



IMPACT OF INDUSTRY 4.0 ADOPTION IN MANUFACTURING

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1. Introduction

Technological innovation is advancing at an accelerated rate. Beginning with the First Industrial Revolution, which introduced mechanization, the world has progressed through the Second, characterized by mass production through the utilization of electricity, and the Third, marked by the introduction of robotics. We are currently in the midst of the Fourth Industrial Revolution, characterized by the rapid introduction and continuous evolution of a wide array of technologies. This revolution impacts every sector, with Industry 4.0 technologies making inroads into both small and large-scale industries, regardless of their domain. Industry 4.0 technologies are used or trailed at many industries like creative industry, Medical, Transportation, Agriculture, Utilities, Retail, Manufacturing etc. The maturity of the advancement varies widely among these industries where creative industries has gone a long way in adopting advanced technologies emerged part of Industry 4.0 like virtual reality (VR), augmented reality (AR), while other industries like agriculture is seeing potential in optimizing farm operation, advanced pest control etc. The manufacturing industry plays a pivotal role in boosting the economy and generating employment opportunities. Therefore, the adoption of Industry 4.0 is imperative for fostering economic and social development. This essay evaluates existing manufacturing systems for its effectiveness and identifies opportunities for Industry 4.0 technologies to solve the bottlenecks and improve productivity. It will also examine the effects of introducing Industry 4.0 technology enablers on a cultural and humanistic level, as well as assess its broader impacts on society and the economy.

2. Analysis of Existing Manufacturing Systems

The term Industry 4.0 was originated in Germany in 2011 and was intended to support manufacturing development (Yin et al, 2018) [\[15\]](#) through advanced technologies. The below diagram describes the journey of industrial revolution from the past to present.

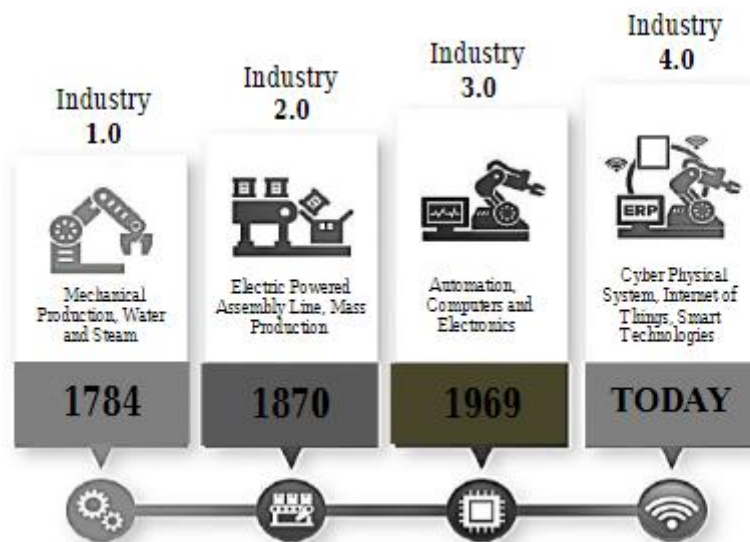


Figure – 1 Industrial revolution stages [1]

Industry 4.0 is the new digital revolution to an industry where the technological advancements transform an industry to a cyber physical connected world to work in most efficient way. where machines become intelligent. According to [1], “It refers to a mechanized system where machines and equipment will operate independently or can cooperate with human beings for customized production with continuous improvement”. Manufacturing has been the primary industry that has both been impacted by and benefited from all past industrial revolutions. Let us analyse why manufacturing is targeted by Industry 4.0 as well. Manufacturing is a major backbone of the economy and according to report by MakeUK, UK remains the ninth largest manufacturing nation in the world with an annual output of £183 Billion [2].

