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Industry 5.0: Tracing the Journey and Shaping the Future

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ABSTRACT- Industrial transformation is fundamentally a socio-technical process that integrates both technological advancements and human factors. Industry 5.0 has recently emerged as a concept that emphasizes a human-centric approach to industrial development. It focuses on aligning technological innovation with the well-being of workers, societal needs, and sustainable practices, including efficient energy use, responsible material processing, and optimized product lifecycles. This study conducts a tertiary-level analysis of thirty-two existing literature reviews on Industry 5.0, supported by bibliometric insights derived from the Scopus database. The findings reveal that research on Industry 5.0 has evolved through three distinct phases since 2018, initially marked by its differentiation from Industry 4.0. Recent research trends highlight a growing emphasis on circular manufacturing approaches, driven by advanced, human-oriented digital technologies capable of predicting and addressing potential impacts proactively. Unlike Industry 4.0, Industry 5.0 adopts a broader, future-focused, and cross-sectoral perspective. From a theoretical standpoint, this paper synthesizes key insights from existing literature to provide a clearer understanding of the Industry 5.0 research landscape and outlines directions for future exploration. From a practical perspective, it identifies critical societal considerations that organizations should integrate into their digital transformation strategies, alongside the goal of enhancing economic performance.

Keywords: Industry 5.0, bibliometric analysis, tertiary study

INTRODUCTION

Industry 4.0 emerged as a policy-led initiative aimed at transforming manufacturing through the integration of advanced digital technologies. First introduced in 2011 as part of Germany's high-tech strategy, the concept rapidly gained global attention. It encompasses a wide range of technologies such as cloud computing, the Internet of Things (IoT), artificial intelligence, autonomous robotics, augmented reality, and blockchain, all working together to enable the development of smart and interconnected factories. Over the past decade, research in Industry 4.0 has significantly improved manufacturing connectivity and laid the groundwork for the evolution of Industry 5.0, which emphasizes the reintroduction of human involvement within cyber-physical systems.

The current transformation of manufacturing is increasingly driven by long-term societal goals and future-oriented thinking. Policy frameworks, particularly those promoted by the European Union, have played an important role in advancing Industry 5.0. These initiatives focus on creating a people-centered economy, supporting environmental sustainability through green policies, and ensuring readiness for a digital future. While policymakers have been instrumental in shaping this transition, academic research has also contributed significantly since the early development of the concept. Industrial stakeholders have only recently begun actively engaging with Industry 5.0, as reflected in discussions such as the roundtable held in April 2022. These discussions highlight the urgent need to address societal disruptions, strengthen resilience, improve governance, and move beyond the purely competitiveness-driven approach of Industry 4.0 toward a more meaningful and purpose-driven digitalization strategy.

Several recent studies have explored Industry 5.0 through systematic literature reviews. For instance, some researchers have conducted bibliometric analyses using databases such as Web of Science, while others have reviewed selected sets of academic papers or analyzed large collections of abstracts. Despite these contributions, there remains a lack of studies that synthesize findings from existing literature reviews themselves, commonly referred to as tertiary studies. Given the rapid growth of research in this area, it is important to examine how the concept of Industry 5.0 is evolving and to identify emerging trends and future directions. Accordingly, this paper aims to evaluate the development of Industry 5.0 research over time, provide a clear overview of the current research landscape, and propose recommendations for future investigations.

To achieve these objectives, this study adopts a two-stage methodology. The first stage involves a bibliometric analysis using the Scopus database, expanding on previous studies by including a total of 277 publications, with a significant number published between 2021 and 2022. This analysis was conducted using VOSviewer to examine patterns such as authorship, geographic distribution, and thematic development. The keyword "Industry 5.0" was used as the basis for data

collection, while excluding irrelevant publications prior to 2018. This step enabled the identification of different phases in the evolution of Industry 5.0 research.

In the second stage, a tertiary study was carried out focusing specifically on literature reviews published in academic journals. From an initial pool of 184 articles, relevant review papers were selected through both automated filtering (based on Scopus classification) and manual screening by the researchers.

