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The Rise of Artificial Intelligence in Manufacturing

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The fourth industrial revolution (Industry 4.0) is based on the use of cyber-physical models and digital integration across the connected value chain. This has led to the next generation of technological capabilities and the expansion of the digital ecosystem across industries, including manufacturing. Digital transformation in manufacturing is bringing opportunities to new areas and capitalizing on exiting values in more efficient ways by optimizing operations, increasing productivity, linking suppliers, transforming customers experiences, increasing workforce productivity and developing new ways to realize or monetize value.

Technological investments continue to advance the relevance of artificial intelligence (AI), where digital incumbent manufacturers take advantage of intelligent automation, transcending conventional performance tradeoffs to achieve unprecedented levels of efficiency and quality.

Artificial intelligence (AI) jump-starts the transformational process and powers Industry 4.0 through integration with the Internet of Things (IoT) and interconnected machines, enabling real-time visibility across entire supply chains and allowing for more accurate guidance or decisions far beyond what human intelligence could offer.

Technological advances over the past few decades and the refinement of AI algorithms have offered manufacturers the leading-edge in delivering timely end-to-end solutions, helping to manage data, deploy applications on cloud of choice to transform products, reskill and upskill the workforce to develop the next generation of relevant skills and enhance operational performance at enterprise scale. Hardware and software performance have also significantly improved the application of AI techniques including machine learning, teaching and translation, knowledge mining, cognitive learning, language processing, etc., allowing manufacturing and assembly line machines to process large volumes of data at high velocities.

AI technologies rely on neural networks that are synonymous to the biological neurons in the human brain. These networks use various architectures to process information and are comprised of nodes and layers that perform different functional analyses such as object and speech recognition, machine tuning and calibration, robotic motion control, process automation, cognitive quality assessment and factory assistance.

There are three main categories of companies that can benefit substantially from the enormous potential that AI brings to manufacturing;

- Digital natives – companies that started with digital core holdings and continue to innovate by adopting digital technologies for all business sectors.
- Digitized incumbents – these are incumbent businesses with over 20% digitalized core holdings and continue to transform the core by launching new digital businesses with over 25% organic revenue growth.
- Traditional incumbents – incumbent companies that continue to compete mainly in traditional ways and over 80% of their business holdings is not digitized.

The World Economic Forum predicts that manufacturing companies that adopt AI-enabled cloud technologies at scale (either through partnerships or acquisitions of digital assets) will lead in the emerging market, providing end-to-end solutions in cloud and edge meeting end-users demands, and will see more than 120% in productivity growth in the next few years (Martin and

Leurent, 2017). Manufacturing companies are implementing AI tools to optimize digital operations, using intelligent supply chain networks to reimagine their brand and are empowering their workforce as AI can handle mundane and repetitive tasks across the organization, freeing people up to solve more complex problems and focus on getting more impactful work done.

With the adoption of AI, other manufacturing areas will have substantial gains as well, including additive manufacturing by creating new efficient products and reducing waste and emissions, robotics and process automation by enhancing human-machine collaborations and increasing workplace safety and cybersecurity by embedding smart safeguards into manufacturing systems to combat vulnerabilities and threats. Automotive manufacturing is poised for making vehicles that will be fully autonomous by 2030 and electric battery vehicles are expected to experience an astronomical growth of about 4,000% with an average vehicle generating roughly 30 terabytes of data per day (McKinsey, 2016). These potentials will largely depend on AI and data analytics. These disruptive trends require manufacturers to realign their operating model to remain competitive. These product changes will introduce new competitors, replace component parts with new ones and require more adaptable supply chains.

Emergence of AI in Manufacturing

In the 1950s, English sage Alan Turing began to examine the ability of a machine to simulate human cognitive functions of reasoning, perception, learning and teaching, problem solving and decision making. Over time, it was realized that systems and machines can learn (machine learning - ML) from data and utilize the obtained information for better visualize detections and high accuracy predictions, which are helpful for making valuable and informed decisions. With the desire to observe and analyze more complex systems, the concept of deep neural networks (deep learning - DL) was introduced in 2010. Convoluted neural networks (CNN), self-learning and other problem-definition and problem-solving AI approaches were subsequently developed.

Today, in manufacturing, AI can, for example, power machine learning in metal cutting equipment. Through AI, machines cut metal with higher accuracy and speeds by making more timely adjustments compared to operator-run equipment. The application of AI can be applied across the value chain. For example, AI is particularly popular in autonomous vehicles where the onboard software has been trained exhaustively to be self-functioning. Parts of the training involve pattern recognition tests where large volumes of images are presented to the neural nets. The network parameters are adjusted until there is enhanced accuracy in the visual recognition of pedestrians, road features, expected and unexpected objects, etc. Future improvements in the application and adaptation of AI technologies will include reducing the volume of data required to train and test them. Within the systems, AI-enabled edge computing (which is at the device level), is emerging as the preference for applications with secure cyber-physical components.

The following pages will explore how AI is impacting people, processes and technology in short, medium and long terms.

People

AI is set to disrupt the world we live in. According to the McKinsey Global Institute, accelerated advances in AI and intelligent automation will radically impact our productivity and the way we work. This will include how we design and manufacture robots to perform simple repetitive tasks thereby reducing production errors. Consequently, fewer workers would be required to perform simple tasks, and more workers would be needed for cognitive tasks such as analysis and programming. In 2020, there will be over 3 million AI-enabled industrial robots installed and functional in factories around the world (IFR, 2019). ABI Research projects that "the total installed base of AI-enabled devices in industrial manufacturing will reach 15.4 million in 2024, with a compound annual growth rate of 64.8% from 2019 to 2024" (Robotics Business Review, 2019).

