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The Importance of Implementing Full Autonomy into the Global Manufacturing Industry

Developing a Dynamic and Efficient Manufacturing Environment

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Abstract

Global manufacturers in the future will experience high levels of competition with the development of industry 4.0 technologies. The advancement of automation is a key aspect of remaining competitive. As industry continues to head towards automated manufacturing, Internet of Things (IoT), Artificial Intelligence (AI), Digital Twin (DT), big data, and other technologies will increase in relevance: needing continual research and development. When combined they will revolutionize industry, enabling companies to employ new methods of manufacturing and assembly to their operation. While critical, this will also give rise to new ethical issues, collaboration possibilities, and research challenges. This essay will define some existing Industry 4.0 technologies, present theoretical and developing ideas for their application, and discuss the ramifications of the advancement of automation in the global manufacturing market.

1. Introduction

One of the greatest challenges of modern manufacturing is keeping up with rising consumer demands for greater customization, quality, and variety of manufactured products [1,2]. To remedy this, companies have been advancing towards industry 4.0 – increasing automation by incorporating technologies such as IoT, AI, DT, and big data, among others [1,3]. These technologies will assist companies to minimize cost [3] and allow for more customer involvement in the manufacturing process [4].

Though it is not viable to immediately implement these technologies in unison, the development and eventual combination will be critical to remain competitive in the manufacturing scene [5]. As such, one should look forward to how these technologies can be applied once fully integrated with one another.

Perhaps inevitably, future manufacturing will involve fully automated facilities that only require human supervision to verify that products are being manufactured properly and on schedule [1]. To fully automate the manufacturing process, a company needs to have an organized timeline to implement AI, IoT, and DT technologies. Specifically, there needs to be a plan in place to organize the company's structure, predict challenges that could hinder development, and create increasingly detailed implementation plans for these technologies. This paper will briefly overview the individual use cases of Big Data, AI, Internet of Things, and Digital Twin in manufacturing and design and how, when combined, can guide a company towards full automation. In addition, challenges and partnerships will be discussed to better understand what preparation will be essential for smooth implementation.

2. Background

To maintain competitiveness in the manufacturing industry, a company needs to continually develop and adapt to the environment. Currently, companies are trying to improve and implement technologies from industry 4.0 to meet this demand [4]. A study by Peerless Research Group discovered that 21% of manufacturing firms surveyed have a plan for implementing automation or partial autonomy by 2025, while an additional 23% of firms already employ this technology. [6]. This increase in automation demand is mirrored in global market studies where "the global smart manufacturing market size is predicted to hit USD 787.54 billion by 2030" with CAGR of 14.9% from 2023 to 2030 [7].

One realistic solution to remain competitive is supervised autonomy in manufacturing. Supervised autonomy is where facilities will be capable of operation autonomously for most cases but will keep a set of human supervisors informed of needs and process statistics. Specifically, it will notify when there are issues and transmit all relevant information and/or conclusions to the operators. Additionally, control can be returned to the operator if desired - keeping decisions in human hands. The University of Nottingham also has a novel approach to manufacturing, called the Omnifactory. The Omnifactory utilizes a modular, reconfigurable manufacturing floor, in which all of the equipment can be repositioned to best fit the needs for manufacturing/assembly. This allows the space to be customized for the specific task, as shown in Figure 1, below.

