

Assignment 02 (Essay)
Advanced Industry 4.0 (ACPA7000)

**Current Manufacturing Systems and Impact of Adopting
Emerging Industry 4.0 Technologies**

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Abstract:

Since the 21st century, manufacturing industry has witnessed a groundbreaking transformation through the intervention of Industry 4.0, also known as the fourth industrial revolution. This emerging paradigm is supported by advanced technologies, data analytics, and super-fast connectivity to create automated and intelligent manufacturing systems. This report investigates the effectiveness of the current manufacturing systems and identifies the potential fields where emerging technologies can be implemented successfully. The real time applications of these technologies have been supported by appropriate case-studies. Finally, technological factors that afford beneficial impact and any humanistic or environmental implications of such technical adoptions have been discussed.

1. Introduction

From the era of third industrial revolution or Industry 3.0, the manufacturing systems have relied on machines and humans and making extensive use of control systems such as SCADA. Since then, chain of advancements in manufacturing systems and automation has been witnessed worldwide leading us all to the fourth industrial revolution, or as we say, Industry 4.0 (I4.0) (Yin, et al., 2018). Due to rapid transformation of the society by the global competitors and environmental challenges, manufacturing processes have become automated, faster and smart enabling people to run and control the machines in more flexible ways enabling customization of the product and processes (Qin, et al., 2016). The age of internet and 5G connectivity has driven us to realization of humans and machine interaction in real time and decision making. The evolution in agile manufacturing drives this transformation into waste-free and more efficient digital and automated industrial machines.

As an example, the adoption of dextrous robots has introduced multi-machining and manufacturing operations such as drilling, cutting, milling, and welding process by the same robot arms saving time and cost in addition to flexibility to the producer and customization possibilities. The effectiveness of current manufacturing systems can vary depending on various factors, including the industry, company size, technological advancements, and implementation strategies. Overall, modern manufacturing systems have significantly evolved and become more efficient compared to traditional methods. Here are some key aspects contributing to their effectiveness.

- i) Use of robotics and automation: Robots have revolutionized manufacturing processes, allowing faster and more efficient production. A wide range of industries especially healthcare, finance, and transportation are benefiting from the automated systems and robots, contributing to their increased efficiency and accuracy in these fields. This in turn enables them to achieve a higher degree of precision, speed, and consistency in manufacturing operations. These systems

have disrupted the human intervention and errors by automating repetition of tasks in a way that increases efficiency and productivity.

- ii) Digitalization and Data Analytics: Manufacturing systems are increasingly making use of digital technologies such as the cloud computing, Internet of Things (IoT), artificial intelligence (AI) and data analytics to optimize their processes and efficiency. These tools provide real-time analysis and monitoring of production data that leads to proactive decision-making, predictive maintenance reducing down times, track and trace of problems at source for faster troubleshooting and optimization of production processes.
- iii) Lean Manufacturing and Continuous Improvement: To streamline operations and enhance efficiency, lean manufacturing principles such as just-in-time production, reduction of waste; overproduction, excessive inventory and production errors, and continuous quality improvement are widely adopted. Moreover, maximum value creation and eliminating defects have been pursued and techniques like Six Sigma and Kaizen have been actively pursued by the manufacturing companies.
- iv) Supply Chain Integration: Supply Chain Integration is essential to make the manufacturing process more effective. Connecting and collaborating with suppliers and consumers helps businesses benefit from better inventory management, faster lead times, and improved responsiveness in general.
- v) Customization and Flexibility: Modern production systems are embracing flexibility because demand for customer personalized products is increasing. In this instance, modern manufacturing technologies like additive manufacturing (also called 3D-printing) allow for rapid prototyping and on-demand production, reducing time to market and enabling mass customization.
- vi) Sustainability and Green Manufacturing: The global challenges like climate change, carbon footprint and mass production have stressed the need for evaluation of manufacturing systems in terms of environmental impact and sustainability. This has spurred efforts globally to adopting eco-friendly practices, optimizing energy consumption, reducing waste generation, and exploring renewable resources to ensure long-term viability.