As AI technology becomes more entrenched in our daily lives, future products will require more manufacturing innovation that will be demanded by the end-users. AI transformation of the workforce will take play in six major areas as shown in Figure 1: talent management, skills enhancement, productivity enablement, accessibility, change management and the work environment. Digital natives or incumbent companies are exploring various opportunities and people-centered strategies in order to secure the value chain in the expanding market.

Companies competing to become top economy performers are expected to invest substantially in AI technologies. There are nine layers of technology stack for which forward-thinking companies may compete by providing end-to-end solutions across services, training, platform, interface and hardware requirements.

Fig. 1: AI Transformation in the workforce through connection, prediction and cognition.

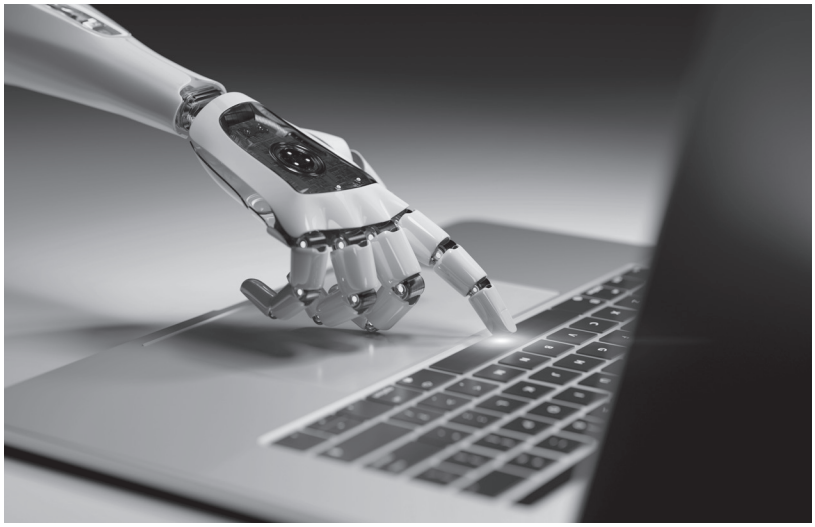
		End-End Use Cases				
	Talent management	Recruiting talents	Making smart hiring decisions	Building shared experiences	Empowering talents to succeed	Build winning teams
	Skills enhancement	Technical education in AI	AI skills & competency training	AI standards & ethics training		
	Productivity enablement	Guided process management	Smart factories & assistance	Machine assistance	Remote assistance	AI knowledge management
	Accessibility	Jobs & tasks	Daily life activities	Communication	Mobility	Connectivity
	Change management	Lean process in manufacturing	Cross-team management	Stakeholders	Review boards	
	Work environment	Smart spaces & collaboration	Knowledge workers	Design, process/ facilities simulation	Safety & health	Quality of life

Most of the opportunities are expected to come from layers across hardware, **accelerator and head node layers**, which will account for up to 50% of total value to AI vendors. These layers coordinate computations and perform highly parallel operations based on AI requirements. Examples include field programmable gate arrays (FPGAs), graphic processing units (GPUs), central processing units (CPUs) and application-specific integrated circuits (ASICs). At the **interface layer**, the framework facilitates communication between hardware and the software such as computation for unified device architecture and Open Computing Language.

Similarly, about 50% of total value from AI solutions are expected from services at the **solutions and use case layer**. Trained DL models will provide improved efficient solutions and efficacy across all other layers of the stack requiring investments. System integrators with direct interface with end users will capture majority of the gains by developing more accurate and insightful AI solutions for customers such as visual recognition for autonomous vehicles. Customers are more likely to pay for AI solutions based on total economic benefits and sustained values.

The other areas of the AI stack will generate indirect value that is expected to spur growth of the digital ecosystem but may not result to profit in the nearest future. There are three layers for which companies can compete at the platform level: the **framework layer** which includes software suites for invoking algorithms on the hardware and defining the architectures, the **algorithm layer** where we have rules for optimal inference used to adjust artificial neural network (ANN) weights such as contrasted divergence and back propagation, etc., and the **architecture layer** which is a structured approach for data feature extraction such as CNN and recurrent neural networks (RNN). The training stack contains the **methods layer** with techniques that optimize the neural net weights based on data types such as supervised, unsupervised and reinforcement learning (RL), and the **data types layer** which emphasizes application-specific data presentation to AI systems such as labeled vs. unlabeled. With respect to manufacturing investments, these layers would eventually increase in profitability when data can be generated from end users and third-party providers and appropriately shared.

Manufacturing companies must have strategic plans to capture the value in this AI enabled emerging market. The consideration must address core business strategic questions of where, how and when to compete depending on target value and level of maturity. In the automotive industry, for example, companies that focus on microverticals (particular use cases) where AI solution are deployed could see big gains, however, they must be on the same page as their suppliers and original equipment manufacturers (OEM) as far as embracing AI solutions. Customers will continue to be interested in AI solutions that can quickly solve specific problems and generate strong return on investment, this will reduce costs, reduce downtime in



manufacturing, improve predictive maintenance and increase profitability.

When exploring where to compete, manufacturing digital native and incumbent companies must select the microverticals within their capabilities that will give them a competitive edge in the market, and they must be prepared to address emerging challenges such as cyber vulnerabilities, risks and security. How should the companies compete? Partnerships with other forward-thinking companies or through acquisitions of digital assets to broaden the ecosystem will provide value to the bottom line. By establishing digital partnerships across the value chain (with suppliers, logistics partners, etc.), there could be direct benefit to customers and digital leaders.

The time to compete is now, the incumbent companies will continue to improve and gain scale that will define the trajectory of progress in the value chain. Traditional incumbent manufacturing companies should begin to focus on appropriate microverticals solutions for their business transformation that will help them establish presence in the market now, then expand to more areas of opportunities in the future. In this rapidly evolving digital market, businesses or units within the manufacturing industry that procrastinate to establish AI solutions in the next two to three years will find it challenging to catch up.