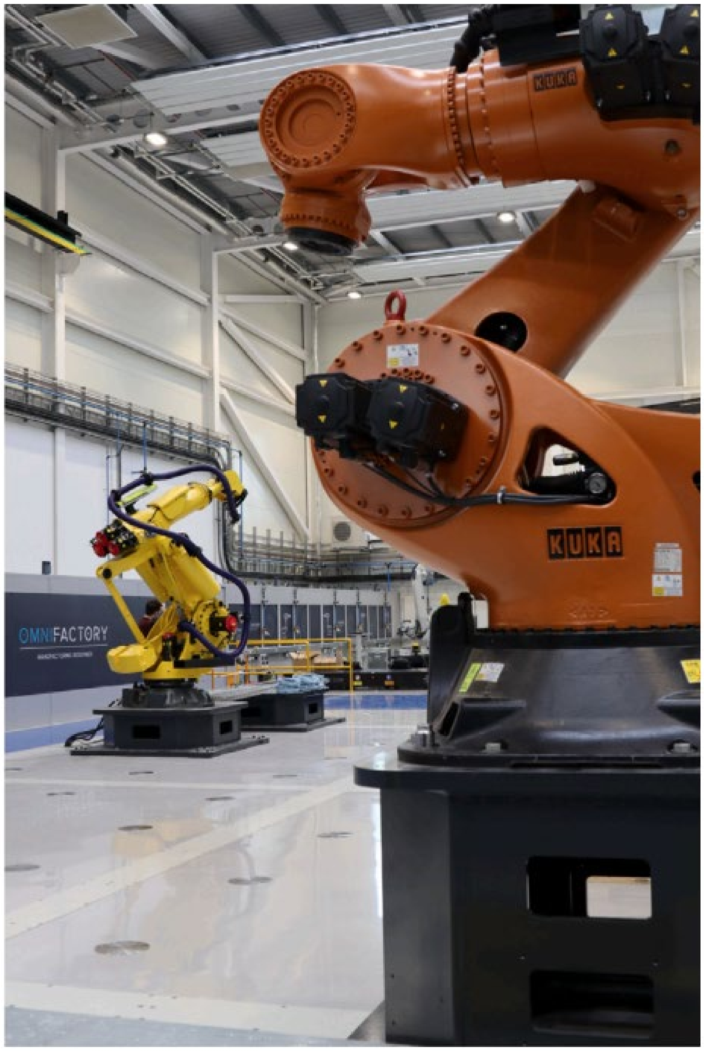

Figure 1: The Reconfigurable Floor of the Omnifactory at the University of Nottingham [4]

3. Developing Technologies

In order to implement autonomous systems, the technologies from Industry 4.0 need to be combined in facility design. This includes not only the operation of said plant, but also planning and optimization [4]. As such, it is important to understand these technologies and how they are important to the continual development of global manufacturing.

Industry 4.0 can be organized into 6 different categories: Automated Manufacturing, Augmented Reality, Cloud Computing, Big Data, Internet of Things (IoT), and Artificial Intelligence (AI) or Machine Learning (ML) [8]. The full list can be seen in Figure 2, below.

