remains difficult, with resistance to digital retraining often slowing adoption (ILO, 2021).
4. Human–Machine Interface Design – Ensuring usability, trust, and ergonomic balance in human–AI collaboration is critical for both safety and worker acceptance (Nahavandi, 2019).

These shared barriers show neither regional model provides a complete solution. Addressing them requires coordinated governance within the policy-organizational ecosystem to align technology adoption with workforce inclusion and sustainability.

Western and Asian approaches merge into hybrid models affecting Industry 5.0 workforce transformation. Figure 10 shows Western/European strengths (certification, quality, standardization) and Asian/Chinese strengths (speed, mobilization, coordination) converging into hybrid pathways. Key challenges include data interoperability, cybersecurity, change management, and human-machine interface design for sustainable Industry 5.0 implementation.

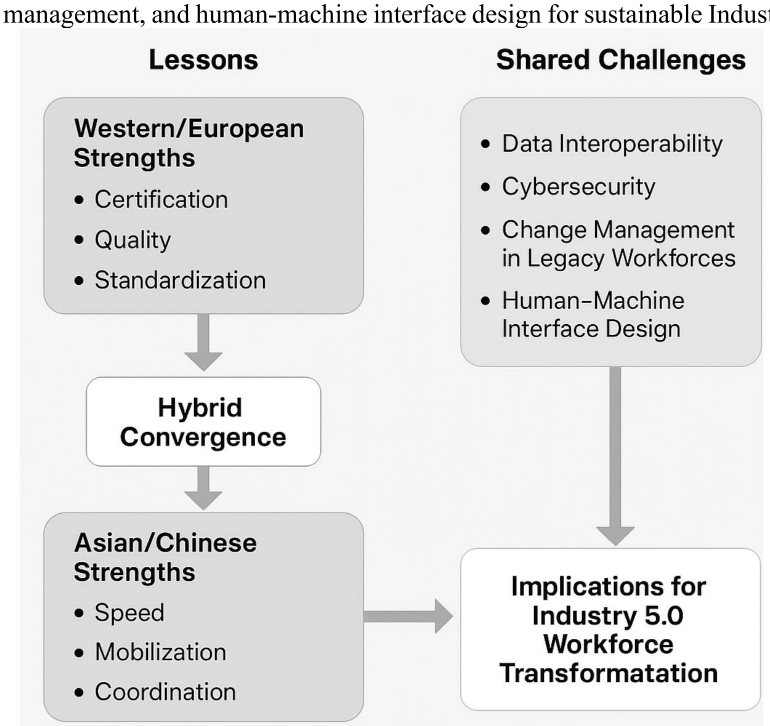

Figure 10. Lessons and Challenges in Workforce Transformation

7.3 Implications for Workforce Transformation

The integration of hybrid pathways suggests combining Western thoroughness with Asian efficiency, supported by AI learning and digital simulations. Policymakers should establish adaptable standards while industries and institutions invest in lifelong learning ecosystems. International bodies like OECD, ILO, and ISO can expedite integration through cross-regional knowledge sharing. These hybrid models provide a framework for enhancing Industry 5.0 workforce preparedness.

8. Conclusion and Future Research

This study examined how AI and digital twins are transforming manufacturing workforces under Industry 5.0. The comparative analysis revealed that Western/European models prioritize quality and certification credibility, while

Asian/Chinese models emphasize speed and large-scale mobilization. As shown in the hybrid pathways (Figure 6c) and phased roadmap (Figure 8), the most sustainable future lies in blending rigor with scalability, supported by AI-driven adaptive learning and digital twin–based training.

The study contributes by:

- Developing a framework linking AI and digital twins to workforce skills.
- Mapping Western and Asian strategies and highlighting hybrid convergence.
- Proposing a multi-stakeholder ecosystem (Figure 7) and a phased roadmap (Table 2).

The analysis relies on secondary sources. Future research should incorporate empirical methods like surveys and interviews to capture worker and firm perspectives. Sector-specific studies in aerospace, automotive, and agro-industrial systems could provide detailed insights. Researchers should evaluate emerging technologies' effects, including AI, edge computing, and blockchain supply chains, on the workforce, while exploring global frameworks to promote inclusivity.

Industry 5.0 will succeed only if technological integration and human-centered workforce development advance together, producing systems that are sustainable, resilient, and competitive.