Now (1-2 years)

Manufacturers are many years away from fully utilizing AI to replace humans from the shop floor to the top floor, as ML is not yet at the level of human intelligence and adaptability (Büchel Bettina Floreano, 2018). The future requires that we begin now to think in new ways of developing and operating business and ownership models that will strengthen ecosystems. Intelligent manufacturing using end-to-end engineering techniques will involve vertical and horizontal integration of AI modeling and IoT technologies. Additionally, AI is required to be fair, explainable, robust and have lineage. Purposeful partnerships with educational systems in preparing talents for smart manufacturing will promote end-to-end value chain, when the right people with keen knowledge of intelligent business processes are involved in problem solving, human centric solutions are achieved. Competencies in how to effectively use AI methodologies can help enterprises close the skills gap, enhance skills personalization and promote transparency in the expanding manufacturing market.

Cities around the world are realizing the ease at which they can collect real-time data and with AI capabilities, decisions can be made quickly for optimizing cities' infrastructure, running systems effectively and efficiently. Some cities are transforming completely into interconnected smart cities. The Trend Force publication "Machine Learning in Manufacturing" highlighted that the global smart manufacturing market will increase to over $320 billion USD at the end of 2020.

Investments by enterprises, local and national governments are already creating prolific prospects for manufacturing companies to compete and provide innovative solutions that will enhance customer experiences, save lives, save time and resources. For example, in the U.S., there are enormous opportunities that government can provide to upgrade traditional city systems to smart city technologies, especially with the advent of autonomous and connected vehicles. Currently, fewer than 1% of traffic lights can be considered as smart traffic lights. Thus, there are growth potentials in the transportation industry that manufacturing can support.

Near (2-5 years)

Modern manufacturing generates vast volumes of data from ERP systems and smart equipment, and AI systems will be needed to detect and solve extremely complex problems in heterogeneous datasets with highly effective results (El Naqa, 2018). Product and process design in manufacturing use

AI-enabled algorithms based on worker behavior and experience, climate change, political status and economics to predict the inventory levels needed, staffing of employees, workforce development and how much demand there is in the market for a certain product (Kozyrkov, 2019). Economy of scale suggests that advancement in AI technologies will produce relevant and practical tools, available to small and medium-sized enterprises in the next 5 years which will lead to efficiency gains across the board. However, human's ability to keep up with the data interpretation will lag, while AI will be able to rapidly interpret the data. In optimized product manufacturing lifecycle management for example, AI can examine product data quickly, to determine averages and performance. The trained networks will be used to improve the output of manufacturing capabilities and AI will be able to integrate data from all areas of the company core business assets to produce quality enterprise solutions.

It is predicted that in 3-5 years, blockchain technology will be more embedded with AI in smart manufacturing to improve supply chain networks, product quality, supplier order accuracy and track and traceability. This will improve the efficiency of how products are made, how fast they are sold, and the quality of services provided. Blending advanced AI with blockchain will also improve operational technology (OT), where it can monitor/control systems and transfer data to informational technology (IT) in a cybersecure convergence, resulting in optimized intelligent manufacturing process. Blockchain is a solution to a security concern that could drive further adoption of AI. It removes a hurdle to broader adoption.

Industrial automation using AI will provide better results than human capabilities, therefore low and moderate-skilled workers will be displaced (Cheatham 2019, Moore 2019). This is because AI powered robots or smart machines are expected to replace most human functions on the factory floors allowing for capital reallocation and innovation; human capacity will be freed-up to create new products and tasks (Sikorksi, 2017). This could allow resources to be traded across global markets harnessing the benefits of the duality of digital capabilities. In addition, the transformation will reduce the safety risks exposures for workers.

Sourcing of tools and manufacturing parts will surge, expanding the global supply chain. Deployment of AI will provide significant improvements to manufacturing efficiency, speed and quality of production process, especially in managing digital supply chain. Expertise in ML will be needed for certain tasks like pattern recognition and to interpret relationships between supply chains, thus people will no longer be responsible for manual intervention in supply chain disruptions. Advances in human machine interface (HMI) will allow people to control machines and analyze data faster, therefore increasing efficiency. In the next 5 years, the technical value of HMI is projected to stimulate manufacturing growth by nearly 11% (Transparency Market Research, 2016).

Broader adoption of AI technologies across the manufacturing industry will enable more to be produced at lower costs. Overall, this benefits the consumers in the market, since this will result in affordable prices for goods and services. On the contrary, many jobs will be lost due to lack of required skills (Forbes Insights, 2018). Significant training will be required for workers in order to adopt this technology. As people in the factory have more tools at their disposal, they will need more skills and on-the-job training in order to use the software and controls in a beneficial manner. Though AI will help people in many other ways, it will inevitably create a barrier for entry into the technical labor pool. As low skill labor jobs disappear, businesses will need to find new ways to ensure that a highly skilled labor pool is always available. It is therefore imperative for enterprises to invest in training unskilled workers and potential workers so they can be valuable assets in the industry of the future.

Far (+ 5 years)

Enhanced AI is expected to dominate the future of manufacturing. This will substantially reduce the need for people in various manufacturing value chains. The performance level and quality of manufacturing robots will surpass human capabilities. Human error is inherent in tedious repetitive work, while AI completes the task the same way, with the same speed, agility and overall consistent quality.

Experts speculate that robots and collaborative robots will replace up to 20 million factory jobs by 2030, smart factories will generate $3.7 trillion USD in value, and more than 50 billion machines will be connected to the internet (Walker, 2019). The cost barrier to entry will likely fall to a point where smaller manufacturers and industries will become adopters. As AI tools gain in popularity and application, the jobs that require social skills, empathy and compassion will continue to be held by humans for many more years (Doyle, 2018). Conventional manufacturing jobs will in due course be replaced by software development and cyber-engineering jobs.