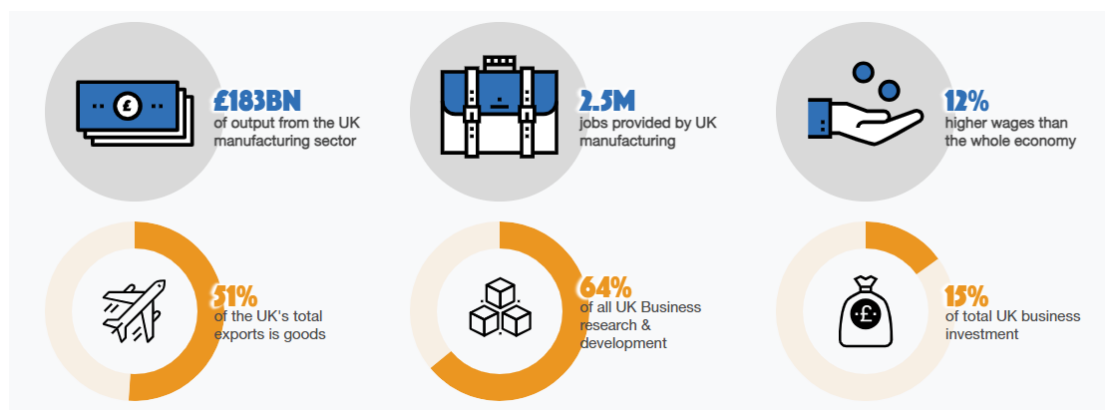


Figure 2: Manufacturing portfolio in UK

From the above image, we can understand that manufacturing has a significant role to play both in economic and social growth of UK and it is crucial to uplift the industry with latest technologies to operate in most efficient way. In a report by Mckinsey & Company on Industry 4.0, “Manufacturers in industries such as automotive and electronics, nearing the tipping point of digital adoption, are achieving even faster and more sustainable change through Industry 4.0” [3]. The manufacturing industry is going through uncertainty and disruption in recent years due to volatile market, quickly changing customer preferences, need for mass customization, improved connectivity etc. To overcome these challenges and face the competition and stay in the leading place, every company

must rethink their strategy and business operation models. Industry 4.0 enablers have become necessity not a decoration anymore.

Many of the businesses operates still manual even though the technology and connectivity has become more accessible. Many organizations has tested and implemented I4.0 technologies like digitalization of shopfloor through IIOT, cloud systems, digital twin, smart planning and scheduling, robotic automation, smart assembly systems utilizing AR(Augmented reality), 3D printing etc while other are still hesitant to try out these. This variation is wide when SMEs are considered. Some companies were brave enough to try out I4.0 enablers early in the phase and adopt them as they developed. But some organizations are still operating in conventional way where they are not aware of the potential uplift the company can go through to improved productivity and profit margins. Leveraging these digital technologies could lead to the possibilities of looking beyond productivity and focus on improving their sustainability, agility, speed to market, customization, and customer satisfaction [3] which means agile enough respond to market changes while staying as customer preferred organization.

Let us take the case study a food and drink manufacturing organization. The company is a major bottled drink producer who supplies range of still, sparkling, and flavoured drinks. They currently have multiple production line with automated lines. The factory as 2 areas and from the first area, raw materials are moved to processing into a mixing chamber. The ingredients quantity and mixing is automated and can be adjusted through an HMI (human machine interface) present in the factory. The water mix is moved from area 1 to 2 for filling and packaging. The preform bottles move through conveyor systems into sorting machine and them to the blowing machine to erect into a bottle form. The premixed water received from area 1 is filled in the moving bottles. The bottle after filling is transferred automatically through the conveyor systems for capping and bottle labelling. There is no manual intervention in these processes and all the processes are automated through machine and their control systems (PLC, Programmable Logic Controller). The bottle is inspected through a bespoke vision system and quality tested bottles are moved into conveyor for wrapping and palletizing for delivery.

