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Research Article

Industry 4.0 and Industry 5.0: A Hybrid Paradigm for Sustainable and Human-Centric Manufacturing

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Abstract **–** Smart manufacturing is made up of two views. Industry 4.0 encourages digitization and automation of processes, while Industry 5.0 focuses on systems that put people first. Climate change, pandemics, hybrid and conventional warfare, and refugees were all issues that Industry 5.0 dealt with. To bring people back into corporate decision-making, we need long-term and strong solutions. This study suggests a mix of Industry 4.0 and Industry 5.0 for operations that are highly automated and focused on value for people. The technology of many jobs improved during the industrial revolutions. "Softwarization" and digitalization are speeding up. To keep up with digital technology, Industry 4.0 needs to become Industry 5.0 by combining its strengths. Over the past ten years, Industry 4.0 has made things better and fixed a lot of problems. Now, Industry 5.0 is possible and needed. Smart manufacturing makes things work better, but Industry 4.0 doesn't help society very much. This paper talks about the good and bad things about Industry 5.0 and suggests that more research needs to be done. Industry 5.0 is more about people and machines working together than it is about technology. In this new industrial revolution, customizing goods and services will make customers happier and businesses more successful. The paper says that smart cities and villages should use the latest technology to make Industry 5.0 and Society 5.0. We want to show business leaders, decision-makers, and researchers how technology can help us reach the SDGs.

Keywords – Industry 4.0; Industry 5.0; Cyber-Physical Systems (CPS); Human–Robot Collaboration; Smart Manufacturing; Softwarization; Sustainability.

1. Introduction

Academics and major European policy organizations are already proposing Industry 5.0 as a new wave of digital transformation, even though the Industry 4.0 paradigm is still relatively young and evolving [1]. The rapid rise of interest in Industry 5.0 makes it important to examine the reasons behind this shift and to explain how it fits into the context of current socio-environmental challenges. Indeed, to live in peace, prosperity, and harmony with the planet, humanity must undergo a profound systemic transformation in response to ongoing economic and socio-environmental crises—such as social inequality, environmental degradation, and disruptions caused by events like the COVID-19 pandemic or the Ukraine–Russia conflict [2].

The term “Industry 4.0” was originally coined to encompass the modern use of smart automation, data processing, and advanced manufacturing technologies, building on growing interconnectivity potential [3]. Industry 4.0 technologies revolutionized computer-integrated manufacturing and flexible manufacturing systems [4], and they have introduced opportunities across the “triple bottom line” of sustainability (economic, environmental, and social). Notably, Industry 4.0 innovations have even been adopted at governmental levels, particularly with regard to social dimensions of technology use [5].

In contrast, Industry 5.0 shifts the focus toward broader societal goals and human factors, beyond the earlier emphasis on productivity and efficiency. Industry 5.0 production envisions leveraging intelligent healthcare, personalized manufacturing, cloud computing, advanced supply chain management, and virtualization technologies [6, 7]. Key supporting technologies for Industry 5.0 include collaborative robots (cobots), machine-to-machine (M2M) communication, multi-access edge computing (MEC), network slicing, the Internet of Space (IoS), as well as the integration of softwarization techniques, blockchain, and emerging 6G networks [8-10]. The topics covered in this article play a significant role across many industrial sectors.

This paper’s primary goal is to highlight the key linkages between the fundamental driving concepts of Industry 4.0 and Industry 5.0, while emphasizing three critical enablers—people, organization, and technology—in both theoretical and practical contexts. Over the past ten years, the evolution of industry has been closely examined with respect to these major enablers. By referencing important works in the field, we aim to provide deeper insight into the emergence of Industry 5.0 and the new research directions associated with it. Gaining a deeper understanding of the advent of Industry 5.0 serves as a foundation to reconsider current industrial processes and to identify opportunities for applying appropriate concepts that effectively address the specific challenges faced by industry, in order to maximize outcomes in each domain—individuals, organizations (groups), and technology [11].