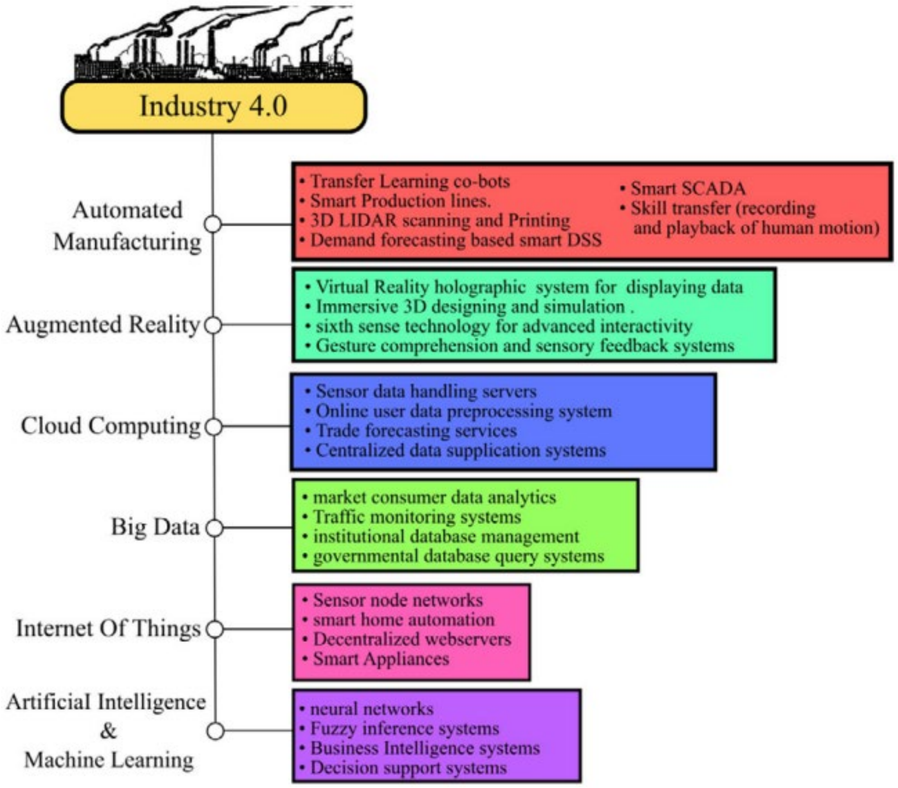

Figure 2: Components of Industry 4.0 [8]

Big Data

A primary component of Industry 4.0 is big data. Big Data is an enormous amount of information typically stored in magnitudes of petabytes or zettabytes [9]. The massive amounts of information will be utilized to teach AI and Machine Learning algorithms to process data and intelligently react in real time.

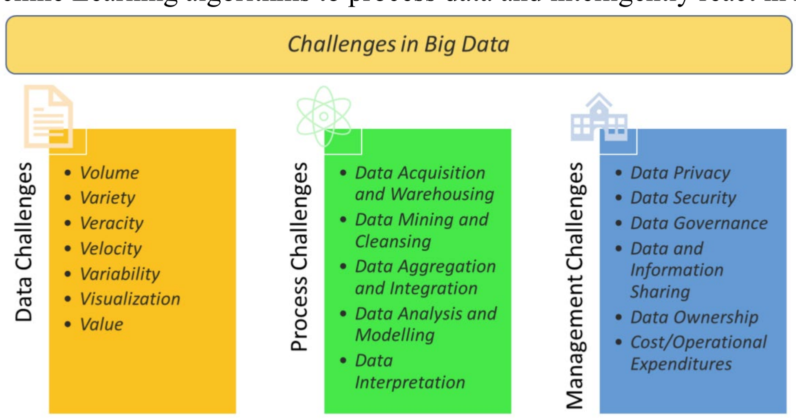

Figure 3: A List of Possible Challenges with Big Data [9]

Information can come from multiple sources and be applied in multiple ways. For instance, internet searches, public discussions, and market data can be analyzed to determine demand or product feedback when combined with AI.

Big Data is not without its problems, however. One issue lies with the quantity of information being produced: it being estimated that the amount of information being recorded doubles every year [9]. Even after storage is handled, it will need to be processed, which will become an increasingly difficult problem to overcome with time.

Artificial Intelligence

Artificial Intelligence and Machine Learning are closely tied together and are a method of communication between data, machines, and reports to human operators. AI is a computer algorithm meant to impart "intelligence" to a machine or program. This technology operates using computer algorithms which describe to the computer how it must process data. There are a multitude of different algorithms such as k-NN, Naïve Bayes, ANN, and Deep Learning: each with their own benefits and drawbacks [9]. Similarly, Machine Learning, a subset of AI, uses algorithms to connects different components of machinery together and improve the process using feedback from sensors [9].

