A Review on Artificial Intelligence in the Context of Industry 4.0

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***Abstract*—Artificial Intelligence (AI) is seen as the most promising among Industry 4.0 advancements for businesses. Artificial intelligence, defined as computer models that mimic intelligent behavior, is poised to unleash the next wave of digital disruption and bring a competitive advantage to the industry. The value of AI lies not in its models, but in the ways in which we can harness them. It is becoming more common for industry objects to be converted into intelligent objects that can sense, act, adapt, and behave in a given environment. Leaders in the industry will need to make deliberate choices about how, when, and where to deploy these technologies. Our work highlights some of the primary AI emerging trends in Industry 4.0. We also discuss the advantages, challenges, and applications of AI in Industry 4.0.**

Keywords*—*Artificial intelligence; Industry 4.0; intelligent manufacturing; industry analysis

I. Introduction

Industry 4.0 is a term used to describe the Fourth Industrial Revolution. Manufacturing technologies are part of this revolution. Among the technologies included in this group are technologies like the Internet of Things (IoT), cyber-physical systems (CPS), and artificial intelligence (AI). A machine's ability to perform human functions, such as learning, reasoning, and solving problems, is commonly referred to as artificial intelligence. Using sensor technologies, machine intelligence agents can perceive and interact with their surroundings.

Artificial Intelligence allows computer systems to learn from experience, adjust to new input data, and make intelligent tasks. Fig. 1 illustrates the major areas and technologies associated with artificial intelligence.

- Machine learning is the process of developing computer systems that can detect patterns from raw data. There are two major types of machine learning: supervised and unsupervised.
- Supervised learning involves algorithms that generate a predictive model from a set of training data, which includes both training observation/examples and labels [3].
- Unsupervised learning refers to the creation of a model from observations/examples that do not have class labels [3].
- Deep Learning is concerned with algorithms inspired by the structure and function of the brain called artificial neural networks. These algorithms are used for a variety of tasks, such as image classification, by learning from large amounts of data and using multiple layers of artificial neural networks to produce intelligent decisions [4].
- Natural Language Processing (NLP) is a subfield of computer science and artificial intelligence concerned with the interactions between computers and human languages, with a focus on making it possible for machines to read, understand, and generate human language [5].
- Expert systems are designed to mimic the decision-making abilities of a human expert in a specific domain. They use a combination of knowledge representation, inference rules, and a database of facts to provide reasoning and advice to solve complex problems in fields such as medicine, finance, and engineering [6].
- Computer Vision is concerned with enabling computers to interpret and understand visual information from the world in the same way that humans do. It involves the development of models to perform tasks such as image and video recognition, object detection, and image segmentation [7].
- Speech Recognition, also known as Automatic Speech Recognition (ASR), is concerned with the ability of computers to recognize, understand, and transcribe human speech. The goal of speech recognition is to develop algorithms that can accurately transcribe or translate spoken language in real-time, enabling natural and convenient human-computer interaction [8].

AI is considered the next revolution in health care, manufacturing, and mobility. AI plays a vital role in Intelligent Manufacturing Systems (IMS) by introducing learning, acting, and reasoning. Manufacturing objects are transformed into intelligent objects that can self-correct without human intervention [11], [60]. Manufacturing will benefit from AI if it is able to harness new capabilities, many of which have seen

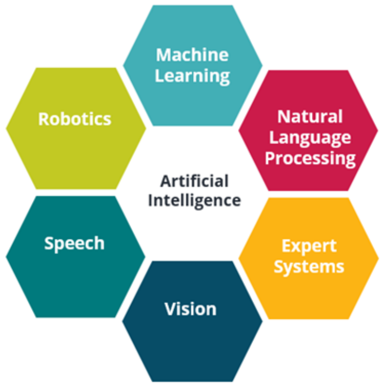

Fig. 1. Key AI areas and tech

dramatic increases in recent years [2].

AI combined with emerging technologies such as Big Data, Blockchain, and IoT can eliminate downtime, maximize throughput, and improve efficiencies. For example, FANUC and Cisco have optimized systems that enhance value for manufacturers [18], [47]. To reach the goal of autonomous machines in Industry 4.0, blockchain can be utilized by connecting the ERP, parts supplier, and the cyber-physical system in a factory, enabling the machines to order replacement parts securely and independently. Additionally, blockchain's ability to facilitate seamless and transparent financial transactions between smart devices is essential for the economic changes brought by Industry 4.0 [10].