In 5 years and beyond, more companies will continue to automate their manufacturing systems. The risk of cyberattacks will also increase since AI can be manipulated by system intruders with destructive motives in forms of Botnets, a network of private computers infected with malicious software and controlled as a group without the owners' knowledge, e.g., to send spam messages. As AI technology becomes ubiquitous in manufacturing, there should be equal investments in protecting assets through strengthened security measures and the development of cyber-resilience plan for recovery after an attack.

One of the benefits of full integration of AI in manufacturing is risk reduction. The U.S. reported over 5,000 job fatalities in 2017 alone (U.S Bureau of Labor Statistics, 2018). Advancements in AI will provide the ability for the remaining workers on the factory floors or other manufacturing settings to utilize mixed and augmented reality to quickly identify hazards and control risks in real-time. This will potentially help to reduce the numbers of manufacturing workplace injuries and fatalities.

The AI of the future will be raptly incorporated into people's lives and will be able to diagnose physical and mental health issues that may affect job performance. Through real-time analytics and monitoring of worker's health and work conditions, AI will be able to prescribe corrective actions, leading to a happier, healthier workforce. Advanced AI applications are expected to reduce risk in all categories of the enterprise. Integrating AI into product lifecycle management will improve human factors and provide people with enormous benefits from an agile, waste-free system.

Process

Now (1-2 years)

Industry 3.0 led to mass adoption of electronics and IT assets to further automate production, improving visualization for operators. From that period onward, companies have implemented AI-based decision analytics support systems to enable supervisory control systems, distributed and advanced process controls for digitizing their plants. However, many manufacturers are yet to take advantage of these benefits and still expect operators to manually monitor an array of signals and make decisions based on instinct, experience and personal judgement. This may have worked for some, but the fundamental question that remains is that what happens to the operational performance and business profits when the experienced operator retires?

AI can enhance production and continuous maintenance, leveraging other modern tools like IoT and Big Data for providing autonomous and smart solutions. The integration of AI in manufacturing processes is the driving force behind the Fourth Industrial Revolution (Harari, 2018). The processing power of high-performance AI-enabled computing tools together with low cost memory requirements (due to innovations with cloud computing) offer cost effective alternatives to manufacturing companies. Complex tasks can be automated at reduced costs, requiring less manpower; and AI provides the benefits of dynamic adaptability to market and operational improvements. New or existing software resources powered by AI are used to analyze massive volumes of data routinely generated for customizable results.

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The unique ability of AI to reliably deliver consistent complex operational decisions, sustain, enhance, and normalize knowledge, makes it an indispensable tool especially where it is becoming more challenging to attract and retain skilled operators. Companies that are digitizing their core process operations, are capturing the maximum value by offering operators the ability to readily make a switch from scheduled visual on-screen information mode to autopilot mode. The use of machine intelligence will improve performance and human dependencies such as variations in skill levels, experience and aspirations not applicable to machines.

Predictive maintenance

Predictive maintenance is an essential business solution for manufacturers, where advanced AI algorithms (e.g., ML and ANN) are used to predict process errors and asset malfunction. In situations where maintenance cannot be avoided, AI solutions provide advanced notice on specific components requiring attention and advice on optimal methods and tools for focused repairs that are scheduled in advance.

In 2018, McKinsey & Company reported that the use of a root cause analysis software tool with ML capabilities lead to a manufacturing yield increase of 30% while reducing scrap in manufacturing operations (Columbus, 2018). The report

also showed that AI has the capability to reduce testing costs while increasing the predictive maintenance accuracy for the manufacturer's tooling. Other studies have shown that unplanned downtime costs manufacturers an estimated $50 billion USD annually, and that asset failure is the cause of 42% of this unplanned downtime (Kushmaro, 2018).

AI-assisted predictive maintenance is effective for both planned and unplanned downtimes by taking advantage of the technology's essential elements, ANN and ML, to develop prediction models for resource malfunction. The model algorithms perform regular evaluations and updates of the production processes with enhanced sensitivity, to identify system and program anomalies. This is helpful for reducing downtimes, providing just-in-time and focused repairs, pre-scheduling of maintenance tasks and for extending the Remaining Useful Life (RUL) of production machineries.

For example, Rolls Royce, manufacturer of luxury automobiles, provides specialized maintenance services to airline companies. Their operations generate enormous amounts of data and, hence, the company deployed Microsoft Cortana Intelligence Suite to perform large scale data modelling for anomaly identification in aircrafts, offering clients the opportunity to deliver uninterrupted schedules.

Production Quality and Efficiency

Digital integration allows different units in a manufacturing facility to access and use real-time information. AI tools can improve process conditions by detecting quality errors that human operators may not find. The design and manufacture of products must consider consumer variables such as changes in customers choices, durability, high quality, perfection and usability. Meeting these needs with short time-to-market deadlines while complying with all required quality regulations create substantial challenges for manufacturers.

To attain operational excellence and remain competitive, Quality 4.0 is being implemented where AI tools are integrated with data analytics and conventional quality models. For example, many companies are installing 3D cameras or laser inspection equipment to replace human visual inspection. The pieces of equipment generate data that AI uses to improve quality results. Companies are making strategic and socio-engineering decisions using Quality 4.0 by embedding AI into their existing quality models for early detection of quality anomalies, such as subtle abnormalities in machine performance, variations in quality of raw materials, microscopic deviations from design intent, etc. This is prevalent in semi-conductor manufacturing where highly magnified images of finished wafers are scanned and AI compare to clean wafers to detect quality issues.

Real-world Success with AI

A Siemens factory in Amberg, Germany uses digital twins to optimize throughput. Before the products hit the physical assembly line, they are tested in the digital twin to highlight possible bottlenecks or problems in real time. This has increased productivity by over 1,400% (Forbes, 2019).