As we can see, lot of the processes are automated and control systems are enabled to ensure seamless operation. The area 1 has systems in place to choose mixing ingredients and conditions through a control system and HMI for real-time modification and customization. This ensures quality and repeatability of products and minimal errors. The entire conveyor system and machines used for bottle preparation, filling and packaging has a control system in place to ensure smooth operation. There are machine lights present in the factory to visually alarm state of the machine (working/alarm/issue). The operator can easily detect issues at the production lines and attend the issue quickly and locally.

The vision system enabled at the end of filling lines checks for label quality, under/over fill, cap position etc. these vision systems were developed internally by collaborating with third party for software.

The quality system in the factory is automated developed bespoke by third party. The operator can monitor quality checks and fill the observation through user interface present at the shopfloor and it is moved to central database through server.

The company has also got a wastewater treatment system which reuses wastewater collected from the production floor for other purposes. This system is automated and equipped with necessary SCADA (Supervisory Control and Data Acquisition) systems to monitor and control the process.

From the above assessments, we can understand that the entire shopfloor is heavily automated with control systems in place to monitor and navigate the process for seamless operation and production. Even though the processes are automated, the organization was not really doing live monitoring of OEE and parameters influencing OEE. The production count was noted manually, and downtimes were recorded by operators manually to fill in the paper spreadsheet and the operation manager used to fill the information into excel sheets manually and present the OEE values to higher management in scheduled time periods. From this we can understand that the top floor lacks real-time insights on production, unplanned downtimes, and productivity impacts.

Discussion with key stake holders of the company revealed that they want to move digitally monitoring the production, real-time insights on downtimes and explore possibilities of monitoring the production remotely and developing mitigation strategies. They were interested to look at other aspects of OEE like Machine mechanical efficiency, MTBF (Mean time Between Failure), MTTR (Mean Time to Restoration), Utilization etc. The organization also had ambition for energy monitoring, optimize power consumption and advance towards sustainability goals.

3. Possibilities of Industry 4.0 Enablers

Site visit concluded that there are multiple possibilities of introducing Industry 4.0 technologies and potential for OEE improvement, enhanced growth through real-time monitoring of assets and optimized factory operation. The SDA (Smart Digital Accelerator) project was proposed to this company to digitalize OEE monitoring in multiple levels. The proposal 1 was to use the existing method of paper-based production and downtime capturing while digitalizing the information to generate a PowerBI dashboard for descriptive and diagnostic insights. This dashboard would give an overview of productivity per production line, its performance, downtime, and details of the duration.

Proposed level 2 of capturing method suggests using excel spreadsheets at the shopfloor to manually enter the productivity and downtime information to display real time information based on scheduled refresh of the dashboard. The third level of integration proposes using IOT sensors to collect the data automatically from the machines and detect downtimes based on the signals from machines. The level 3 suggests complete automation using integrated IOT sensors and databases (SQL, Cloud) for storing and processing data and finally displaying real-time information on the dashboard. The following figure depicts the solution proposed.