The Reference Architecture Model Industry 4.0 defines the Industry 4.0 layers [16]. It consists of the following layers [16]:

- The business layer organizes business operations and connections between different processes, adhering to the legal and regulatory restrictions, to support the underlying business models.
- The functional layer describes an asset's role in Industry 4.0-based systems based on its logical functions.
- The information layer represents the assets' technical features, like services and data.
- The communication layer provides regular communication between the integration layer and the information layer about services and data.
- The integration layer represents the physical assets, and the digital capability provides computer-aided control and creates events based on the assets.
- The assets layer serves the physical world, such as physical objects, software, and actors in the physical world.

The service-oriented RAMI 4.0 goes deeper into representing digital manufacturing models [16].

LinkedIn reported in 2018 that six of the top 15 emerging jobs were related to AI, with positions requiring expertise in deep learning experiencing the highest growth, according to data from Monster.com [22]. Deep Learning is a branch of machine learning that utilizes multiple non-linear layers for feature extraction, transformation, and classification, either in a supervised or unsupervised manner [23].

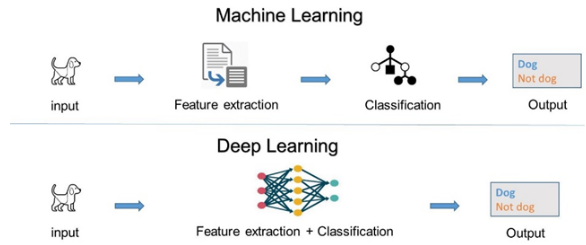

Fig. 2. Comparison between machine learning and deep learning

Deep learning and classical machine learning are intended to model the relationship between inputs and outputs. Deep Learning distinguishes itself from traditional machine learning in its approach to feature learning, model building, and training. It combines these elements into one model, adjusting kernels or tuning parameters for optimal results [26]. Fig. 2 shows the main difference between traditional machine learning and deep learning.

Deep learning revolutionizes manufacturing by transforming facilities into highly efficient smart operations, leading to reduced operating costs, increased productivity, and decreased downtime [26]. Fig. 5 illustrates the main differences between machine learning and deep learning. Deep learning eliminates the need for expert involvement by incrementally learning high-level features from data, while traditional machine learning requires domain experts to identify features.

The remaining sections are organized as follows. Section II describes the methodology we followed in conducting the review. Section III presents the typical applications of AI in industry and shows some use cases. Section IV discusses the advantages and the challenges that are currently noticeable by using AI. Section V demonstrates the industry analysis. Section VI reviews some future trends. Section VII concludes the paper.

II. Methodology

This study follows the two-stage approach developed by Webster and Watson[9] for reviewing relevant literature. As a first step, the following search phrases were used to search for papers published between 2016 and 2020 on Google Scholar and ScienceDirect:

- "Industry 4.0" & "Artificial Intelligence"
- "Industry 4.0" & "Trends"
- "Industry 4.0" & "Intelligent Manufacturing"

The search returned 176 results. In the second step, these papers were carefully reviewed, and unrelated papers were eliminated. We have compiled a final list of 39 relevant articles. Fig. 3 and 4 show the publication years and citation numbers of these papers. For example, 13 relevant articles have a total of 1400 citations in 2018. The selected papers are then grouped into four research categories, as shown in Table I. The

TABLE I. RESEARCH CATEGORIES OF THE SELECTED PUBLICATIONS

Research Category	No. of Publications
Applications of AI in Industry 4.0	24
AI technologies and approaches in the Industry 4.0	10
Advantages and Challenges	3
Emerging Trends	2

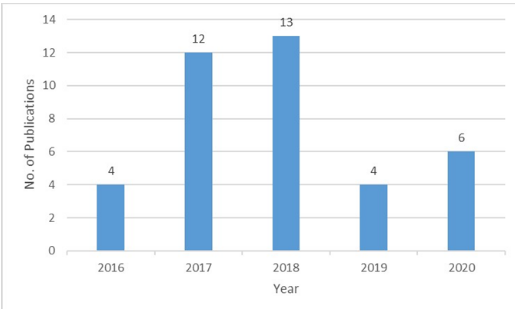

Fig. 3. The number of publications per year (2016–2020)