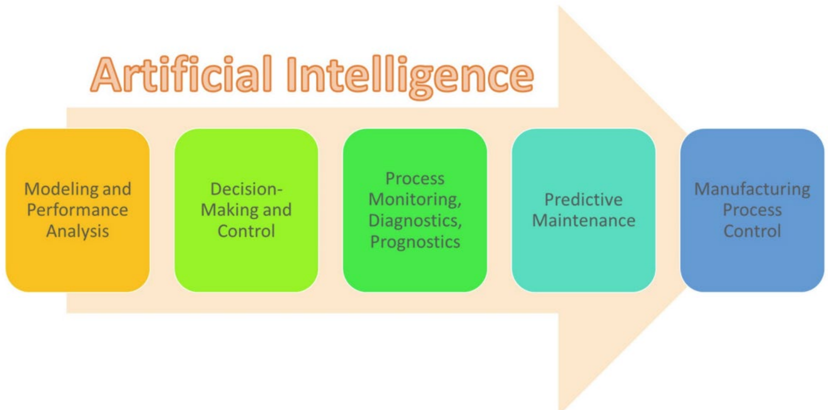

Figure 4: Development and Applications of AI in Manufacturing [9]

AI and ML will have a large effect on manufacturing, especially when combined with other components of Industry 4.0. As seen in Figure 4, above, artificial intelligence will continue to develop and allow for more automation in manufacturing – reaching closer to autonomy. This technology, to some extent, has already started seeing implementation in manufacturing, according to Santhi and Muthuswamy [9]. In their article some successful applications of ML were listed in the form of Table 1 seen below. Namely, ML was used to predict the results of performing classical manufacturing processes before beginning operation.

Table 1: Successful Applications of Machine Learning Based Algorithms [9]

S#	Authors	Application
1	Cao et al. [22]	Predict rolling force in hot rolling of electrical steel
2	Reddy et al. [23]	Predict temperature distributions in electron beam–welded plates
3	Shahani et al. [24]	Predict slab behavior in the hot rolling process
4	Hu et al. [25]	Predicting failure pressure of composite cylinders for hydrogen storage
5	Kazan et al. [26]	Prediction model for spring back in wipe-bending process
6	Umbrello et al. [27]	Predict optimal cutting conditions and residual stresses in machining
7	Jun et al. [28]	Stress prediction in SLA additive manufacturing process
8	Patil et al. [29]	Deep learning algorithms for condition monitoring of milling tools
9	Fahle et al. [30]	Machine learning algorithms for various manufacturing processes

Internet of Things

Internet of things is the concept where objects will directly communicate with each other over the internet. This communication creates an environment functioning on the 'connectedness' of products, allowing for more cohesive operation and integration. The objects or "things" can directly convey information to one another, with the goal of making an industry run more "efficiently, smartly, and safely" [9]. One example of the deployment of IoT in the manufacturing sector involved researcher Jianjing Zhang and his colleagues developing a program that utilized IoT to monitor the health and performance of an aero propulsion engine and predict its deterioration [9]. In this case and others, IoT is often used in combination with other Industry 4.0 technologies to make useful manufacturing tools and programs.

Digital Twin

Digital Twin (DT) creates a virtual simulation that parallels an existing object in the physical world. This simulation will copy the exact dimensions, properties, and behavior of its physical counterpart. These environments will be capable of communicating with one another in real time: constantly providing feedback to the virtual environment [10]. This technology allows for virtual "experiments" to be performed instead of trial and error using physical machining: reducing cost and improving plant efficiency [10].

Of course, this technology can be applied to more than simply simulating a specific process; it can be applied more generally. For instance, DT systems can be used to model or predict the operation of an entire facility: predicting shortages, potential errors, or maintenance [10].

4. Automation in Industry 4.0

The concepts of Industry 4.0 are slowly being applied to manufacturing industries; however fully autonomous robotic systems are not ready for the factory floor [6]. The cost and technological foundation required to start a fully automated facility create a large roadblock in achieving this level of automation [11]. Despite the roadblocks, the promise of increased capacity, quality, and operational speed promised by the implementation of this technology continues to drive industry forward. To better accomplish the development, five levels of automation are defined as milestones and company goals [11].