2. Emerging Technologies for Advanced Industry

The manufacturing systems performance can vary from one industry to another and from one company to another. The variations in budgeting, staffing capabilities, management tactics, and market trends are major determinants of how well these tools will work in a particular situation. Emerging technologies offer vast opportunities for adapting and enhancing current manufacturing practices under the umbrella of

14.0. Some of the key areas where these technologies can be best exploited in the modern age is discussed as follows.

2.1 Internet of Things and Edge Computing

The IoT has brought a revolution to the modern industry and production processes. By IoT we are talking about a broader range of interconnected devices and sensors within the manufacturing ecosystem. These devices interact with the machines, production lines and humans in real time and transfer data to the server or through cloud where machine learning algorithms and predictive analytics techniques are applied to the collected data to detect patterns, anomalies, and potential issues through alerts and notifications. With this information, manufacturer can further deploy inline process monitoring, optimization and implement predictive maintenance in timely manner.

As an example, IoT implementation in the food sector has been pursued by integration of smart and connected refrigeration system (Jambrak, et al., 2021; Jagtap, et al., 2021). This is utilized to monitor and control storage temperatures and conditions of various food products which is essential amid the WHO report on food crisis/shortage (FSIN, 2023) globally induced by severe supply chain disruptions since the pandemic, Ukraine war and climate change factors. Food safety and reduction of food waste is thus become a vital challenge which needs innovative strategies through use of IoT technologies. A typical IoT enabled refrigeration system is equipped with various components e.g. digital sensors, connectivity modules, and data analysis working in tandem to collect real-time data on temperature, humidity, and other relevant parameters inside refrigerated environments such as storage warehouses, transport vehicles, and retail refrigerators.

Figure 1 shows how IoT is deployed in agriculture and food supply chain (Luo, et al., 2022). The diagram explains the variety of sensor network that gets input signals from the food environment such as temperature, humidity, gas release, logistical disruption e.g. an accident, location tracking through GPRS all feed in important data the microcontroller for digital signal processing and decision making or output generation such as dynamic shelf life estimation, food traceability from production to consumption, instant food location and safety and food quality is recorded. Therefore, a more sustainable and reliable food supply chain system may be envisaged through the adoption and integration of IoT technologies in the food or agriculture sector. This would lead us to improved visibility, increased food safety, and reduced waste helping to cut emissions by the food processing industries.