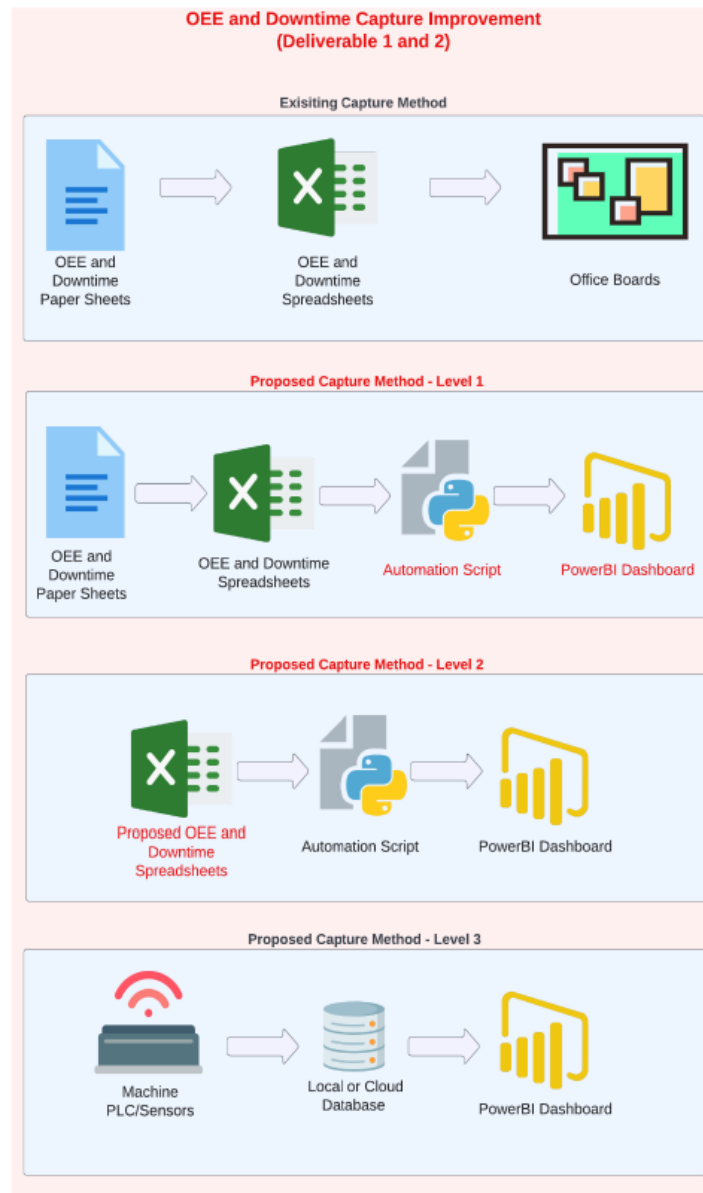


Figure 3: Proposed levels of digitalization for OEE measurement

There are possibilities of implementing other I4.0 technologies like DES (Discrete Event Simulation) for redesign for optimized factory layout, energy monitoring and optimization, advanced vision system for quality and incident monitoring, predictive maintenance of machine through machine learning algorithms etc. The organization's infrastructure maturity has an important role to play in implementing these technologies within the project timelines. For the proposed solution 2 & 3 also, the company IT infrastructure need to be involved to facilitate connectivity. The facility has intermittent Wi-fi availability in several production lines and have potential for further integration to employ advanced techniques in the future.

Similarly, [5] described about DT (Digital Twin) case study of an automotive plant where multiple parameters of the robot and environment were captured to detect the deviations and generate alarms based on the analysis. Temperature sensor for monitoring the temperature of motor in robotic arm, dust sensor for measuring the environment dust concentration, frequency sensor for measuring the CNC machine speed were employed. A detailed study was conducted to understand the sensor operating ranges and optimum range of selected parameters for convenient operation. Artificial

intelligence technique were used to develop the DT and visualization software to display the results. The below diagram showcases data generation to visualization steps employed.

