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Transition to Industry 5.0 and beyond

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Abstract – This paper examines how industrial revolutions have changed throughout time, focusing mostly on the new Industry 5.0 framework that brings an adaptable, sustainable, and human-centered component to the advancement of technology. Industry 5.0 is positioned as a strategic extension of Industry 4.0 and is defined by the incorporation of innovative technologies, including Big Data, collaborative robots, and Artificial Intelligence, into systems that place an importance on ethical design, human involvement, and long-term social value.

Keywords: Industry 5.0, Industry 4.0, artificial intelligence (AI), digitalization

I. INTRODUCTION

Advanced technologies like automation, artificial intelligence (AI), the Internet of Things (IoT), and big data analytics have caused a remarkable shift in industrial processes worldwide during the last several decades. These technological advancements, which are sometimes grouped under The Industry 4.0, have completely changed the way that items are made, increasing accuracy, productivity, and efficiency. But as these developments progress, they have also raised questions about job displacement, the morality of automation, and the changing role of the human worker in industrial processes [1].

Industry 5.0, which highlights the combination of human intelligence with advanced technology to build a more equitable, sustainable, and balanced industrial environment, has become an appealing concept in response to these issues [2].

II. THE EVOLUTION OF THE INDUSTRIAL REVOLUTIONS

The First Industrial Revolution

Mechanized manufacturing replaced manual labor in Industry 1.0, which started in the late 18th century. Textiles and mining were transformed with the introduction of steam power and mechanical instruments like the power loom and spinning jenny. Efficiency and manufacturing capacity were greatly enhanced by these improvements. Mechanization increased employment as well as wage growth, according to empirical research looking at the spread of steam power in the 19th century. Industries that adopted steam had up to 94% more workers and paid salaries up to 5% more than their non-steam alternatives [3].

The Second Industrial Revolution

The development of assembly lines and electricity production in the 19th century marked the start of the Second Industrial Revolution. The idea of mass processing was adapted by Henry Ford (1863–1947) from a Chicago slaughterhouse where each butcher only performed a portion of the cow slaughtering duties and the pigs were suspended on conveyor belts. These concepts have been used by Henry Ford in the production of automobiles, and he has substantially improved the method of manufacturing [4].

It was marked by the widespread use of electricity, which paved the way for the creation of assembly lines and mass manufacturing methods. Faster production with consistent procedures and more effective machinery operation were made possible by

electrification. A case study examining the development of production systems demonstrated the flexibility and efficiency gains made possible by the implementation of flow line production and the Toyota Production System (TPS), which optimized supply to satisfy changing customer demands [5].

The Third Industrial Revolution

The third industrial revolution started in the 1970s [4], (1950s from other sources [28]) with computers and memory programmable controls for partial automation. Given that these advancements have been made, researchers can optimize the whole development process without the need for human intervention.

Robots that execute program sequences without human intervention are examples of this. Henry Ford's desire for increased productivity and the intelligent procedures that are beginning to appear under Industry 4.0 are connected by Industry 3.0. Not only were procedures like those at Ford made simpler, but automation also increased the safety and efficiency of crucial production processes [4].

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The Fourth Industrial Revolution

The German government first announced Industry 4.0 as the start of the fourth industrial revolution during the 2011 Hannover Fair [6].

Comparably, to fully understand irreversible changes, a thorough understanding of the shift from Industry 3.0 to Industry 4.0 is required. This transformation has several components that also have social consequences. Among them is the Internet of Things (IoT). Machine-to-machine (M2M) communication is made possible by this technology. A more human-free industrial environment is produced by this capacity. The second significant factor behind these shifts is "autonomy." The systems are increasingly acting on their own initiative. Cyber physical systems (CPS) and a few sensors are additional crucial components of this change. They make it easier for machines to communicate with one another. More reliable, flexible, and intelligent production systems are created when CPS, IoT, M2M connectivity, and autonomy work together [7].

Industry 4.0 refers to the way production processes are organized using technology and autonomously communicating devices along the value chain. This represents a model of the future "smart" factory, where computer-driven systems keep an eye on physical processes, create a virtual environment, and make decentralized choices using self-organization mechanisms. The notion considers the growing computerization of manufacturing sectors, where tangible items are easily incorporated into information networks [8].

The Fifth Industrial Revolution

The need for productivity, efficiency, and technical improvement has continuously fueled the development of industrial paradigms. Nevertheless, Industry 5.0 represents a dramatic change toward a more human-centered strategy, merging human intelligence with innovative technologies to build inclusive, sustainable, and resilient industrial systems [9].