INDUSTRY 5.0: A CRITICAL ANALYTICAL PERSPECTIVE

The overall examination of the literature reveals four key thematic groupings within Industry 5.0 research. The first group focuses on the foundational ideas of the field, bringing together concepts such as advanced manufacturing, customization, digital transformation, sustainability, and the broader vision linked to Society 5.0. The second group emphasizes the transformation of the workplace, particularly the collaboration between humans and intelligent machines, along with growing attention to resilient supply chain systems. The third group highlights the increasing relevance of digital twin technologies, especially for modeling, forecasting, and improving the performance of physical systems. The fourth and most extensive group includes the core technological drivers of Industry 5.0, such as distributed ledger systems, connected devices, immersive technologies, and next-generation communication networks.

The development of Industry 5.0 research over time can be viewed in three major phases. In the early phase (2018–2019), the focus was mainly on understanding the outcomes of digital transformation and how the transition from Industry 4.0 to a more human-centered approach could be achieved. During this stage, attention was given to the interaction between humans and machines, along with the role of enabling technologies, which gradually introduced more socially oriented aspects of industrial development. The second phase (2020–2021) brought a stronger emphasis on societal needs, particularly sustainability, while still maintaining its technological roots. Concepts such as human-centric operations and socially integrated systems gained importance during this period. The most recent phase, beginning in 2022, reflects a shift toward more advanced and integrated applications, including smart urban systems, enhanced simulation models, and improved data security mechanisms. This stage demonstrates a clearer alignment between technological progress and long-term societal benefits. From a global perspective, contributions to Industry 5.0 research are widely distributed. Countries such as India, China, and the United States emerge as leading contributors, followed by several European nations. Other regions, including parts of Asia, the Middle East, and Australia, also show active participation. However, there is comparatively limited research output from certain regions such as Africa and parts of Latin America, suggesting opportunities for further development in these areas. In terms of academic disciplines, the majority of studies are concentrated in engineering and computing fields, reflecting the technological foundation of the concept. At the same time, contributions from social and economic disciplines highlight the broader societal implications of Industry 5.0. Additional fields, including environmental studies, energy, and materials science, further demonstrate the interdisciplinary nature of this research area.

The publication landscape shows that both specialized and multidisciplinary journals are actively contributing to the dissemination of Industry 5.0 research. Leading journals in industrial technology, sustainability, and applied sciences play a major role, while information systems journals are increasingly engaging with the topic as its relevance grows.

Financial support for research in this field is provided by a wide range of organizations across different countries. European funding bodies are among the most prominent contributors, alongside major national research agencies in Asia. The diversity of funding sources reflects the global importance and growing recognition of Industry 5.0.

Overall, the analysis confirms three important patterns: a consistent rise in research activity since 2018, widespread international interest with strong participation from advanced economies, and a dominant focus on technological disciplines, supported by expanding attention to social and environmental considerations.

FUTURE OUTLOOK AND STRATEGIC RECOMMENDATIONS FOR INDUSTRY 5.0

The main directions of research in Industry 5.0 emphasize a forward-looking and interdisciplinary approach. Unlike Industry 4.0, which largely focuses on the application of digital technologies to improve manufacturing efficiency and productivity, Industry 5.0 adopts a broader perspective. It places greater importance on both customer needs and human values, extending beyond purely technological goals. In this context, digitalization is not an end in itself but a means to address wider environmental, social, and energy-related challenges. Thus, Industry 5.0 integrates the technological foundations of Industry 4.0 into a more comprehensive framework that prioritizes human well-being and societal development. It reflects a shift from a technology-centered model to one guided by values and purpose.

Within this framework, humans play multiple roles. As consumers, they increasingly demand personalized products at

scale. As workers, they collaborate closely with advanced machines and robotic systems, requiring new skills and capabilities. At a broader level, humanity is viewed as part of a global system facing critical challenges, such as climate change and resource scarcity. Industry 5.0 can therefore be seen as a transformative approach that connects industrial development with the resolution of these global issues through a value-driven lens.Ethical considerations are fundamental in this new paradigm. The responsible use of technologies, particularly artificial intelligence, is essential in supporting decision-making processes within highly digitalized environments. There is a growing need to design systems that inherently incorporate sustainability principles, such as reducing transportation impacts in supply chains or selecting environmentally responsible partners. Artificial intelligence can also contribute to minimizing waste, improving demand forecasting, and ensuring fairness in production processes. To support these objectives, the development of new performance indicators is necessary. These indicators should enable organizations to measure and demonstrate responsible practices, including efficient energy use and sustainable resource management. Advances in areas such as blockchain and data analytics offer promising tools for enhancing transparency and accountability.