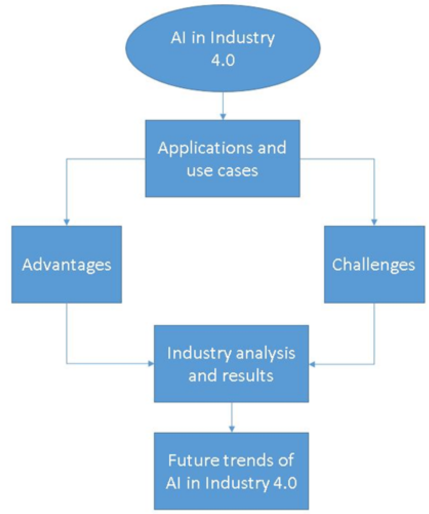

Fig. 5. The organization of the paper

categories' distribution shows that more attention has been paid to AI applications in Industry 4.0, followed by the primary approaches and methods of AI in Industry 4.0. Fig. 5 shows the paper organization's block diagram and an overview of AI in Industry 4.0.

III. AI APPLICATIONS AND USE CASES

This section represents applications of AI in major industries. Some case studies are then presented.

A. Applications

Today's society uses artificial intelligence in a variety of ways. It has been used to develop and advance many fields and industries, including aerospace, automotive, electronics, finance, medical, education, retail, and more. Ahuett- Garza et al. provided a brief review of machine learning, IoT, and adaptive manufacturing in industry 4 [56]. Preuveneers et al. developed a study in AI and machine learning in intelligent manufacturing environments settings [57]

Intelligent manufacturing tools and models are explained in [58]. Lee et al. proposed that industrial AI's main elements include analytics technology, cyber technology, and big data technology [59]. Cheng et al. discussed the future development direction of Industry 4.0, which provides a reference for its intelligent manufacturing [61]. Liu et al. presented the manufacturing demonstration system based on IoT in Industry 4.0 [62]. Table II shows some main applications of AI in several industrial sectors.

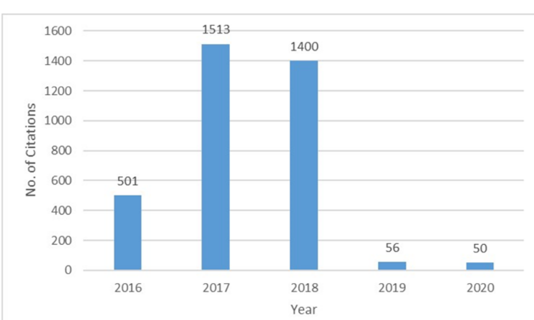

Fig. 4. The number of citations per year (2016–2020)

B. Use Cases

This section includes several examples of the successful implementation of AI in Industry 4.0.

1) Doxel robots use AI to improve accuracy and efficiency on large construction projects: A new robot can check that building projects are going planned using AI and LIDAR. After a construction site shuts down for the day, robots created by Doxel can start working. Using LIDAR, it scans the construction sites and feeds that data into deep-learning algorithms.

The deep learning algorithms find anything that deviates from building plans so that the management team can fix the problems the next day. The main premise is that if errors have not been noticed directly on the worksite, they will create complex issues that take time and money to fix. Instant problem resolution leads to substantial cost savings. A recent test of the approach on an office building project improved labor productivity by around 38%.

2) Anomaly detection of bearings at Altair engineering: Bearings play a crucial role in the automotive sector. This example uses sensor data from four bearings, sampled at 20kHz, resulting in 1-second sampling every 10 minutes for 9 days. The dataset originates from NASA's Prognostics Center of Excellence. The initial sampling, representing a new bearing, serves as a reference for detecting anomalies. The goal is to monitor the bearings' health as they age and predict the beginning of degradation, which will be flagged as an anomaly to the user. Identifying anomalies enables the user to plan