The use of AI-enabled generative design software can improve design quality of products, where through exhaustive iterations, the optimum product solutions are proposed relative to parameters such as type of materials, budgetary requirements, time to production, manufacturing methods, etc. provided by the design engineers. An advantage of this is that AI algorithms do not make human-like assumptions, optimal solutions are selected based on thorough analysis of actual process performance across a wide range of possible outcomes.

In 2016, Bosch conducted a case study that utilized a network of ML programs to analyze their manufacturing processes. The study lead to isolating bottlenecks in manufacturing processes resulting in a leaner process with 35% reduction in hydraulic calibration test times (Srinivasan, 2016).

Siemens has installed many sensors in its gas turbines, and data is transmitted to an AI-enabled data processing solution which intelligently adjusts fuel valves to maintain the lowest emission levels possible. Cloud-based smart factory service solutions such as Microsoft Azure, DocumentDB and HDInsight provide manufacturers the ability to automate their processes, collect Big Data on production history, ensure production efficiency and quality, and project emerging defects.

Manufacturing companies are collecting data from customer experience, demographics, political immediacy, climate change, geographic trends, macro and socioeconomic variables. With the help of AI algorithms, they can use the data to predict how to optimize energy resource consumption, how to manage the manufacturing supply chain and staffing needs in order to better respond to market demands. Studies have shown that AI integration into automated manufacturing processes yielded 10% reduction in annual maintenance costs, 20% reduction in downtime and a 25% reduction in costs from quality inspection. (Kushmaro, 2018)

Risk and Opportunities for Solutions

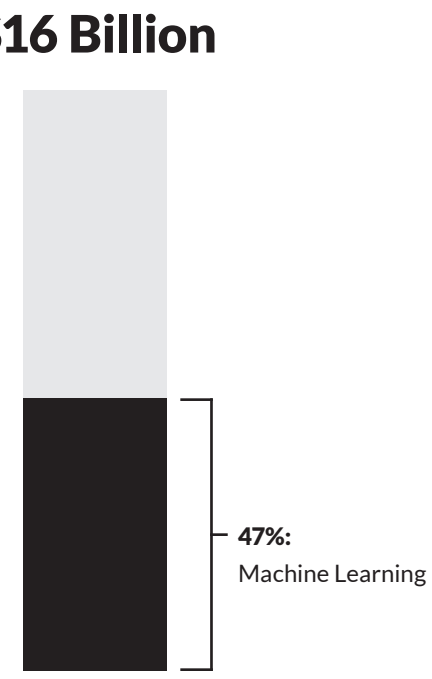
Presently, most manufacturing-based AI tools are either reactive machines or limited memory AI, that assist humans in decision making. A major risk with AI-assisted manufacturing is that it is difficult to fully understand how AI reaches its decision. For example, an object recognition AI was developed to tell the difference between huskies and wolves from a picture. The program reported accurately for some time, but unbeknown to the developers, was analyzing the background rather than the foreground of the images. The pictures with the wolves had snow in the background and the images of huskies did not. The algorithm taught itself "if snow, then wolf." It was making the right decision for the wrong reasons (Kenyon 2018). Based on this possibility for error, digital developers need to monitor and rigorously test how AI is coming to conclusions, to ensure it is congruent with the enterprise's best interests. AI can be prone to "bias" based on the data presented to the model. Developers need to ensure they are not introducing bias into the model based on validation data sets or classifications.

Cyber-attack is another risk which can be from internal and external corruption from both current and ex-employees as well as intruders. Information technology experts have begun to use ML algorithms to identify suspicions patterns (Forbes, 2019) and secure the cyber infrastructure of manufacturing processes, overall strengthen the security of their systems.

Near (2-5 years)

The market for AI in manufacturing is projected to exceed $16 billion USD by 2025 with compound annual growth rate of 43% in North America (Figure 2) (Global Market Insight, 2019). The ML segment for AI in the manufacturing market is predicted to be over 47% of the industry share. Businesses are exploring AI technology to improve efficiencies in biotech manufacturing and process development to improve their gross margins.

Fig. 2: AI in Manufacturing Market in the next five years. (Courtesy Global Market Insights)



The drivers of this economic indicator include increases in venture capital investments in AI and rapid adoption of industry 4.0, both are projected at 7.7% growth medium term. Expansion of digital data is predicted at about 4.8% within the next five years. All of which will enhance operational efficiency and reduce time to manufacture and market products.

The Asia Pacific (APAC) region is expected to continue to dominate the market growth of AI in manufacturing, largely credited to rapid adoption of Industry 4.0 for smart manufacturing plants in China, Japan and South Korea. Increased investments in AI technologies in India and China contribute to this growth. In Europe, proliferation of Industry 4.0 in manufacturing and the rise in labor costs are expected to drive the growth of AI-powered advanced manufacturing adoption in the region.

Of all respondents surveyed in a recent poll by Forbes Insights, results showed that 44% from the automotive manufacturing sector consider AI as 'highly important' to the manufacturing function in the upcoming five years, while 49% deemed it as 'absolutely critical to success.' In 2020, estimates of about 1.7 megabytes of new data will be created per second mainly from IoT devices. It is critical for manufacturers to adopt AI technologies for extracting valuable insights from the data.

There are still several challenges obstructing the wide-spread adoption of AI technologies, including the complexities of industrial data sets and the shortage of skilled workface needed for full adoption in manufacturing.

The rapid, across-the-board adoption of AI tools, principles and methods in manufacturing will be driven by the empowered end-users in the new economy.