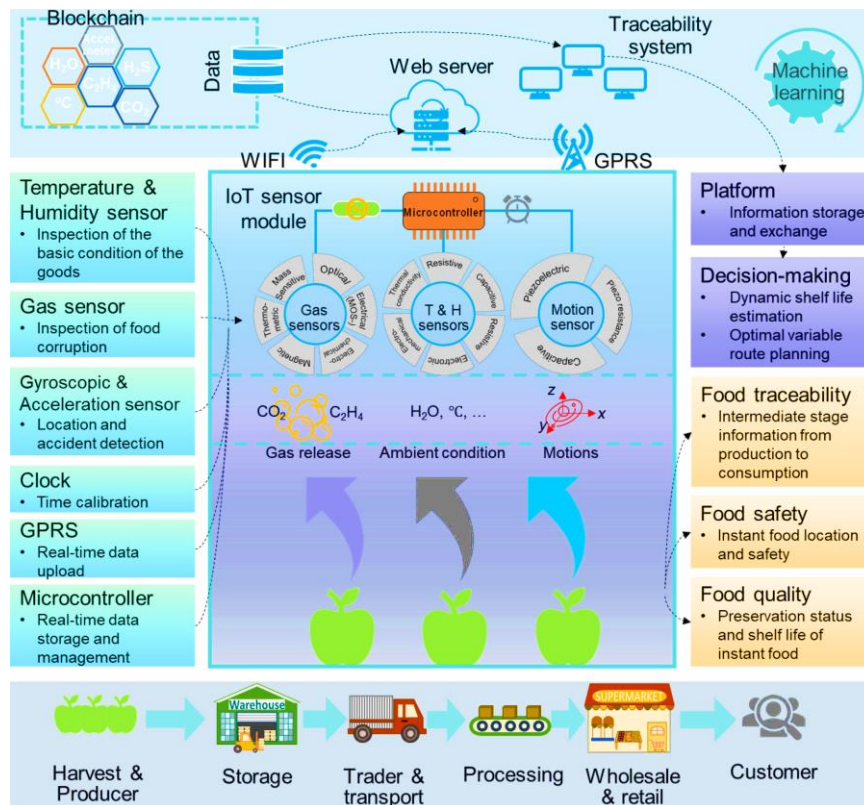


Figure1. Conceptual IoT architecture coupled with the food supply chain (Luo, et al., 2022)

In addition to IoT, edge computing (EC) plays a key role in enhancing the efficiency and responsiveness of manufacturing processes in I4.0. By bringing computational power closer to the data source, EC enables real-time data processing and analytics at the edge of the network (Nain, et al., 2022; Hassan, et al., 2018) as shown by the layered network model in Figure 2. This capability is particularly valuable in manufacturing, where time-sensitive decisions and actions are crucial without disruption in the production line. EC reduces latency and process lead time, improves data security, and minimizes the need for sending large amounts of data to centralized cloud servers for processing. With edge computing, manufacturers can perform analytics locally, monitor and control machines in real-time, and enable faster decision-making, resulting in increased operational efficiency and agility in the I4.0 landscape.

For a smart factory concept to work, it needs real-time or near real-time responses to control various operations on a factory floor. Sending all raw data from here to a remote cloud server could be challenging and cumbersome and may result in unforeseen losses and disruption in communication. Current centralized remote cloud servers and communication services do not meet critical latency requirements for real-time Big-Data stream analysis. The framework lacks the capability to manage geographically distributed sensors on remote industrial sites with intermittent Internet connectivity. The EC provides a panacea solution to all these issues and refers to intelligence and computation at the edge of the device. An edge is anything other than a remote cloud data centre in computing and storage. A very

good example of EC has been proposed by Satyanarayanan et. al. in the form of “GigaSight”, which a hybrid cloud design that uses a decentralized cloud computing infrastructure in the form of virtual machine (VM)-based cloudlets (Satyanarayanan, 2015). In addition, several hypothetical use cases have been included where crowd sourced videos will be disseminated through EC model allowing high band width and data rates. It is claimed this concept can be implemented in marketing, theme parks, locating people, pets and things, public safety, and fraud detection applications.

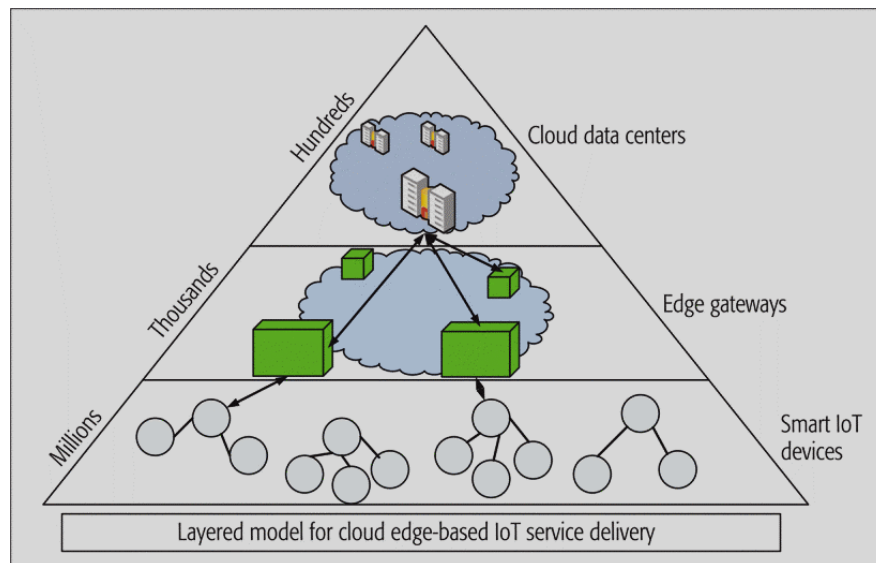


Figure 2. Layered model for cloud edge-based IoT services delivery (Hassan, et al., 2018)