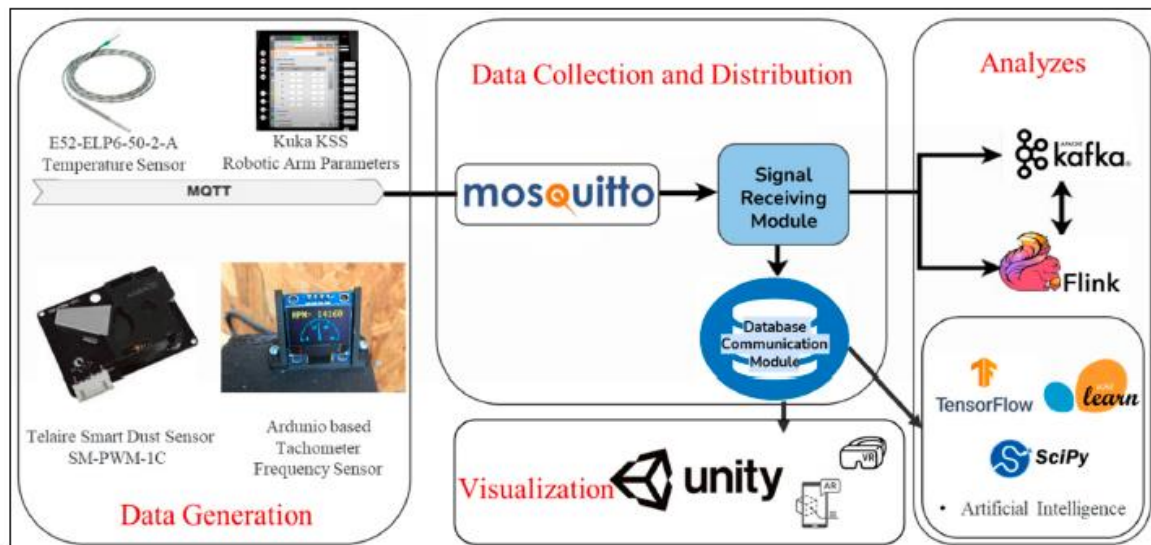


Figure 4: Visual representation of DT system architecture [5]

The data generated from IOT sensors were transported to database using MQTT (Message Queuing and Telemetry Transport) protocol and analysed at Kafka (). The data received were processed and utilized by AI software like TensorFlow, Scipy etc to do analytics and derive insights about safe, unsafe, and dangerous situations to operate. This allowed to assess the reliable operating conditions and deviations with respect to the monitored parameters. This can be integrated to add more critical sensors and monitor the plant entirely and make data driven decision using DT models. The DT model requires continuous tuning and improvement. Hence the uninterrupted data flow is essential and as mentioned before, organization's IT infrastructure need to be ready for such implementation.