Understandable or explainable AI (U/XAI) technologies are emerging and will come with most AI-based systems by 2025. This will help companies better understanding how AI reaches optimal solutions for intelligent decision making. The UAI or XAI will be able to generate detailed reports for human understanding about the AI's ability to function correctly and reach the best decisions appropriately. Though not currently widely used in manufacturing (Turek, 2018), the tool will further improve how accurate results are obtained. It will enhance users' experience where users can reteach the AI if determined that it is returning erroneous solutions.

Based on economic indicators and other factors, more manufacturing companies are expected to take steps in digital development and transformation by investing in IT infrastructure that will be scalable and agile. Enterprises will seek IT/OT convergence so that their system can be controlled, monitored and analyzed efficiently.

This convergence of IT/OT assets is expected to open the door for cyber vulnerabilities, risks and attacks even further. Therefore, investments in AI-based digital transformation must include security and mitigation strategies such as recommended by the SANS Institute (2017):

- documenting network maps
- procuring tools to analyze network traffic
- establishing cybersecurity assessment and audit plans
- establishing credential security program
- implementing tools to identify and notify security analysts of incidents
- regularly reviewing and patching vulnerabilities
- creating a security protocol for informing employees of phishing and social engineering

Presently, only about 6% of manufacturers have implemented blockchain technologies at-scale (Columbus, 2018). Growth trends are forecasted in coming years which will allow for effective communication between suppliers, at the same time reducing the risk of fraudulent disruptions.

Far (+ 5 years)

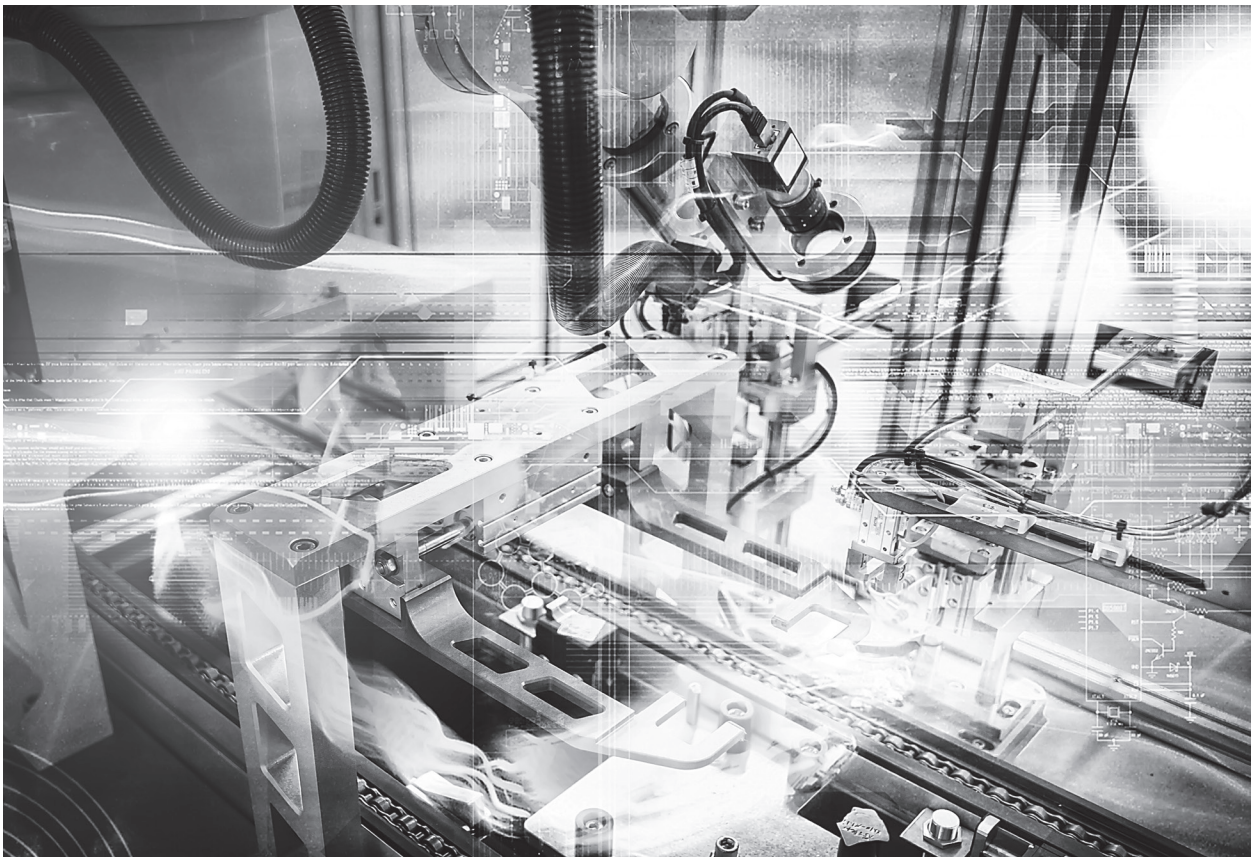
Machine learning tools will be used to optimize the digital supply chain by analyzing big datasets in order

to determine predictive metrics that may cause economic and environmental disruptions.

Literature shows that researchers have been working on the concept of developing artificial general intelligence (AGI). This will be a variation of AI where the machine intelligence will be equal to and exceeds human-like intelligence. The AGI will not be developed with any specific application in mind which would make it to be super powerful because there would be little or no restrictions on how it can be utilized. The AGI will incorporate fundamental psychological elements including object permanence and how to use machine learning algorithms. When it is market ready, AGI could ideally design, build and integrate manufacturing processes with little to no input from skilled humans. (Forbes, 2019) This future will allow automated system to achieve reality and robots will become adaptable, cheaper, faster and able to redesign and manage production lines.