The rapid pace of technological advancement has catalyzed the rise of Industry 5.0 in the business environment [12]. Industry 5.0 highlights “human–robot co-working” [13] a vision in which humans and robots collaborate as partners wherever feasible, with humans concentrating on creative and value-added tasks while robots handle repetitive or labor-intensive tasks [13]. This collaborative approach aims to leverage the respective strengths of humans and machines to achieve outcomes that neither could accomplish alone.

In the following sections, we examine the main distinctions between Industry 4.0 and Industry 5.0 from a Lean management perspective to better understand how these paradigms have evolved. To that end, we conducted a Systematic Literature Review (SLR) to identify existing frameworks for implementing new digitalization technologies in production systems and to evaluate their impact on shop-floor work. The findings of this SLR are presented and discussed below.

2. Systematic Literature Review

Lean Production (Lean Thinking): An MIT research on the global automobile sector in the late 1980s inspired lean methodology. Toyota enjoyed a competitive edge due to its unique management style spanning manufacturing, product development, and customer–supplier interactions, according to that research. Lean thinking spread from manufacturing to other industries when Womack and Jones published Lean Thinking in 1998. Lean's five principles are identify value, map the value stream, build flow, develop pull, and achieve perfection, according to Womack and Jones. Lean reduces waste and streamlines value flow by concentrating on customer-defined value and eliminating non-value-added operations [14].

Germany's 2011 strategic plan "Industrie 4.0" launched the fourth industrial revolution [15]. Industry 4.0 integrates CPS [16] and IoT [17] into manufacturing and supply chains. Resources including machines, goods, and processes become “smart” in Industry 4.0 and can detect, act autonomously, and rearrange themselves within an intelligent network [18]. Industry 4.0 affects order management, R&D, user experience, and product lifecycle (including recycling) to meet more customized customer wants while retaining efficiency [19].

Industry 5.0: Building on its predecessor, Industry 5.0 seeks societal goals beyond jobs and growth. It envisions a robust, sustainable industrial system that promotes wealth, environmental protection, and worker well-being [20]. Industry 5.0 emphasizes centring factory activities on workers. Industry 5.0 promotes human–machine collaboration on the production floor, allowing workers to focus on sophisticated decision-making, creativity, and innovation. Human-centric workplaces use technology to improve human talents.

Parallels between Lean, Industry 4.0, and 5.0: Lean, Industry 4.0, and Industry 5.0 have similar goals. All three paradigms target efficiency, quality, responsiveness, waste elimination, and value creation. Many writers have examined these similarities and their links in academic and practitioner groups. Key studies on Lean principles and Industry 4.0 and 5.0 are summarized in Table 1. This article's discussion will expand on these points.

These research [21-23] identified many essential aspects for human-centric Industry 4.0/5.0 transformations:

• Prioritize process over technology: Before implementing new technology, successful projects examine and simplify the work process. After streamlining the process, they apply technology and monitor and regulate it to verify it works [21-23].

• Carefully organize the allocation of duties and responsibilities between people and robots. Effective implementations carefully determine which jobs are best done by humans and which by automation, taking into account both sides' skills. The human–robot interaction is then assessed and modified for compatibility.

• Structured Adoption Methods: Technology development and adoption should be systematic. Successful instances have used well-coordinated, value-oriented multi-disciplinary, transdisciplinary, and worker-centric methods. New technologies are introduced with clear goals and integration strategies to improve value streams.

• Technical Readiness and Infrastructure: Strong technical infrastructure and enabling technologies are essential. The chosen technology must be mature enough for the application. New solutions require trustworthy algorithms and digital systems and hardware/software infrastructure including sensors, network bandwidth, and computer power.

• Stakeholder Engagement: Technology adoption decisions should involve end-users like workers and engineers, management, and other stakeholders. Early worker involvement helps choose acceptable solutions and eases change management since employees are more willing to adopt technology they helped create.