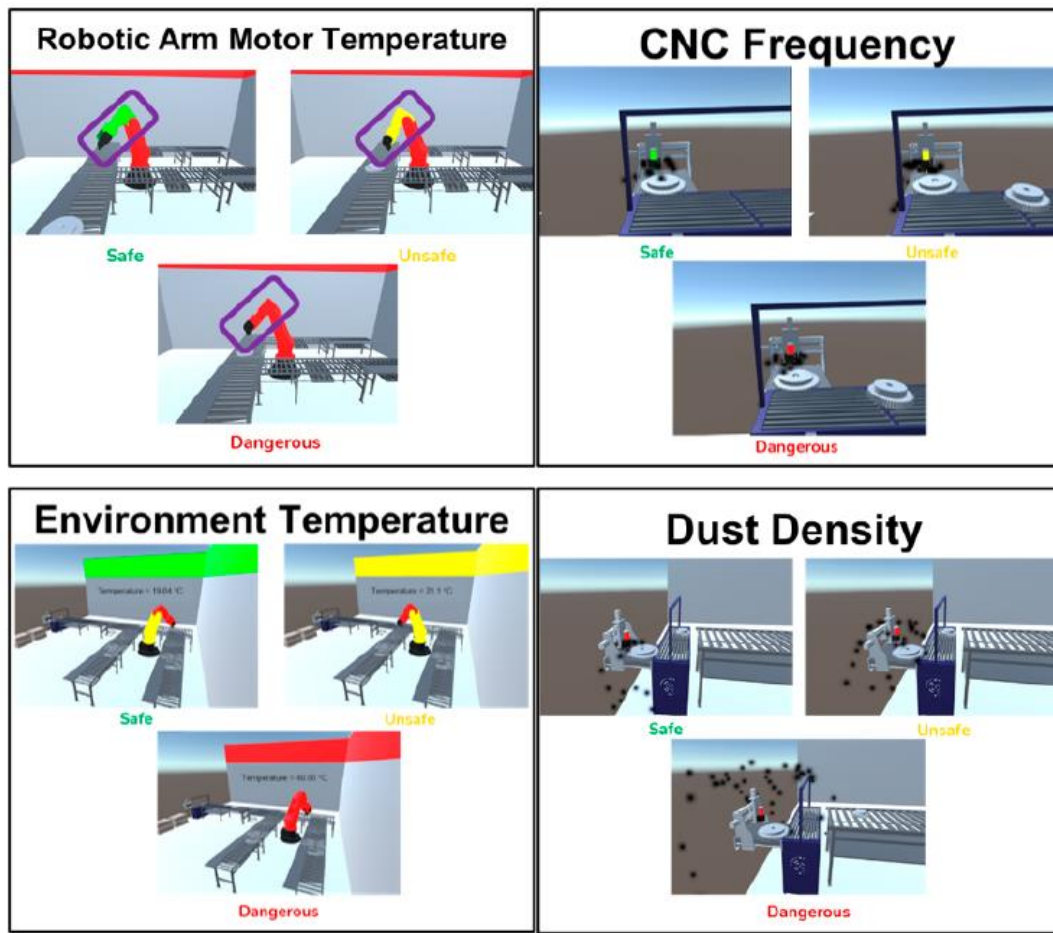


Figure5: Visualization depicting different operating conditions based on the Digital Twin

The Possibilities of introducing I4.0 technologies are immense in the current manufacturing organization. These can be introduced without interrupting the existing system and slowly moving to advancements by maturing in technologies, skillsets, and infrastructure. By automating manual tasks and digitizing processes wherever feasible, resources can be redirected towards roles that demand specific skills. The IOT sensors installed at the factory floor can measure machine performances, detect deviations, and enable predictive maintenance rather conventional corrective maintenance. AI analytics can optimize planning and scheduling improving resource utilization and reducing waste. Additive manufacturing will help prototyping and testing fast and together with collaborative robots can revolutionize assembly process allowing customization and flexibility. For assembly processes, mass customization can be enabled through Assembly 4.0 where productivity and flexibility are met at the same time. Reconfigurable assemblies, Mixed model assemblies, smart workbenches etc are latest technologies under I4.0 umbrella where manufacturing organization are looking at.

4. Benefits of Industry 4.0 Technologies

The major advantage of using I4.0 methodologies are enhanced productivity, higher quality, increased safety, upskilling human resources, open innovation, predictive maintenance, reduced waste, mass customization, environmentally sustainable production, and systems, finally leading to higher economic and social growth.

As illustrated in the case study of the bottling company, having a real-time view of OEE and downtime empowers data-driven decision-making. This enables the implementation of necessary adjustments

in the production plan and the formulation of mitigation strategies to reduce future production disruptions. Additionally, it provides the management with the ability to allocate resources towards addressing bottlenecks and conducting inspections on machines that directly impact productivity, while also arranging for suitable alternatives

In the organizations where increasingly varied demands are present, automation is least considered due to less flexibility of automated machineries. While automation enables increased productivity, manual operation is still preferred where mass personalization is required [6]. The paper analyses various dimensions of industry 4.0 technologies for assembly operations and concludes that reconfigurable assembly lines, mixed model assemblies can solve the above problem along with other smart technological innovations. AR/VR can be used for training the employees for effectiveness, cognitive/handling skills transfer systems, self-adapting automatic quality control and Human–Robot Collaboration (HRC) are some proposed advanced methodologies for future complex assembly operations. The paper concludes that for complex assembly operations, Industry 4.0 technologies have a significant role to play enabling mass customization, flexibility with maximum productivity, cost optimization, but everything without impacting the human resources negatively.

Additive manufacturing enables design and prototyping at a faster pace and many companies have initiated the introduction of this technology. According to [1], with the adoption of Industry 4.0, the use of these technologies will be made for very high performance in producing small quantities or batches of customized products and in designing and prototyping. 3D printing technology also will facilitate decentralized production systems reducing cost of transportation and inventory management.