Opportunity & Cost of AI Adoption

AI represents a paradigm shift—from traditionally difficult, expensive, strict rule-based solutions to cost-effective adaptive self-learning solutions based on Big Data and ML algorithms. Manufacturing companies that realize the value of AI early, and use the tool to enhance decision making will generate higher market margins. The stakes are very high for traditional incumbents and other risk averse companies especially those under capital market pressures and with volatile margins. Reluctance to invest in AI technologies will restrict their capabilities to obtain information from their processes for improving end-to-end performance and adapting to the constant changes in needs of end-users, partners and suppliers. As such, they will fall behind and miss out in the competitive new market.



Technology Evolution

Research and innovation into advancements in AI have grown globally about 12.9% since 2015 (Aguis, 2019). Manufacturing problems such as scheduling, diagnosis, modeling and design are very difficult to solve. However, innovations into AI technology have expanded the opportunities for businesses to monitor production quality control and performance, shorten design and production time, significantly reduce material waste and revolutionize how we use predictive maintenance.

Now (1-2 years)

The AI of things (AIoT) is the digital nervous system of Industry 4.0. Artificial intelligence is considered the functional brain of the system while IoT carries out AI's instructions. The AIoT integration creates a fully independent functional system (Janakiram MSV, 2019). The digital core (a central system for system data and business data) allows businesses to combine data analytics, AIoT and ML to improve the value chain of businesses.

Intelligent automation and the digital core solutions help solve complicated problems in almost all areas of engineering, including manufacturing using rule and knowledge-based systems.

Rule-based system: logic is currently used to automate assembly lines. This is not true AI because humans program the machines and the machines follow the instructions, though the machines are not self-learning or making decisions independently. Moreover, the focus is shifting quickly to true AI technologies.

In 2018, a team of researchers at Siemens Corporate Technology division in Munich, Germany, developed a two-armed robot that can manufacture products without having to be programmed. Both arms of the robot work together to complete tasks that are interpreted from CAD models, without the need to program the robot's movements (Thilmany, 2018). The robot uses digital integration to save time and energy.

Knowledge-based systems: integrated with ANN, CAD and CAE software are used in design and manufacturing processes to increase work efficiency and reduce the design cycle time.

Researchers used an expert system and ANN for automatic design of compound die and predicted its fatigue life. (Salunkhe, 2017).

The mini applications (mini-IAs) from Integrated Analysis Systems provide small and medium size companies the capacity for computer, storage, networking, and analytic software they need for their operations. The mini-IA is often purpose-built, rack-mountable, cloud-ready, and built to scale for data warehousing and analytics —a powerful combination of hardware and software (Hemant, 2018). It has been observed that AI is evolving from complex integrated systems to a modular digital ecosystem. (Satell, 2019).

Near (2-5 years)

Digital twin and digital thread technologies will gain in popularity at the middle of the next decade. Digital twin innovations will help manufacturers save money while in control of their technology by building digital prototypes, while the digital thread and blockchain will assist to secure digital transactions in the ecosystem. These tools will be applied to support generative design which would be used to vastly reduce the time it takes for manufacturers to test new ideas.

A few manufacturers, such as Airbus, Under Armour and Stanley Black & Decker, presently use generative design, but based on performance, generative design is expected to be widely used in the coming years. (Akella, 2018).

Far (+ 5 years)

The goal of manufacturing companies will be to have a 360-degree improvement in the

design of products, digital supply chain networks and enhance the digital core for maximum outcomes. Consequently, it would increase output by improving the speed, quality and flexibility of business operations.

Siemens is already exploring the possibilities of developing future advanced technology such as the Click2Make. This smart application would allow companies to submit an idea for an item they are interested to manufacture. The system will automatically gather bids from numerous manufacturers and allow the customer to select a suitable supplier. Click2Make would then quickly provide the supplier with the plans immediately to ensure a quick turnaround. The technology would focus only on small batches of products.

This technology would increase manufacturers' creative advantage and optimize their facilities, while enhancing the communication between supplier and manufacturer (Walker, 2019).

The dawn of this era will usher in the Fifth Industrial Revolution (Industry 5.0), where products and services will be readily customizable and highly personalized. Automating repetitive and complex future tasks using AI-based algorithms will optimize the existing creative process. Inevitably, in the manufacturing industry, robots will become super intelligent and collaborate with humans on innovation-based projects.

In the future, coding for robots will become more cost effective, offering more options for assembly parts. The requirement will be to specify the task and the system will automatically transform these specifications into actionable programs (Zistl, 2017). A people-oriented, robust, proactive approach can make a world of difference to enhance the customer experience when integrated with advanced analytics and emerging digital technologies. Traditional and digital incumbent manufacturers can compete in the ecosystem and come out on top if they begin now. To design, develop, enhance and sustain reliable AI integration and utilization, it will require focusing on big ideas that will include significant investments in human capital for skills development. This goal can be achieved either by appropriately upskilling current employees, working with expert consultants or hiring new multiskilled employees (translators), who can use technical, business and change management human knowledge for developing new ideas collaboratively with AI-machines. The translators' function will be to integrate management, business and market intelligence, Big Data and quality engineering, using expert perspectives for AI solution delivery that will improve the customer experience.

The manufacturing industry and academic institutions must collaborate even more, on developing human-machine solutions that will replace humans where needed, but ultimately offer solutions that will promote human value.

To make coding part of the elementary school curriculum could be a major component in the development of the platform that will support transgenerational solutions with great potentials for transformation and disruption in manufacturing. Having children learn about how to use AI solutions to build and program machines efficiency with minimal human error will help prepare future skilled translators, engineers, scientists, business and management analysts and decision makers that will innovate and develop future AI-based end-to-end solutions.