References

Bauer, J. M., Herder, P. M., Designing socio-technical systems, In A. Meijers (Ed.), Philosophy of Technology and Engineering Sciences, North-Holland, 2009, doi: https://doi.org/10.1016/B978-0-444-51667-1.50026-4

European Commission, Industry 5.0 – Towards a sustainable, human-centric and resilient European industry, Publications Office of the European Union, 2021, doi: https://doi.org/10.2777/308407

Hazrat, M. A., Hassan, N. M. S., Chowdhury, A. A., Rasul, M. G., Taylor, B. A., Developing a skilled workforce for future industry demand: The potential of digital twin-based teaching and learning practices in engineering education, Sustainability, 2023, doi: https://doi.org/10.3390/su152315066

International Labour Organization, Global Skills Report 2021: Reskilling for the Future of Work, ILO, Geneva, 2021, doi: https://doi.org/10.1787/27452f29-en

Krupas, M., Kajati, E., Liu, C., Zolotova, I., Towards a human-centric digital twin for human–machine collaboration: A review on enabling technologies and methods, Sensors (Basel), 2024, doi: https://doi.org/10.3390/s24072232

Leon, R., Employees' reskilling and upskilling for Industry 5.0: Selecting the best professional development programmes, Technology in Society, 2023, doi: https://doi.org/10.1016/j.techsoc.2023.102393

Liu, Q., Leng, J., Ye, S., Jing, J., Wang, Y., Zhang, C., Zhang, D., Chen, X., Digital twin-driven rapid reconfiguration of the automated manufacturing system via an open architecture model, Robotics and Computer-Integrated Manufacturing, 2020, doi: https://doi.org/10.1016/j.rcim.2020.101895

Liu, S. M., Bao, J. S., Zheng, P., A review of digital twin-driven machining: From digitization to intellectualization, Journal of Manufacturing Systems, 2023, doi: https://doi.org/10.1016/j.jmsy.2023.02.010

Liu, Y., Feng, J., Lu, J., Zhou, S., A review of digital twin capabilities, technologies, and applications based on the maturity model, Advanced Engineering Informatics, 2024, doi: https://doi.org/10.1016/j.aei.2024.102592

Lv, Z., Digital twins in Industry 5.0, Research (Wash D C), 2023, doi: https://doi.org/10.34133/research.0071

Nahavandi, S., Industry 5.0 — A human-centric solution, Sustainability, 2019, doi: https://doi.org/10.3390/su11164371

OECD, Skills Outlook 2022: Skills for a Resilient Workforce, OECD Publishing, Paris, 2022.

Qi, Q., Tao, F., Digital twin and big data towards smart manufacturing and Industry 4.0: 360-degree comparison, IEEE Access, 2018, doi: https://doi.org/10.1109/ACCESS.2018.2793265

Rudolph, H., Vocational training as part of Sino-German contracts, In H. Rudolph (Ed.), Germany and Vocational Education in Republican China: Traveling Texts, Touring Skills, Springer International Publishing, 2022, doi: https://doi.org/10.1007/978-3-030-94934-1_9

Soldatos, J., Ipektsidis, B., Kefalakis, N., Despotopoulou, A.-M., Reference architecture for AI-based Industry 5.0 applications, In J. Soldatos (Ed.), Artificial Intelligence in Manufacturing: Enabling Intelligent, Flexible and Cost-Effective Production Through AI, Springer Nature Switzerland, 2024, doi: https://doi.org/10.1007/978-3-031-46452-2_1

Soori, M., Arezoo, B., Dastres, R., Digital twin for smart manufacturing: A review, Sustainable Manufacturing and Service Economics, 2023, doi: https://doi.org/10.1016/j.smse.2023.100017

Tan, J.-P., Lee, K. H., Flynn, R., Roseth, V. V., Nam, Y.-J., Workforce Development in Emerging Economies: Comparative Perspectives on Institutions, Praxis, and Policies, The World Bank, 2022, doi: https://hdl.handle.net/10986/24541

Tay, A., Bogaars, M., Rodriguez, C., Creating Training Capacity with Digital Twins, illumialabs.ai, 2023, doi: https://illumialabs.ai/wp-content/uploads/2023/09/White-Paper-Illumia-Labs-Digital-Twins.pdf

Toprak, M., Architecting the new-generation university: Integrating Industry 4.0, Society 5.0, and digital transformation, 17th International Conference On Knowledge, Economy & Management, 2024.

Wang, B., Peng, T., Wang, X. V., Wuest, T., Romero, D., Wang, L., Human-centric smart manufacturing, Journal of Manufacturing Systems, 2023, doi: https://doi.org/10.1016/j.jmsy.2023.06.001

World Bank, World Development Report 2021: Data for Better Lives, Washington, DC, 2021.

World Economic Forum, The Future of Jobs Report 2023 – Workforce Strategies, World Economic Forum, 2023, doi: https://www.weforum.org/publications/the-future-of-jobs-report-2023/in-full/5-workforce-strategies/

Xu, X., Lu, Y., Vogel-Heuser, B., Wang, L., Industry 4.0 and Industry 5.0 — Inception, conception and perception, Journal of Manufacturing Systems, 2021, doi: https://doi.org/10.1016/j.jmsy.2021.10.006

Zhang, L., Ye, F., Xie, K., Gu, P., Wang, X., Laili, Y., Zhao, C., Zhang, X., Chen, M., Lin, T., An integrated intelligent modeling and simulation language for model-based systems engineering, Journal of Industrial Information Integration, 2022, doi: https://doi.org/10.1016/j.jii.2022.100347