DES (Discrete Event Simulation) is another area in I4.0 where factory floor layout can be designed for optimum resource utilization. When scaling up or integrating new production lines, DES can benefit to simulate and test the operating sequences of factory operation, by replicating the existing processes and conduct ‘what-if scenarios’ to test alternative solutions that may enable potential improvements to be trialled virtually without disruption to the physical production line. This will help to make necessary changes in the factory layout to utilize the resources in best possible way and improve productivity.

Cyber security is another major area developed recently to ensure reliable and secure communication between entities inside an organization and with other external software. Many organizations hesitate to implement IOT based system due to the risk of cyber-attack. Any security breach could affect multiple area of business operation and it is absolutely important to protect production lines and IT from cyber threats. With the advancement of big data and communication systems, organizations should pay attention to accommodate proper machine access management systems and encrypted data transfer to remain secure. The cyber security systems have developed and are capable of ensuring reliable communication and most of the IOT systems now incorporate safety protocols to prevent any security breach.

From the above discussion, we have understood that there are significant benefits that Industry 4.0 can bring to any organization irrespective of how they operate. A successful implantation of I4.0 technology depends on IT infrastructure of an organization while its adoption and ROI (Return on Investment) is only reflected when the cultural and workforce factors are treated properly. The organization should implement I4.0 enablers with genuine purpose, supported by its workforce. The organizational culture should cultivate a positive environment that enables the workforce to embrace and appreciate the new technological changes occurring within the organization. The I4.0 technologies is in the maturing stage and workforce should be upskilled to utilize it in best possible way. The

capabilities could be under utilized if the workforce is not skilled enough and the management is not supporting learning. The management should be aware of dedicating their resources for training and development while the business operation is redefined. There should be proper alignment between shopfloor and top floor to have a sustainable growth due to I4.0 implementation.

The workforce should be skilled to operate and maintain the advanced systems. Continuous upskilling and reskilling are required to bridge the knowledge gap and ensure smooth transition into Industry 4.0 era. There is a myth in manufacturing that automation would lead to manual job elimination and risk of labour loss. It should rather be understood as automation and advanced technologies would repurpose work forces in the factory floor to more skilled works where human attention is required rather than doing the tedious manual non-value-added work. This would implant the sense of responsibility and continuous innovative mindset in workforce and positive environment for growth of human resources as well as the entire organization. The I4.0 technologies can be used for upskilling the human resources through AR/VR assisted training, promoting HRC for human and robot collaboration and working together (Co-bots) etc. The digital technologies in the factories could help human operators to shift from work-focused activities towards dispositive tasks, supervision, and decision activities.

5. Socio Economic Impacts

Manufacturing is playing a key role in the economic development of both developing and developed countries. The advancement in manufacturing productivity, quality, sustainability, cost optimization, waste reduction is directly influencing the economy. Hence it is critical how the manufacturing industries are shaped to move towards growth and improve in the economic and societal aspects.

The rising automation and digital innovation have increased manufacturing capital intensity and resulted in increased efficiency compensating for increased incomes. As a result, it reduced the capital cost and the need for export to overseas to lower-salary countries.

Sustainability plays a crucial role in continuous and steady growth of any economy and many countries have stringent sustainable targets to achieve within define time frame. According to [8], “The technologies of Industry 4.0 and green manufacturing go hand in hand and guide the production talks”. Sustainable Industry 4.0 involves collectively informing, innovating, and developing environmentally friendly, cost-effective, and people-based practices [8]. Climate crisis has been the major issue discussed in many world forums and collective decision of becoming environmentally responsible is drilling down to industries in the countries. In order to address this climate crisis, every small- and large-scale industries must ensure operating sustainably. Government is imposing reduced carbon footprints within defined time period, and it has become part of many organization’s one of strategic goals as well. Organizations are required to show different levels of emission (Scope1, Scope 2, Scope 3 etc) and has the responsibility to acquire emission related information from outsourcing suppliers or contractors. Hence it is a concern for small /large industries. Industry 4.0 combines developments in emerging technology, advances in robots and artificial intelligence, advanced sensors, cloud computing, the IoT, mobile enforcement and many other applications [8]. Organizations are ready to invest in investigating carbon footprint from various resources and develop roadmaps for sustainable growth. They are ready to look for sustainable alternatives and optimizations in current consumptions like energy monitoring and optimization, renewable power sources, water usage optimization etc.