TABLE II. APPLICATIONS OF AI IN INDUSTRY

Industry	Applications	Summary	Technology/Technique	Ref.
Aerospace	- Fuel consumption prediction	- A genetic algorithm-optimized neural network topology is designed to predict the fuel flow-rate of a transport aircraft	-Feed-forward backpropagation, Levenberg–Marquardt algorithms, and genetic algorithms	[25]
	- Aircraft failure times prediction	- Predict when the failure will happen by aircraft type and age	- Artificial neural networks and genetic algorithms	[15]
	- Aircraft design cycle time reduction	- AI is used to expedite the decision-making process in the early stages of the aircraft design process	- fuzzy logic and neural network	[14]
Automotive	- Driving Assistance and Autonomous Driving	- State-of-the-art deep learning technologies used in autonomous driving	- AI-based self-driving architectures, convolutional and recurrent neural networks, and reinforcement learning	[17], [37]
	- Driver monitoring	- Monitor drivers and identify driving tasks in vehicles	- Kinect, Random Forest, and Feedforward Neural Network	[13]
	- Vehicle manufacturing	- Human–collaborative robot assembly in cyber-physical production. Manufacturing system produces products from scratch without any human intervention during the process	- collaborative robots and additive manufacturing	[12, 53]
Electronics	- Diagnosis of electrical machines and drives	The AI methodologies are applied to an induction machine, utilizing as input signals the instantaneous voltages and currents	- Expert systems, artificial neural networks, and fuzzy logic systems	[50]
	- Smart refrigerators	- The intelligent refrigerator is capable of sensing and monitoring its contents and notifying the user about the type, quantity, and freshness of the food in the refrigerator	- Internet of Things, Mobile Internet, advanced control and sensing, and food preserving technology	[20], [30]
	- Intelligent video surveillance systems	- Intelligent video surveillance systems that control private and public places and detect dangerous situations	- Neural networks, classification, and clustering techniques	[24]
Medical	- Breast cancer detection	- Performance comparison between different machine learning algorithms on the Wisconsin Breast Cancer datasets	- Support Vector Machine, Decision Tree, Naive Bayes, and k Nearest Neighbors	[39]
	- Disease Diagnosis and symptoms checker	- Artificial intelligence platform for self-diagnosis and symptom checker	- Artificial Intelligence	[40]
	- Robot-assisted AI surgery	- deep learning approach for robotic machine segmentation	- Deep neural network	[43]
Retail	- Customer segmentation and clustering	- Systematic Approach to Customer Segmentation and Buyer Targeting for Profit Maximization	- K-mean clustering	[44]
	- Retail recommendation engines using machine learning	- Use of Deep Learning in Modern Recommendation System: A Summary of Recent Works	- Natural language processing, Deep Learning	[45]
	- RFID network planning	- Artificial intelligent paradigm is developed to model and optimize RFID networks	- Artificial neural networks and computational artificial intelligence algorithms	[46]
Telecom	- Smart traffic prediction and path optimization	- Optimizing space-air-ground integrated networks by artificial Intelligence	- Deep Learning	[49]
	- Security	- Articulating a comprehensive threat model for ML and categorize attacks and defenses within an adversarial framework	- Machine learning	[51]
	- Customer segmentation based on mobile usage	- Identifying prime customers based on mobile usage patterns	- Support vector machine and K-mean clustering	[52]

proper maintenance of the bearings, avoiding potential failures and irreversible issues.

Initially, Principal Component Analysis (PCA) is applied for dimension reduction. The samples are then compared to the healthy sample to assess the current health of the bearing, and the comparison is represented as a Health Index (HI). An anomaly is detected if there is a 95% decrease in correlation in 5 or more out of 10 consecutive samples. The entire machine learning model is located on an edge device and transmits the HI and anomaly status of each vibration pattern from the sensor in real-time to Altair's SmartSight. The user can view the status graphically and, if an anomaly is detected, Altair's SmartCore sends an email alert to the user.

3) AI from the factory floor to the showroom at Mercedes-Benz: The widespread use of AI in the automotive industry's manufacturing process is well documented. OEMs are now incorporating AI into all areas of their business, including sales. With AI insights, companies can determine the best product segment to sell, to whom, and when. Mercedes-Benz, a large-scale truck and bus production plant in Brazil, uses Azure Machine Learning to transform its sales process. The tool combines internal and external data, such as registration numbers, macroeconomic indicators, local laws, sales info, and stats, to aid the brand's sales reps in making tailored offers at the right time. The system improves with each monthly data report inputted by dealers, resulting in more accurate recommendations.

4) AI from the ford motor company and Argo AI: Ford Motor Company announced a partnership with Argo AI in 2017, investing $1 billion in the virtual driver system for its SAE Level 4 autonomous vehicles [36]. The vehicles, equipped with Argo's cutting-edge machine learning and computer vision technology, will be deployed for ride-hailing and delivery services in several cities in the US.

IV. ADVANTAGES AND CHALLENGES

This section highlights the significant advantages and challenges currently noticeable in using AI, especially in industrial environments.