AI Solution Use Cases

In advanced manufacturing, where corporate performance is driven by operational performance, the greatest potential for AI-based solutions is in digital manufacturing supply chain and logistics management. Advanced DL, RNN and CNN collectively account for 40% (up to $5.8 trillion USD) of the annual potential value of all analytics techniques in the market (Chui et al., 2018). Ongoing advancement is helping to address the technical constraints hindering the full adoption of AI techniques including availability of large volume training data sets. Business readiness and societal constraints such as AI ethics, safety, regulation, privacy and security may slow the adoption of AI solutions for manufacturing of products and delivering services in public, automotive, food and drugs, medicine and pharmaceutical, health care management, banking and insurance sectors.

AGI also called strong AI is the human-level AI that will be required for tomorrow's manufacturing. After this period, we will enter the era of superintelligence where intellects that vastly exceeds the cognitive capabilities of humans will develop, in almost all areas of interest. Available solutions like the Microsoft Azure Suites, Amazon Web Services, Google Cloud, Baidu AutoBrain, IBM Watson or in-house AI algorithms are improving the customer experience and changing the way businesses operate, but more will be needed to keep up with our changing world. Investments in AI must address research challenges with innovation, AI scalability, security, trust and privacy issues. It is crucial to accelerate AI research collaborations with institutions to push the boundaries of AI possibilities farther and the full benefits to humanity nearer.

Some examples of where AI can help improve end-to-end performance include:

Predictive maintenance: This technology uses the power of machine learning to detect anomalies. Data from IoT-based sensors have been analyzed as time series data for predicting the RUL of components. High dimensional data in different formats and configurations can now be analyzed using DL to predict future failures and warn of planned interventions to help drastically reduce costs and downtimes and boost productivity.

Real-time predictive modeling powered by AI: Real-time optimization using logistic modeling add significant value to the bottom line and saves cost. For example, a European trucker in the manufacturing supply chain optimized its routing delivery traffic through continuous logistic estimation and behavioral coaching for drivers powered by AI. Fuel consumption and costs were reduced by about 15%, which also reduced the maintenance costs.

Personalized marketing and customer service: Customer experience can be enhanced with natural language processing for advanced speech recognition and emotional intelligence management. DL analysis can help identify problems in

message tone from audio, video or transcripts. For instance, AI can analyze multiple variables in split seconds from the customers initial contacts and recommend the best solution that will make the experience seamless for the customer, including connecting to a human operator, therefore shortening the service time. In sales and marketing, companies like Netflix, Facebook and Amazon have already implemented tools that quickly recommend the "Next Product or Service to Purchase" with individualized pricing to targeted customers. Using customer data to personalize offers can convert a lot of sales and will drive growth in the manufacturing sector.

Smart AI Robots in Manufacturing: Manufacturing companies are developing and acquiring intelligent and autonomous AI robots for smart manufacturing. Industrial analytics systems such as Intelligent process automation (IPA) and robotic process automation (RPA) are used to improve process and product quality, reduce downtime, predict performance and optimize labor. Advanced AI algorithms are used to improve the supply chains such as logistics, warehouse, fleet and freight management (real-time tracking). New AI-enabled solutions include the manufacture of autonomous and connected vehicles, and intelligent drone delivery. Complex AI-powered vision and Quality 4.0 techniques to explore defects in produced items can be a great way to ensure product quality.

At one of the largest adhesive manufacturers with over 130 plants worldwide supports the aviation, automotive and electronics industry supply chain, Cerebra's IoT signal intelligence platform was implemented to improve quality and increase the yield by controlling softening points and viscosity. Within three years, sensor data (i.e., torque, RPM, temperature and pressure) from plant operations analyzed helped the company save over $140 million USD from defective parts.

Asset Protection and Cybersecurity: Advancements in technology will also drive attackers to innovate in new ways to bypass security and cause intentional damages. The cyber-physical nature of most manufacturing enterprise creates vulnerabilities; however, AI is an effective predictive tool for vulnerabilities, risks, and attacks. The use of AI predictive tools can improve forecast accuracy by over 20%, according to McKinsey & Company. User and Entity Behavioral Analytics (UEBA), and other AI tools are used to analyze Big Data and for detecting odd patterns such as micromovements of data packets.

These tools can effectively detect exposures to bugs and botnets and use appropriate techniques to secure the automation with cybersecurity and cyber-resilient solutions. According to ABI Research, it is projected that by 2021, AI cybersecurity expenditure on Big Data, smart automation, and data analytics will reach $96 billion USD. There are opportunities exist and for all businesses to excel in this new market.

Action Items

- Manufacturers without concrete plans for AI adoption into their operations must start now by implementing a stepwise adoption approach with the best benefits for the value chain. This will also reduce the dependency on the human labor force. Therefore, all end-to-end solutions must consider the improvement of both human and machine intelligence within an enterprise to ensure the adoption is sustainable.
- Upskilling of existing manufacturing workers in automation and AI tools will play to the advantage of the business. Efforts must be made to hire new employees that can use automation and intelligent strategies to solve problems, this will help prepare future operators, engineers, digital experts, translators and innovators for the factory of the future. The business must also engage AI experts that will continuously reflect on market evolution and the value chain.
- Based on the cyber-physical nature of digital manufacturing, there will be increased emerging risks to automated and connected systems/processes which may expose manufacturers to cyber-attacks. Appropriate investments in robust physical and cybersecurity systems must be prioritized.
- Collaboration within the ecosystem will help develop interactions between AI platforms across similar industries and partners in the value chain, allowing for efficient learning from one another and quick implementation of useful knowledge.

About Automation Alley

Automation Alley is the World Economic Forum's Advanced Manufacturing Hub (AMHUB) for North America and a nonprofit Industry 4.0 knowledge center with a global outlook and a regional focus. We facilitate public-private partnerships by connecting industry, education and government to fuel Michigan's economy and accelerate innovation. Our programs give businesses a competitive advantage by helping them along every step of their digital transformation journey. We obsess over disruptive technologies like AI, the Internet of Things and automation, and work hard to make these complex concepts easier for companies to understand and implement.

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