Industry 5.0 places more emphasis on human-machine collaboration than its predecessor, Industry 4.0, which mainly dealt with automation and digitalization. It does this by using technologies like robotics, the Internet of Things, and artificial intelligence (AI) to improve human capabilities rather than replace them. This paradigm shift highlights the benefits of human creativity, critical thinking, and adaptation in complex industrial situations, as well as the limits of a solely technological approach [10].

III THE IMPORTANCE OF INDUSTRY 5.0

It has been observed that the goal of maintaining customer pleasure by mass production modifications is no longer enough in the setting of Industry 4.0. However, if people are actively involved in the production processes, consumer satisfaction may rise when mass production and customized manufacturing are combined. Consequently, there is an increasing need to establish an Industry 5.0 environment. Industry 5.0 promotes active participation in smart factories and human-machine collaboration to enhance product customization and boost production capacity [11].

Data analysis by artificial intelligence and value creation allows the custom manufacture of items based on each customer's demands, considering the various needs of users and consumers. It is possible to do the following:

- Stability and adaptability in production scheduling and ideal inventory control in response to the client's present needs.
- Increase production efficiency, save expenses, and optimize labor use, timely and appropriate product or service delivery.
- Reduce shipping delays and deliver goods to clients quickly.

The implementation of these solutions will boost industry competition and consumer happiness, lower costs, and enhance environmental circumstances [12].

IV. CHARACTERISTICS OF INDUSTRY 5.0

Implementation of intelligent technologies in Industry 5.0 significantly boosts innovation and creativity. In this phase, organizations employ tools, equipment, and intelligent materials to enhance smart manufacturing, enhancing productivity, quality, and flexibility. Enhanced customer satisfaction is related to high-quality products as well as services. Utilization of tools and sensors in the industrial revolution increases a system's processing ability, enhancing its ability to meet customer expectations. By simplifying the decision-making process in complex procedures, modern technology and software also ease operations [11]. The four main elements of Industry 5.0 are elaborated further in Table 1.

Through the implementation of smart materials, Industry 5.0 offers a change of produced product qualities to meet specific requirements and standards. Since software is the foundation of digital manufacturing, understanding this field is crucial for creating sophisticated, high-tech products. During this revolutionary time, the creation of innovative and creative products is prioritized, which reduces the need for inventory and physical storage [11].

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Table 1

Main characteristics of Industry 5.0 [12]

No.	Elements	Description	References
1	Intelligent materials	• Smart materials have changeable properties that change with temperature, humidity, light, etc. • These materials are used in various industries such as textiles, medicine and electronics and aerospace industries • In the 5.0 industry, smart material capabilities play an important role	(X. Li, Shang, & Wang, 2017),(Hakanen & Rajala, 2018),(Yang et al., 2019),(Haleem & Javaid, 2019a)
2	Intelligent devices	• Computing capabilities are a prominent feature of smart devices in the Industry 5.0. • Ability to connect in smart devices for effective management and monitoring. • Internet-connected cameras in smart devices improve the operation control system.	(Crutzen, 2005),(Derby et al., 2007),(Matindoust, Baghaei-Nejad, Abadi, Zou, & Zheng, 2016),(Shammar & Zahary, 2019)
3	Intelligent automation	• This element integrates different aspects of humans, software and machinery and improves their participation. • Automation system is effective for detecting process errors. • Machine learning in this system increases productivity in complex tasks and processes and is useful in reducing process time.	(Mekid, Schlegel, Aspragathos, & Teti, 2007),(Butner & Ho, 2019),(Pagliosa, Tortorella, & Ferreira, 2019)
4	Intelligent systems	• Intelligent systems can be used in various parts of the supply chain, such as transportation, logistics, research and development, etc. • In industry 5.0, this system increases the ability to interact and react to environmental changes • Intelligent systems allow the customer's personalized needs to be met at the required time	(Dragcevic et al., 2007),(Sykora, 2016),(Xie, Liu, Fu, & Liang, 2019),(Sakamoto, Barolli, Barolli, & Okamoto, 2019)