2.2 Blockchain Technology

Blockchain has been regarded a key I4.0 technology that revolutionized the supply chain management bringing traceability, transparency, fraud detection, authentication of high-value assets and services in real time at source, and immutability of transactions. Implemented in manufacturing, blockchain technology can facilitate data exchange, enhance trust between supply chain partners, and enable fast tracking throughout product lifecycles. On the administrative levels, by automating and streamlining contractual agreements, smart contracts reduce administrative overhead while improving compliance.

The potential of blockchain to achieve high level of transparency and trust for customers can be elaborated with a case study that demonstrates the collaboration between Everledger and the Diamond merchant industry. Everledger, a global leader in digital registry and record keeping of high-end diamonds, implemented a blockchain solution to improve public trust for diamond provenance and introduce more transparency (Cholteeva, 2020) . By leveraging blockchain technology, Everledger created an immutable ledger that securely records the journey of each

diamond from mining to the end user including its origin, certifications, and ownership history (Gokhberg, 2023).

Likewise jewellery industry, other high-end producers and businesses can greatly benefit from the blockchain in the following ways:

The blockchain enables a transparent and tamper-proof record of a diamond's entire supply chain. This helps to overcome issues like conflict diamonds, unethical practices, and counterfeit products. Authenticity validation and ethical sourcing of jewellery purchases enhances customer confidence fostering trust in the industry as well as ensures sustainable practice.

Blockchain can be utilized to create unique digital identities (UDI) for each diamond, storing key characteristics and ownership information which can be encrypted. By associating a digital identity with a physical diamond, it becomes difficult for counterfeiters to substitute diamonds. There is no doubt that this protects the consumer and the industry from a potential loss of trust due to a bad reputation. Figure 3 shows the typical application model developed by the Everledger and the diamond industry collaboration.