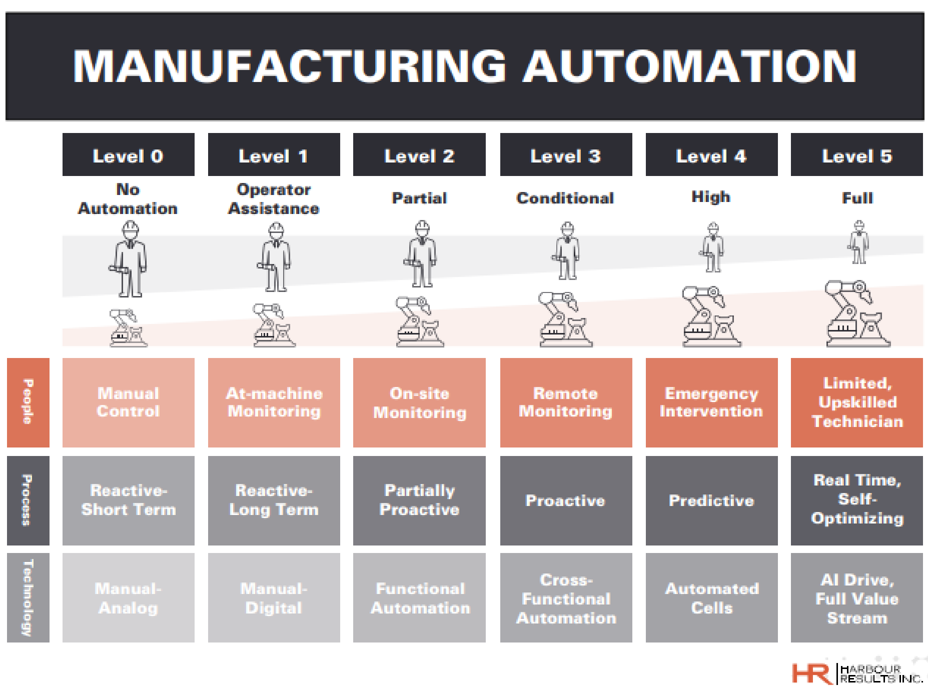

Figure 5: Five Levels of Manufacturing Automation [11]

Levels 1 through 3 of manufacturing automation have already been achieved and implemented in industry. However, "some of the most sophisticated shops are approach[ing] Level 4 automation, while Level 5 is a future state just now becoming achievable" [11]. These last two levels of automation will cause massive changes to not only factory operation but also company operation [12]. However, implementing automation requires the recent developments in IoT, AI, DT, and big data to advance to Levels 4 and 5. The following sections will cover some of the possible workings of a Level 5 facility using the technologies from Industry 4.0.

Factory Planning

The benefits of Level 5 automation expand beyond just the operation of a facility, but also its layout and possible methods of optimization. A possible implementation of this concept is Rapid Manufacturing Systems (RMSs), which allow for "sudden change of system configuration whilst maintaining full system effectiveness" [4].

Powered by large amounts of manufacturing and market data, RMS can be optimized by a DT concept [4]. In this case, a digital copy of a possible facility will be generated based on existing equipment by an AI. This virtual copy will test the concepts presented by the organizational AI and recommend possible solutions for configuration before workstations are permanently placed [4].

Quality Control

An integral component of fully automatic manufacturing is quality control. More than the quality of processes, but key information on machine performance can be determined from this data. The technology used can be easily accomplished using visual means- combining AI with cloud computing [13].

Figure 6: Identifying Defects Using Visual Inspection Technology [13]

From the information generated during the inspection process, AI algorithms can identify where and how errors are occurring [13]. Furthermore, automating the process allows for a 100% examination rate – greatly decreasing occurrences of faulty products, or even processes.