• Multi-Disciplinary Knowledge: Human-centered Industry 4.0/5.0 implementation demands multidisciplinary expertise. Life sciences (understanding human physiological parameters, ensuring worker health and safety, and scientifically validating new processes), social sciences (workforce characteristics, organizational behavior, and ethical principles), and psychological sciences evaluate cognitive models, workload, and other psychosocial factors affecting workers.

• Standards and Change Management: Standards and guidelines provide compatibility and interoperability of new systems in technical development. Successful implementation also depends on business policy and change management. Organisational preparation, clear communication, and training may greatly impact advanced technology implementation.

• Reliability and accuracy Concerns: The technology's accuracy, dependability, and precision must satisfy a level to maintain user confidence. If a technology regularly makes mistakes or gives inconsistent outcomes, it will hinder its intended use and raise effectiveness concerns, weakening implementation goals.

• Challenges in Technical Integration: Technology development and integration may provide practical challenges. These include managing multiple vendors and disparate systems (leading to API or data format integration issues), managing interdependent technologies, and overcoming immature technology drawbacks like long time-to-market, poor hardware ergonomics, inflexible customization options, or low technology readiness.

• Data Management Concerns: Advanced digital technologies provide data difficulties. Big data management may be tough for companies without a digital strategy. Repetitive data production, data storage

difficulties, and privacy concerns are common. Sustainable implementation of Industry 4.0/5.0 technology requires addressing these problems.

These factors emphasize the need for a holistic strategy to combining Industry 4.0 and Industry 5.0 with Lean thinking. Understanding and tackling these characteristics can help enterprises move to a sustainable, resilient, and human-centric industrial future. The paper's Discussion and Conclusion will discuss how these findings influence a framework for Industry 5.0 and Society 5.0 and how they connect with sustainability goals.

Industry 4.0 and Industry 5.0 are two successive industrial paradigms with unique but similar traits. A literature assessment shows disparities in emphasis, enabling technology, human participation, production methods, and sustainability and resilience approaches. Table 1 compares these important distinctions based on numerous research.

Table 1. Comparison of Industry 4.0 and Industry 5.0 across key dimensions.

Dimension	Industry 4.0 (Fourth Industrial Revolution)	Industry 5.0 (Fifth Industrial Revolution)
Primary Focus	Primarily focuses on maximizing productivity and competitiveness through advanced automation [24]. Technological integration is driven by goals of efficiency and economic gain.	Shifts to a human-centric paradigm prioritizing sustainability, resilience, and broader social value [24]. Emphasizes goals beyond efficiency, incorporating environmental and societal objectives.
Enabling Technologies	Utilizes cyber-physical systems and networked digital technologies (Industrial IoT, cloud computing, big data analytics, AI, robotics) to enable smart, automated manufacturing [24]. These technologies facilitate highly automated and data-driven processes.	Builds upon Industry 4.0's digital technologies while adding an emphasis on collaborative robots (cobots) and advanced AI that work with humans [25]. The technology toolkit is extended to support human–machine co-working and intelligent decision support, rather than automation alone.
Role of Humans	Humans play a supervisory or peripheral role in production; the paradigm gives limited emphasis to human factors and labor aspects [24]. Workforces are expected to adapt to automated systems, with less direct intervention in routine tasks.	Places humans at the center of industrial systems. Emphasizes human–machine collaboration and ensures production adheres to the welfare and development of workers [26]. Workers' creativity and well-being are integral, with technology designed to augment human capabilities rather than replace them.
Production Paradigm	Smart factories with highly automated, flexible production lines enabling mass customization of products [24]. Manufacturing is optimized for efficiency and scalability, often aiming for "lights-out" operations with minimal human involvement.	Flexible, integrated production systems that leverage human creativity for mass personalization of products [25]. Production is adaptable to individual customer needs, combining automation with artisan-like customization. Human insight is used to improve customization and innovation in the manufacturing process.
Sustainability Approach	Efficiency-driven, with sustainability and environmental considerations as secondary concerns [24]. Reducing waste or energy use may occur as a side effect of efficiency, but environmental or social sustainability is not a core objective of Industry 4.0 initiatives.	Proactively incorporates sustainable manufacturing practices to minimize environmental impact [24]. Industry 5.0 explicitly elevates sustainability to a core principle, aligning industrial growth with ecological responsibility and ethical standards (e.g. circular economy, low carbon footprint).
Resilience to Disruptions	Lacks an explicit focus on resilience; systems assume relatively stable conditions and are primarily optimized for performance [24]. The limitations of Industry 4.0 became evident when facing major disruptions (e.g. global pandemics), revealing a gap in adaptability.	Emphasizes building resilient systems capable of adapting to and recovering from disruptions [24]. Designing for agility and robustness (e.g. to pandemics or supply shocks) is a key feature, ensuring continuity and responsiveness in the face of crises as part of the Industry 5.0 vision.