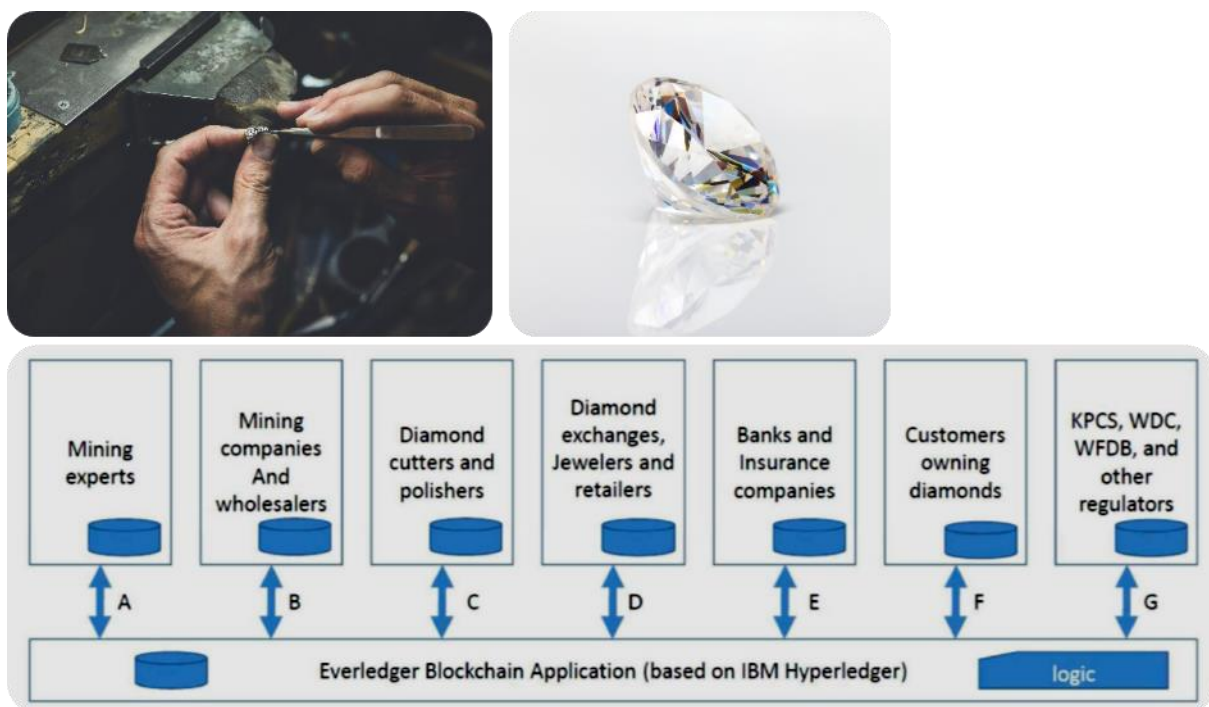


Figure 3. Concept of the Everledger Blockchain application in the diamond industry (Smits & Hulstijn, 2020)

Finally, the blockchain technology streamlines operations associated with supply chain by providing real-time tracking and movement of diamonds while they leave the mine to the final consumer. This transparency helps improve visibility, reduces paperwork, eliminate inefficiencies, minimizes disputes, and ensures faster and more

secure transactions. As a result of simplified supply chain management, operational efficiency and costs are improved.

2.3 Augmented Reality (AR) and Virtual Reality (VR)

AR overlays digital information onto the real world, while VR creates a completely virtual environment. Manufacturing operations can be leveraged to improve worker efficiency, reduce errors, enhance safety and training by employing AR and VR technologies in the processes. The maintenance of the equipment and troubleshooting tasks and exercises can be deployed through AR can provide real-time guidance and instructions to operators, overlaying relevant information on physical objects. On the other hand, VR can offer immersive training simulations for complex tasks. These technologies offer unique experience how businesses can engage with customers, train their employees, and customer expectations. One notable case study is the collaboration between IKEA and Apple's ARKit. IKEA developed an AR app that allows customers to virtually place and visualize furniture items within their own living spaces using their smartphones or tablets. This enables customers to make more informed purchase decisions by visualizing how the furniture will look and fit in their homes. The AR experience also improves customer engagement, reduces order returns and increases customer satisfaction. By combining the digital and physical worlds, this case study demonstrates how AR can transform the retail industry by enabling immersive and interactive shopping experiences.

Another example case study highlighting the transformative impact of VR is the collaboration between Ford Motor Company and the development of their immersive design process (Lingeman, 2023). Ford incorporated VR technology into their automotive design process to enhance collaboration, efficiency, and creativity. Automotive designing traditionally involves physical clay models, which can be time-consuming and expensive to create and use. Ford adopted VR technology and streamlined their process, allowing designers to visualize and iterate on vehicle prototypes in a virtual environment. With the help of VR headsets and motion tracking, designers can experience the virtual vehicle as if they were physically inside it, examining the design from various angles and making real-time modifications (Figure 4).