Table 2

The benefits and risks of Industry 5.0

Benefits	Risks
Human centric focus The focus on human-centric cooperation, in which people and robots collaborate in a synergistic way, is a fundamental component of Industry 5.0 [13]. This paradigm change puts human innovation and decision-making at the forefront, departing from Industry 4.0's automation-centric approach [14].	**Cybersecurity vulnerabilities** The attack surface for cyber-attacks is enhanced in Industry 5.0 environments due to the increasing interdependence of devices. To protect sensitive data and maintain system integrity, the integration of AI, IoT, and other cutting-edge technologies calls for strong cybersecurity measures [18].
Resource efficiency and sustainability Industry 5.0 technology adoption supports environmentally friendly production methods [15].	**Workforce skill gaps** Employees must learn new skills to work with modern technology, involving the ability to comprehend and control complex robots and advanced technology [19].
Improvement of customer satisfaction Mass manufacturing gives way to mass personalization with Industry 5.0, allowing producers to customize goods to each customer's tastes without compromising productivity [16].	**Financial and investment** Industry 5.0 will necessitate a large financial outlay. Particularly for SMSs, high expenses of hiring new staff, updating infrastructure, and purchasing new technology can be a major deterrent. Financial risk is increased by the possibility of a delayed ROI [20][21].

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V. COMPARING THE BENEFITS AND POTENTIAL RISKS OF INDUSTRY 5.0

It's essential to take into consideration both the potential advantages and disadvantages of Industry 5.0, as it continues to influence discussions about the future direction of manufacturing and innovation. [22]. Understanding its deeper implications from a technological, economic, and social perspective requires a balanced approach. The main benefits and risks of Industry 5.0 will be shown in Table 2.

Future perspectives on human-centricity include improving human-robot interaction in dynamic and complex industrial systems and achieving the balance and fullness of human-machine collaboration, which aims to empower humans and human operators by enhancing their individual capabilities and skills [14].

Businesses may minimize their environmental impact, save waste, and maximize resource consumption by utilizing real-time monitoring and sophisticated analytics. This encourages ethical production and consumption and is consistent with global environmental goals [15].

Industries may quickly modify manufacturing lines to produce personalized goods at scale by using cutting-edge technology like artificial intelligence (AI), the Internet of Things (IoT), and collaborative robots (cobots). In addition to improving customer happiness, this strategy gives businesses a competitive edge in industries where customization is becoming more and more important. By utilizing smart technology, items are produced with greater quality and consistency, which increases consumer loyalty and confidence [17].

To enable the safe adoption of Industry 5.0 concepts, studies have shown how inadequate current industrial implementation frameworks are at resolving these cybersecurity issues. Accordingly, new frameworks focused on cybersecurity are required [18].

Increasing the skills of the workforce is a major concern, especially in emerging nations where training resources may be scarce [19].

VI. FUTURE PERSPECTIVE ON INDUSTRIAL REVOLUTIONS BEYOND INDUSTRY 5.0

Discussions concerning how future developments could impact industries and societies continue to be caused by the development of revolutions in industry. Researchers argue that in future Industry 6.0 could have technologies such as improved biotechnology and quantum computing, making industries more adaptable, sustainable, and responsive to concerns about the environment [23]. Some academics wonder if Industry 4.0 and 5.0 are really revolutions or perhaps these are just little steps toward greater transition. Alongside technological innovation, an actual industrial revolution often involves significant systemic transformations, such as social, economic, and political conflicts [24]. Although they attempt to solve urgent global challenges like climate change and ethical concerns in automation, the changes anticipated for Industry 6.0 and beyond could be considered more revolutionary in nature [25].

Beyond automation and digitalization, Industry 6.0 is envisioned as an innovative phase in the development of industry. It places an extreme value on excessive personalization, emotional intelligence in machines, and harmonious human-AI interaction using technologies like virtual twins, quantum computing, and autonomous systems [26]. Although still theoretical, Industry 7.0 expands on these concepts by putting ahead a post-industrial, regenerating society in which industries function in harmony with ecological systems [27].

Looking ahead, these future revolutions will likely require new frameworks for governance and collaboration among governments, businesses, and communities. The success of these changes will depend not only on technology but also on how well industries align their goals with societal needs and sustainability principles. [24]

The trajectory of industrial revolutions suggests that more profound transformations are on the horizon, potentially redefining the concept of what an industrial revolution truly means.

VII. CONCLUSIONS

Industry 5.0 is a value-driven development that combines resilient systems, sustainability, and human empowerment. Through cobots, it improves human-machine collaboration, promotes skills investments, and reinterprets success in terms of mindfulness of the environment. It must be implemented strategically and inclusively, though, because it confronts significant challenges in the areas of investment, skills, and security. Organizations can move toward a responsible future by using human-centered design, pilot-based expansion, thorough training, and cyber-sustainable governance. This continuous change encourages cross-sector movement and collaborative studies to achieve a future in where technology promotes human potential in a flexible, caring industrial society.

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