The comparison above shows that Industry 5.0 is not a rejection of Industry 4.0; it is an improvement on it. Industry 5.0 keeps the advanced digital backbone of Industry 4.0 (IoT, AI, and automation) but shifts its priorities to be more focused on people and the environment [24]. To put it simply, Industry 5.0 wants to mix new technologies with people's morals and understanding. This synergy solves the problems with Industry 4.0 that were talked about before, like how it doesn't care about people and the environment [24]. It does this by adding social and environmental awareness to the way things are done in business. The literature says that companies that are moving toward Industry 5.0 will be responsible and efficient by using

smarter technologies and smarter ways of doing things. This unified view is the first step in figuring out how the two paradigms can work together and help each other in modern business strategies.

3. Conclusion

In conclusion, our extensive research on Industry 4.0 and Industry 5.0 highlighted their similarities and differences. This taught us modern business practices. The key findings reveal that Industry 4.0's objective of improving productivity and efficiency led to digital infrastructure. However, Industry 5.0 prioritizes people, sustainability, and resilience. Instead of replacing the fourth industrial revolution, the data supports combining its finest features with the next one. AI, IoT, robotics, and data analytics help generate company concepts. They now prioritize people, the environment, and flexibility (engineeringmastersonline.rutgers.edu). This method ensures that manufacturing and associated technology advances and society's ideals don't conflict. Company problems abound. Businesses must do more than automate to enable people and smart technology to work together as Industry 4.0 and 5.0 expand. Workers require training and new skills to use AI and robotics. This ensures that technology matches human abilities. Making durable products, using less carbon, and using circular economy principles may help businesses assess their performance. Companies stay legal, do what the public wants, and grow stronger this way. We need flexible supply chains, production, and backup plans. COVID-19 and climate change demonstrate this. Real-time data and human judgment may strengthen industrial systems from the outset in Industry 5.0. This aids problem-solving. Last but not least, this review proposes several study directions. We need real-world research to apply Industry 5.0's people-centered and ecologically responsible principles to all companies. Researchers might study early Industry 5.0 consumers' interactions with equipment and manufacturing workers to determine what works. They might also consider clever automation-era retraining. With the new model, productivity indicators and tools can show how worker happiness, innovation potential, and environmental effect affect your organization. This indicates industry performance. Interdisciplinary study might also examine the regulations and policies needed for this transition. Data ethics, job loss, and change management are examples. Combining Industry 4.0's technological talents with Industry 5.0's people-centered strategy might create efficient, open, creative, and long-lasting industries. It's fascinating to watch this integrated concept improve in school and life. It shifts industrial performance measurement from production and automation to a balanced scorecard that balances people, environment, and profit. Businesses will be able to adapt faster, manage resources more effectively, and satisfy social requirements with this transformation. More school research and company testing will assist realize Industry 5.0 and launch the next industrial revolution.