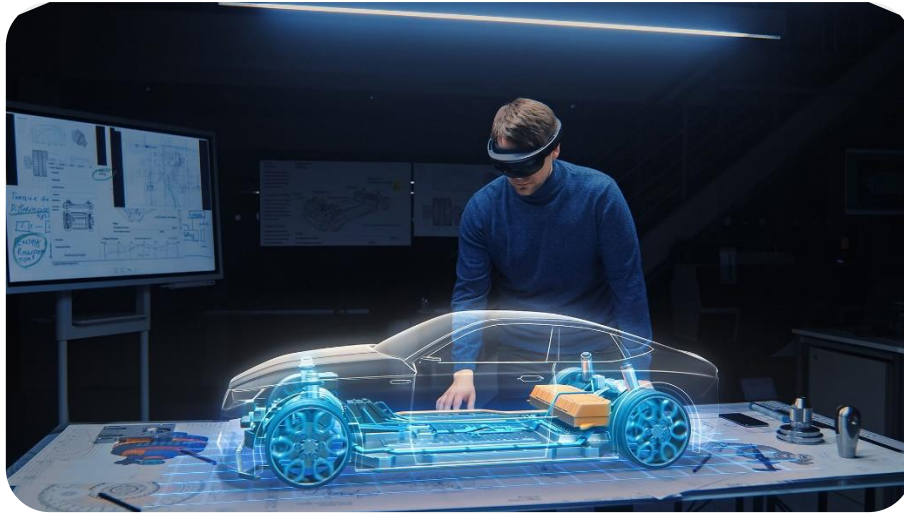


Figure 4. Automotive Engineer Wearing VR Headset Working on 3D Electric Car Design

2.4 Digital Twins

Digital twins are virtual replicas or electronic version of physical assets, processes, or systems. By creating digital twins of manufacturing equipment, products, and even entire production lines, manufacturers can simulate and optimize operations. They can also conduct predictive maintenance, and test new designs virtually (Meeker, et al., 2018). Digital twins allow for real-time monitoring, performance analysis, and scenario testing, leading to improved operational efficiency and reduced downtime. One notable case study showcasing digital twins power is used by General Electric (GE) in their aviation division. GE utilizes digital twins to monitor and optimize aircraft engine performance as shown in Figure 5. Through sensors installed in engines, real-time data is collected and translated into the digital twin, which simulates the engine's behavior and performance as of an actual engine. This enables GE to predict maintenance needs, identify potential issues, and optimize engine performance in a virtual environment. By leveraging digital twins, GE can proactively address maintenance needs, reduce downtime, and improve overall operational efficiency, resulting in cost savings and enhanced safety in the aviation industry. Although GE invested millions of dollars in this technology, using digital twin saved her \$12M, shows possibilities of what the digital twin can do are endless.

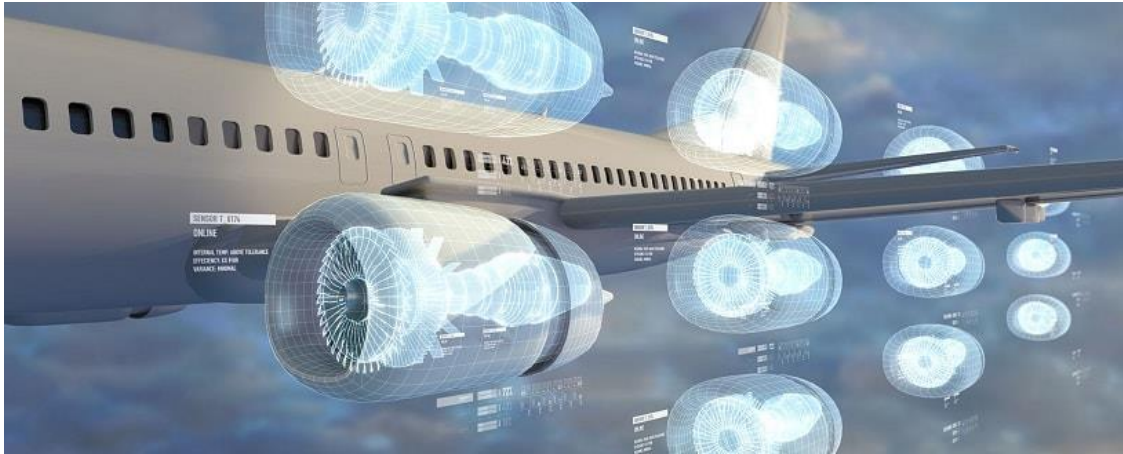


Figure 5. The GE concept of using digital twin for aero engine optimization

In the same way, GE engineers are improving the efficiency of wind turbines for renewable energy application by utilizing digital twins. They installed sensors and data analytics to monitor and estimate the temperature of physical wind turbines. An app that they developed uses the virtual sensors provided by the Haliade's digital twin turbines to perform the monitoring and estimation process. The sensors deployment enables forecasting the wind speed data that will adjust the pitch of the blades and other factors to catch as much wind as possible (Parris, 2017). Sensors also monitor weather conditions and wind to determine whether to run the turbines at full power or if they should reduce their power slightly. While the app is still under development, it will help keep GE's efficient turbines running at improved energy output and contribute cutting emissions.