The major goal of I4.0 technology implementation in manufacturing industry is driving productivity, efficiency, quality, reduce waste, downtimes, cost and move towards sustainable economy. The

increased efficiency and productivity would result in higher output and revenue to any organization and thus to the country. Reduced waste and optimized resource utilization would result in sustainable manufacturing practises. With the advent of automation and digital technologies, routine non-value-added manual tasks can be eliminated, and the human resources can be upskilled to undertake high-skilled jobs where specific attention is required which in turn stimulates economic growth. The increased productivity along with new marketing trends and ever-increasing consumer base would result in increased revenue resulting in workforce growth. Investments should be done from high level management to capacity building and culture transformation. The adoption of digital technologies and automation should be understood for its purpose and the workforce should be trained to accept and utilize these technologies.

The digital technologies like IOT systems can be employed to collect data from machines, analyse and develop models to detect abnormal behaviour of these machines and alarm operator accordingly. These would allow developing proper planning of maintenance and repair to be conducted resulting in minimized downtime, waste, cost. By implementing technologies like these, operator with minimal knowledge in software systems gets upskilled in using the low-code no-code platforms and develop innovative mindset to address the issue and proper logistic planning. In many of the organizations, the ERP (Enterprise Resource Planning) software are not used to its capacity due to lack of skilled personnels. There is a significant potential in many of the software systems already existing in manufacturing industry factory floor but under-utilized due to lack of resources/trained professionals. Proper training and demos would enable them to utilize these for the capacity and improve performance parameters. Industry 4.0 technologies adoption should be combined with proper on boarding of workforce to embrace the technology by shopfloor as they are the major users of these technologies.

Sustainable manufacturing is the new theme developed to integrate the advanced technologies more environmentally responsible way while fostering sustainable development. This would contribute to increased environmental, and social efficiency. The technologies would enable enhanced monitoring of factory operations to improve OEE, profitability, reduce cost and waste which would enable operating at increased efficiency while maintaining the same or minimal increased investment. With technologies like cloud computing, the capital investments on infrastructure can be reduced significantly, attracting more organization and use pay-per-use methodology. The AR/VR can be used for effective training relieving human trainers from the task and repurposing them for more focused work. The IOT based systems would detect machine abnormal conditions early in advance and ensure safety operation throughout. Vision systems and machine learning algorithm can be used for detecting safety breach inside factory floor, provide recommendation on improvement and ensure guidelines are followed within the floor for safe operation. With the connected machines, abnormalities can be detected, and risks can be identified early to save time and resources. Cyber security systems would ensure reliable use of technology while denying any safety breach. Automation and intelligent factory environment will work together to address increased demand, mass customization and mass personalization while maintaining flexibility.

6. Conclusion

The essay evaluated existing manufacturing systems for its effectiveness, need for improvement and opportunities. It is understood that I4.0 enablers are necessity no more an option to advance in the volatile market and stay at the front of competition. The possibilities of I4.0 technology adoption was discussed in various case studies. Innovations like DT, AR,VR, 3D printing, DES can be utilized to optimize the factory operation and improve OEE. The development of IT and network systems are a

requirement for implementation and integration of advanced technologies. The I4.0 enablers would result in increased productivity, profitability at reduced cost and waste enabling economic and societal benefits. The cyber physical connected factory using advanced techniques would provide a positive culture for the workforce to flourish and provide a safer environment to work. Finally sustainable growth of organization and industry is needed to make this journey long term beneficial and meeting environmental responsibilities.

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