A. Advantages

Significant savings in labor costs due to troubleshooting, maintenance, and repair: AI and machine learning allow machines and computers to replace human labor in many tasks, such as manufacturing, agriculture, and business services. Acemoglu et al. discussed the impact of AI in various industries and their economic impacts [28]. Business decision-makers realize that AI can help create new products, services, and business models [31], [35].

Improved reliability and efficiency through extended time between failures: AI enhances systems' efficiency in various ways, including more accurate demand forecasting to better

Fig. 6. How companies are adopting AI

manage goods inventory and storage. AI's predictive maintenance helps prevent costly, unexpected machine shutdowns and maintenance in factories [55]. Many examples of AI's ability to improve systems efficiency have been discussed by Jimenez et al. [32].

Safer work environments through AI's ability to detect and respond to hazardous situations: Workplace injuries can be costly for businesses. AI can perform dangerous tasks, such as in construction, heavy machinery manufacturing, and oil and gas plants, reducing the risk of injury to workers. An example of AI enhancing workplace safety is provided in [33].

AI will generate new employment opportunities in various sectors, including cybersecurity, data analysis, machine learning, deep learning algorithms, and data science.

B. Challenges

Implementing AI comes with its own set of challenges and problems. The issues to be aware of are outlined in Table III, along with recommended solutions.

V. Industry Analysis

The results of a survey conducted by Vanson Bourne in July 2017, with 260 respondents, showed that the main obstacles to the implementation of AI are a lack of IT infrastructure and a shortage of talent, as depicted in Fig. 6 [34]. The development of mature AI infrastructure is likely as the world moves towards IoT, smart cities, and cloud systems. The shortage of talent in the field of AI can be addressed through the creation of graduate certificates and programs focused on AI and machine learning offered by universities.

A survey by McKinsey Global Institute found that AI implementation outside of the tech sector is still in its early stages. Only 20% of 3,000 executives from ten countries and 14 industries reported using AI technology in a significant or central aspect of their business. Many companies are uncertain about the potential benefits and return on investment from AI. The study analyzed over 160 use cases and found that only 12% of these employed AI commercially [19]. Fig. 7 illustrates how companies are implementing AI.

A survey of Michigan-based small and medium-sized manufacturing executives conducted by Automation Alley in 2019 showed that only 22% of the companies were currently using AI, 37% were planning to implement it in the next year, and 4% had no plans to use AI (as shown in Fig. 7). The adoption of AI is expected to drive growth and improve revenue for companies that implement it, while those that don't adopt it risk falling behind.

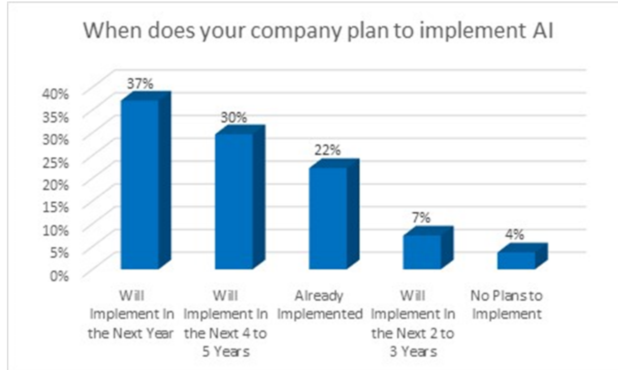

Fig. 7. When does your company plan to implement AI

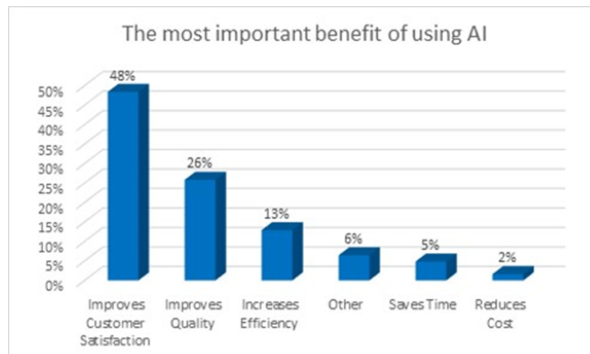

Fig. 8. The most important benefit of using AI

Fig. 8 shows what those Michigan executives surveyed believe to be the essential benefit of using AI, including 1) Improving customer satisfaction, 2) Improving quality, and 3) Increasing efficiency. Initial training and lack of understanding by senior management are the biggest challenges of using AI based on Automation Alley's survey results, as shown in Fig. 9. Many AI consultation companies can provide training and frameworks for AI systems in various business sectors. We believe that identifying AI barriers can lead to accelerating AI adoption.