The regulatory environment surrounding Industry 5.0 is complex and evolving. While existing voluntary standards, such as those related to interoperability in connected systems, remain important, there is also an increasing role for formal regulations. These may address issues such as resource usage, labor conditions, and environmental impact. For example, industries like textiles are expected to adopt practices that ensure traceability, circularity, and waste reduction across the entire supply chain. Digital tools, including product passports, play a key role in meeting these requirements. As a result, digital transformation under Industry 5.0 involves not only technological change but also regulatory adaptation and cultural shifts that influence both organizational strategies and consumer behavior. Practical applications of Industry 5.0 are still developing, and further case studies are needed to support implementation. Potential areas of exploration include technologies that enhance worker safety, such as wearable devices, and innovations that improve product safety during use, including autonomous systems and medical technologies. Additionally, there is significant scope for using data-driven approaches to reduce environmental impact. Industry 5.0 is also closely linked to the development of smart cities, where intelligent systems can support waste management, achieve low-carbon operations, and create improved working environments for citizens.

Despite growing interest, certain research areas remain underexplored, particularly those related to safety, security, and regulatory frameworks. Strengthening these areas through systematic reviews and empirical studies will be important for advancing the field. Future research can focus on improving the resilience of regional economies, identifying technologies that support sustainable policies, and evaluating the outcomes of Industry 5.0 initiatives for both workers and broader society. Understanding the real-world impacts of these transformations is a central concern. Key research themes in Industry 5.0 include the application of technology to enhance human well-being, such as in healthcare, ergonomics, and collaborative robotics, as well as the transition toward more sustainable production systems. Further investigation is needed in areas such as assessing the sustainability of technologies, analyzing the broader effects of digital transformation, enhancing competitiveness through sustainable innovation, and reducing reliance on finite resources through practices like decarbonization. The global adoption of Industry 5.0 also requires greater participation from developing regions. For the concept to achieve meaningful impact, it must extend beyond technologically advanced economies. International collaboration will be essential, particularly as environmental challenges are shared globally. Future research may explore how digital transformation can support circular manufacturing while promoting fair labor practices and sustainable growth in emerging economies. Strengthening supply chain resilience through Industry 5.0 principles can also involve smaller enterprises and local communities.

CONCLUSION

This study provided a comprehensive examination of Industry 5.0 through a combination of bibliometric analysis and a tertiary review of existing literature. The findings indicate that the development of Industry 5.0 research can be understood in three distinct phases since its emergence as a concept separate from Industry 4.0 around 2018. In its most recent phase, Industry 5.0 has established itself as an independent and evolving field, characterized by its interdisciplinary nature, long-term orientation, and strong focus on societal and environmental priorities within manufacturing systems. The tertiary review conducted in this study contributes to the field by consolidating key insights and offering directions for future research. Despite these contributions, certain limitations should be acknowledged. The analysis was based on a single database, which, although widely recognized, does not capture the full range of publications, particularly those presented in conferences or other emerging outlets. In addition, the close relationship between Industry 4.0 and Industry 5.0 presents challenges in clearly distinguishing between the two domains.

Although a structured selection process with defined criteria was applied, some level of subjectivity in identifying relevant studies may remain. Future research could address these limitations by incorporating multiple data sources, expanding the types of publications considered, and refining the criteria for inclusion. Furthermore, the recommendations presented in this study are influenced in part by policy developments and early industry–academic collaborations, particularly within the European context.

The transition toward Industry 5.0 involves complex, cross-disciplinary environments that require strong collaboration among researchers, industrial stakeholders, and policymakers. While Industry 4.0 continues to advance technological innovation, Industry 5.0 complements it by integrating human and societal considerations into industrial systems. Both paradigms are likely to progress simultaneously, reshaping the future of manufacturing.

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