Maintenance

In order for a plant to be fully automated, it must be able to handle unexpected errors and conditions. To accomplish this, IoT can be used in unison with a DT model. The DT would continually simulate the physical environment: updating the model to match the physical reality. The simulation trends would be compared to example data using an AI, which would be used to predict what maintenance will be necessary and when it is expected. Powering this technology would be a large array of different sensors, which provide the robots with the peripheral knowledge required to react [9].

Once a problem is detected, or if a machine expects one to occur in the future, it will prepare a solution. This solution can take multiple forms depending on the situation. For instance, if a machine diagnoses that it requires replacement oil soon, it could request a replacement: of course, taking place at an optimal time for the facility [8]. Additionally, if a machine has a critical error, the device could shut down and distribute the process load to other machines, if possible. Once implemented, this will have an immediate impact on industry. "According to Forbes, unplanned downtime can cost up to $50 billion a year to manufacturers" [3]. Implementation of this technology would significantly reduce downtime for manufacturers.

Supply and Optimization

More than managing individual machines, Level 5 automation will be capable of managing the facility itself. Specifically, using IoT and AI, it will "be able to pre-order input resources, keep inventory, [and] manage the demand and supply cycle based on cloud-stored big data" [8]. This will minimize chances of producing excess product and wasting resources [8].

Additionally, concepts used earlier to plan shop floors can also be used to optimize existing floors. This can include both the position of machines - if they can be moved - and the movements made by robots or other machinery. This involves IoT technology paired with AI to allow for quick responses by the facility. Many times, changes in operation and speed can occur from maintenance needs or shortages, allowing a facility to maximize its performance even under unexpected conditions.

5. Implementing Industry 4.0

To this point, the benefits of Level 5 automation have been thoroughly discussed. However, there are many tasks and challenges that will be necessary to accomplish this level of automation. These challenges stem from research and development (R&D) to ethical issues that need to be considered to assure a successful implementation of the technology.

Ethical Considerations

Probably one of the greatest concerns with the implementation of Level 5 automation are the ethics behind the integration of the technology. Implementing this technology has a high likelihood of causing unemployment to rise as machines take human jobs [9]. In the past, industrial revolutions would assist workers by providing physical services. Industry 4.0 is different. Unlike in the past, machines are capable of "thought" and advanced problem solving- challenging the accuracy of humans at much greater speeds [9]. Unemployment will likely become an issue as a result. To support the likelihood of this occurrence, a UN Department of Economic and Social Affairs study estimated that the "risk of job loss due to automation can be over 80% in the low- and medium-income group" [9].

Though improving efficiency and optimization is important, industry should always strive to better the living conditions of mankind instead of damaging it. As such, steps should be taken to keep humans in the loop. Barring the necessary technical supervisors, it might be wise to move workers towards the creative or maintenance side of labor. It is critical that we are able to maintain human input into the manufacturing environment, transitioning these jobs to successfully work alongside the new technologies. Physical maintenance of machines can be handled directly by the humans working alongside them. As for the creative side of manufacturing, humans can continue to imagine and design products for sale.

Company Structure

In order to identify what needs to be developed, researched, or implemented, companies must have plans in place to facilitate it. Developing Level 5 automation will be costly and time consuming, but if done correctly will be rewarding. According to John Bradford, "to be successful process automation needs to occur across the whole value stream – from marketing and sales to quoting and estimating through design and engineering and manufacturing and assembly. It must not be limited to the shop floor" [11]. Bradford emphasizes the importance of organizing processes into a system process-hierarchy, which would separate core processes into tasks to better understand the system and optimize it. Additionally, he stated that shops need to continue to increase data collection and analysis to form a foundation for the training of AI models in the future.

Shops would have to slowly develop through the levels of automation, first optimizing a Level 3 facility, then working towards Level 4, and so on. Rushing the process could cause issues in the future and might add extra costs or complications to the manufacturing processes. Though developing in a certain direction might look promising at one time, rushing towards that technology without thorough regard for implementation can cause costly needs for redirection in the future as more discoveries are made. Additionally, developing too quickly can be more costly to a company and will nullify any benefits gleaned from improvements [11].