3. Impact of I4.0 Adoption

1. **Increased Efficiency and Productivity:** By leveraging real-time data and intelligent automation, manufacturers achieve enhanced efficiency, reduced downtime, and improved resource allocation. Predictive maintenance and remote monitoring enable proactive equipment servicing, minimizing unplanned downtime. Additionally, AI-powered systems optimize production workflows, reducing lead times and maximizing output.
2. **Enhanced Quality Control and Customization:** I4.0 enables real-time monitoring and control over the manufacturing processes, ensuring consistent product quality. Advanced sensors and analytics detect anomalies and deviations, allowing for immediate corrective action. Furthermore, the customization potential offered by additive manufacturing and digital design tools enables manufacturers to cater to individual customer preferences and market demands.
3. **Supply Chain Optimization:** I4.0 facilitates end-to-end supply chain visibility, enabling real-time tracking of inventory, demand forecasting, and streamlined logistics. Smart logistics systems employ IoT

4. Implications of I4.0 Technologies

The impact of I4.0 technologies is diverse and adoption of these technologies has both humanistic and environmental implications either positive or negative. Here are some key forecasts for Humanistic and environmental aspects.

Humanistic:

- i) Displacement risk: The increased automation and use of advanced technologies in I4.0 can displace worker jobs and change the industrial workforce. Certain roles may become obsolete, requiring workers to acquire new skills and adapt to new job requirements. It is essential to provide adequate training and support to ensure a smooth transition and minimize the negative impact on workers.
- ii) Skills Gap: like many other emerging technologies, the speed of technological advancements in I4.0 may result in a skills gap between the demand and supply of high skilled workforce. It is crucial to invest in education and training programs for skills and competencies development required by the existing workforce to thrive in the digital age.
- iii) Safety and Well-being: New challenges are introduced by adoption of I4.0 technologies in terms of workplace safety. Careful planning and process design methodology is required for collaborative robots (cobots) and human-robot interactions to ensure the well-being of workers and safeguard of the environment. Organizations must prioritize employee safety, provide appropriate training, and establish protocols for safe human-machine interactions.

Environmental:

- i) Resource Efficiency: I4.0 technologies offer opportunities optimized utilization of resources and improving the energy efficiency. The analytics from real-time data and process optimization algorithms can help industry to minimize their waste, reduce energy consumption, and reduce their negative environmental impact.
- ii) Sustainable Practices: I4.0 technologies brings sustainable practices across the supply chain i.e. from tracking and optimizing energy consumption to enhancing management of inventory and logistics. Organizations can help improve making informed decisions that map with sustainability goals through adoption of these technologies.
- iii) Electronic Recycling: The scale of connected I4.0 devices and the regular upgradation cycle may lead to increased electronic waste (e-waste). It is vital to solve this problem for safe disposal and recycling to mitigate environmental hazards and introduce safe waste management practices.
- iv) Privacy and Data Security: The extensive use of data in I4.0 raises concerns about data safety and cyber security. Organizations must prioritize the protection of sensitive data, adhere to standard regulations,

and implement robust security measures to prevent unauthorized access and potential harm to the environment by data breaches.

5. Conclusions

- New and emerging technologies bring various opportunities for further adaptation and improvement in manufacturing practices within the framework of I4.0.
- From IoT and edge computing to blockchain, VR/AR, digital twins, advanced robotics, AI/ML, and 3D printing, these technologies have the potential to enhance efficiency, quality, and flexibility in manufacturing operations.
- By embracing these innovations, manufacturers can stay at the forefront of the industry and unlock new levels of productivity and competitiveness.
- A just transition for workers and investing in skills development is essential by organizations to address the humanistic implications.
- Organizations need to proactively consider the environmental implications and adopt sustainable practices throughout the value chain to minimize the ecological impact of these technologies.
- Balancing technological advancements with human well-being and environmental sustainability is key to maximizing the benefits of I4.0.

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