AI implementation in a business requires the higher management to have the flexibility to change, openness and vision,

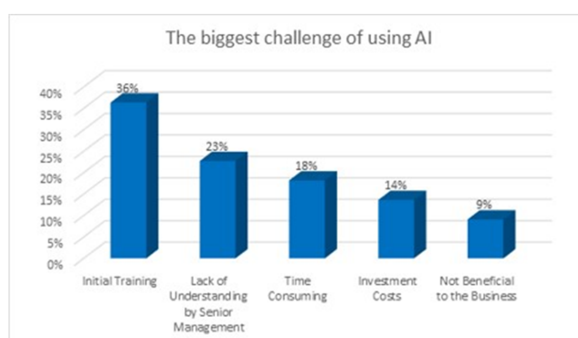

Fig. 9. The biggest challenge of using AI

TABLE III. AI CHALLENGES

Challenge	Description	Suggested Solution	Ref.
Quantity of data	One of the major challenges in manufacturing systems is handling and utilizing the large amounts of data generated, including understanding, cleaning, using, and storing it.	The suggested solution incorporates the latest cloud computing and high-performance cloud techniques to create a large-scale remote sensing data processing system that can handle on-demand real-time services	[38]
Privacy and ownership issues	The widespread collection of data by corporations raises privacy concerns, leading society to consider questions of data collection scope, accessibility, and ownership	Strong privacy guarantees, competitive advantages, and discriminatory policies	[29]
Difficulty collecting and labeling data	Collecting and labeling data is a costly, time consuming, and lengthy process	Transfer learning can be used to tackle this problem by creating high-performance learners that are trained with easily obtained data from different domains	[41]
Difficulty generalizing the results	It is hard to find one algorithm to be effective across a range of inputs and applications	The proposed learning theory analyzes individual problem instances using measure theory instead of sets of instances using statistics. It is not meant to compete with previous learning theories, but rather to complement them, due to differences in assumptions and objectives	[42]
Computation and run-time for AI algorithms	Machine learning and deep learning algorithms require heavy computation and large memory to perform in real-time applications	Algorithms optimization, virtual machines, and cloud computation	[54]

long-term objectives, and effective collaboration. However, there are also some specific challenges where executives may still need to learn more about AI and increase their knowledge on how to organize their business using AI [48].

VI. EMERGING TRENDS

The major AI trends are discussed in the following subsections.

A. Smart Devices

The manufacturing industry necessitates the use of sophisticated smart digital devices. Industry 4.0 utilizes AI and IoT to create intelligent objects. Future AI and IoT will possess features like self-configuration, self-defense, self-repair, and self-improvement [1].

B. Manufacturing Systems

A predictive manufacturing system (PMS) is an intelligent manufacturing system that provides self-awareness, self-predictability, self-maintenance, and self-learning capabilities. In PMS, various technologies and techniques, such as statistics, data mining, models, and AI methods, are used to convert data into information, identify uncertainties, and make predictions about manufacturing systems [21].

The PMS conceptual framework includes a platform, predictive analytics, and visualization tools. Data is generated by the monitored assets. Platforms are chosen based on several factors, including computation speed and investment cost. The purpose of predictive analytics is to extract and predict future outcomes and trends. Among the benefits of PMS are cost reductions, improved operation efficiency, and improved product quality.

C. Human-Machine Interaction and AI

The integration of AI with human-machine interaction is a crucial aspect in constructing Industry 4.0 enterprises. The goal is to optimize efficiency by seamlessly connecting human dynamics with hardware and software in machine-to-human and human-to-machine interfaces. One example is the AI-powered workspace where humans and machines work together to achieve outcomes not possible by either alone [27].

VII. CONCLUSION

The meaning of AI and its subfields are continuously evolving. Industry 4.0's IoT, Big Data, cloud and cybersecurity pave the path for AI implementation and usage. Deep Learning revolutionizes manufacturing into highly efficient smart facilities. IT infrastructure investment and a talent pipeline for AI are crucial for unlocking its potential. The most common benefits of AI are improving customer value and quality. Adopters of AI should be aware of data privacy and ownership challenges, the cost of labeling data, and difficulties in generalizing results. AI adoption outside the technology sector is still in its early stages and manufacturers are aware of AI but its use is still limited. Future developments will involve further exploration of AI and its implementation in industrial settings.

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