Research Challenges

To facilitate these advances, Industry 4.0 technologies will need to be explored in increasing detail. The specific topics that need research will become clearer as knowledge expands, but currently there are some fields that require advancement.

A piece of infrastructure integral to Levels 4 and 5 automation is the development of digital and IT environments. Due to all intelligent operations requiring large amounts of data processing, advancing in this field would "effectively promote the digital transformation of manufacturing industry and the development of manufacturing quality" [12]. Further, IT is necessary to maintain the order and security of any digital or cloud systems and will need development in unison with digital transformation.

Further development of robotic technology is also necessary to achieve the highest levels of automation This includes flexible technologies such as robotic arms, which can operate more processes and are more dynamic. This advancement would need support from the other factors of industry 4.0 such as the following:

- Machine learning algorithms for manufacturing processes such as machining and assembly.
- AI algorithms for advanced analysis of market trends.
- AI algorithms for the optimization of manufacturing processes across a shop floor.
- Improved training and remote servicing technologies.
- Improved data storage and processing, both optimization using AI or better hardware.

As stated previously, the fields of interest will become more apparent as industry progresses. It is important to keep note of additional research pathways that might appear along the way to improve the company.

Possible Collaborations

With such a vast topic as Industry 4.0, it will be impossible for a single organization to fully explore the technologies it encompasses. As such partnerships will be common and necessary for mutual benefit. Each organization will have its individual specialty which will help focus development. A list of potential companies and specialties is outlined in Table 2.

Table 2: Collaboration Companies [14, 15]

Company	Specialties
ABB Ltd.	Automation, Robotics, Data Analytics, etc.
Capteurio	Predictive Maintenance, IoT, AI
Cisco Systems Inc.	IoT, Security, AI, AR, DT, etc.
General Electric Company	Manufacturing, Electronics, Energy, Finance
IBM Corporation	Computer Hardware/Software, Finance
I4Twins	Digital Twin, AI
Intel Corporation	Processor Tech, Cloud, IoT, Data storage
Robco	Advanced Robotics, Cloud Analytics
Siemens AG	AI, IIoT, Logistics, Energy, Smart Tech, etc.

For instance, Capteurio, which specializes in IoT and AI based solutions for predictive maintenance would benefit from collaborating with ABB ltd. for their expertise in data analytics and large industrial machinery [14,15]. I4Twins can also analyze data from larger manufacturing corporations- like ABB, to build datasets and perform more tests on their technology. Companies such as Intel and General Electric can use their expertise with computer processors and electronics to provide the necessary chips or equipment to develop on.

In addition to companies exploring industry 4.0, universities can provide a fresh mode of thought to the industry [16]. Collaborations between companies and Universities can be highly beneficial for both parties, as they can expand outside the mentioned technologies and continue to further explore possible applications of Industry 4.0 and beyond.

6. Conclusion

To conclude, multiple groundbreaking advancements are being made in Industry 4.0 technologies. For companies to remain competitive in manufacturing, the technologies of Industry 4.0 need to be explored and implemented. As automation progresses through Level 4 and up to Level 5, advancements in predictive maintenance, quality control, AI, cloud computing, IoT, and DT, among others will continue to develop and expand in relevance. Technologies stemming from this will revolutionize manufacturing- providing benefits for automation in the form of predictive maintenance, factory planning, and quality control.

Despite these benefits, technology is still maturing, and multiple research challenges and obstacles stand in the way of Level 5 automation. Researchers and companies will need to collaborate to advance the field and explore issues in digital infrastructure, computational capability, and ethical issues.

Overall, Level 5 automation will be the future of manufacturing: keeping the company competitive and improving efficiency. Development in Industry 4.0 should be a primary focus of a global manufacturing company as industry and technology continue to develop.

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