References

1. Ivanov, D., The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. International Journal of Production Research, 2023. 61(5): p. 1683-1695.
2. Commission, E., et al., Industry 5.0, a transformative vision for Europe : governing systemic transformations towards a sustainable industry. 2021: Publications Office of the European Union.
3. Kagermann, H., W.-D. Lukas, and W. Wahlster, Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. VDI nachrichten, 2011. 13(1): p. 2-3.
4. Oztemel, E. and S. Gursev, Literature review of Industry 4.0 and related technologies. Journal of Intelligent Manufacturing, 2020. 31(1): p. 127-182.
5. Bongomin, O., et al., Industry 4.0 disruption and its neologisms in major industrial sectors: a state of the art. Journal of Engineering, 2020. 2020: p. 1-45.
6. Jafari, N., M. Azarian, and H. Yu, Moving from Industry 4.0 to Industry 5.0: what are the implications for smart logistics? Logistics, 2022. 6(2): p. 26.
7. Haleem, A. and M. Javaid, Industry 5.0 and its expected applications in medical field. Current Medicine Research and Practice, 2019. 9(4): p. 167-169.
8. Raman, S., R. Weigel, and T. Lee, The Internet of space (IoS): A future backbone for the Internet of Things? IEEE IoT Newsletter, 2016.
9. Akyildiz, I.F. and A. Kak, The internet of space things/cubesats. IEEE Network, 2019. 33(5): p. 212-218.
10. Nguyen, T., et al., The intersection of blockchain and 6G technologies, in 6G Mobile Wireless Networks. 2021, Springer. p. 393-417.

11. Zizic, M.C., et al., From industry 4.0 towards industry 5.0: A review and analysis of paradigm shift for the people, organization and technology. Energies, 2022. 15(14): p. 5221.
12. Atwell, C., Yes, Industry 5.0 is already on the horizon. Machine Design, 2017.
13. Demir, K.A., G. Döven, and B. Sezen, Industry 5.0 and human-robot co-working. Procedia computer science, 2019. 158: p. 688-695.
14. Souza, R., H. Ferenhof, and F. Forcellini, Industry 4.0 and Industry 5.0 from the Lean perspective. International Journal of Management, Knowledge and Learning, 2022. 11.
15. Lee, J., Industry 4.0 in big data environment. German Harting Magazine, 2013. 1(1): p. 8-10.
16. Khaitan, S.K., J.D. McCalley, and C.C. Liu, Cyber physical systems approach to smart electric power grid. 2015: Springer.
17. Atzori, L., A. Iera, and G. Morabito, The internet of things: A survey. Computer networks, 2010. 54(15): p. 2787-2805.
18. Zhong, R.Y., et al., Intelligent manufacturing in the context of industry 4.0: a review. Engineering, 2017. 3(5): p. 616-630.
19. Neugebauer, R., et al., Industrie 4.0-From the perspective of applied research. 2016, Elsevier. p. 2-7.
20. Xu, X., et al., Industry 4.0 and Industry 5.0—Inception, conception and perception. Journal of Manufacturing Systems, 2021. 61: p. 530-535.
21. Kurschl, W., et al., Using mixed reality in intralogistics-are we ready yet? Procedia Computer Science, 2021. 180: p. 132-141.
22. Siew, C., et al., Human-oriented maintenance and disassembly in sustainable manufacturing. Computers & Industrial Engineering, 2020. 150: p. 106903.
23. Gualtieri, L., et al. Evaluation of variables of cognitive ergonomics in industrial human-robot collaborative assembly systems. in Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021) Volume V: Methods & Approaches 21. 2022. Springer.
24. Fogaça, D.R., M. Grijalvo, and M. Sacomano Neto, What Are Industry 4.0 and Industry 5.0 All About? An Integrative Institutional Model for the New Industrial Paradigms. Administrative Sciences, 2025. 15(4): p. 118.
25. Alojaiman, B., Technological Modernizations in the Industry 5.0 Era: A Descriptive Analysis and Future Research Directions. Processes, 2023. 11(5): p. 1318.
26. Industry 4.0 Versus 5.0: What's the Difference? 2024; Available from: https://engineeringmastersonline.rutgers.edu/articles/industry-4-0-vs-5-0-whats-the-difference/#:~:text=The%20Fifth%20Industrial%20Revolution%2C%20or,like%20climate%20neutrality%20by%202050.