

The Manufacturing Evolution

How AI Will Transform Manufacturing &
the Workforce of the Future



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Executive Summary

For manufacturing enterprises, the advent of artificial intelligence (AI) will reshape the source of value creation, the formation of new business models, and the delivery of value-added services such as mass customization, predictive maintenance, and “product servitization” (i.e., the process of building revenue streams for manufacturers from services related to your products). As AI becomes more prevalent in various aspects of business management and operations, investing in people will become even more important. AI and automation will not displace people but rather combine their capabilities in new ways to create new forms of value and new opportunities. The manufacturers that identify how to empower their workforces through AI applications will create the greatest value going forward.

For manufacturers who fear they are behind the curve in preparing for this AI revolution, you are not alone: Just 5% of MAPI member companies have mapped where AI opportunities exist and developed a clear strategy for sourcing the data that AI requires. And 56% of companies currently have no plans to do so. The picture improves over the next five years, as 14% of respondents expect to have completed such mapping by then, while 63% expect to be in the process of doing so. This summary outlines the key findings and recommendations to guide manufacturers in the next leg of the transformative journey with artificial intelligence and their workforce.

KEY FINDINGS

AI Making Inroads in Manufacturing. AI is most commonly deployed in industrial robotics, machine vision, intelligent products, machine learning, and cobots. Over the next five years, industry leaders expect significant growth in predictive systems and in their use of AI to manage intelligent supply chains. Manufacturers also expect significantly increased use of robotic process automation (RPA).

Significant Technical and Workforce Barriers Remain. At present, a lack of clarity about how to implement AI solutions, and a lack of interoperability between equipment are the most significant barriers to deployment. However, these are paired with significant workforce challenges, including a lack of employees with the necessary digital skills to implement AI or understanding of how to define the AI skills needed.

New Roles Emerging for Humans and Machines. AI will generate new roles where human capacity will reign supreme (e.g., creating and judging) and others where machines will outperform humans (e.g., iterating and predicting). Hybrid roles will arise where humans will enable machines (e.g., in training, explaining, and sustaining) and where AI will augment human capabilities (e.g., in amplifying, interacting, and embodying).

New-to-World AI Jobs on the Way. Few organizations have introduced dedicated new job categories focused on AI. However, such jobs are emerging. Fully 43% of manufacturers have added “data scientists/data quality analysts” to their workforces, and 35% more expect to do so within the next five years. A sizable proportion of manufacturers are also creating “machine learning engineers or specialists” (33% today, 70% within five years), “collaborative robotics specialists” (29%), and “data-quality analysts” and “AI solutions programmers/software designers” (26%).

Demand for Fusion Skills. “Fusion skills” refer to the combination of human and machine talents within a business process to create superior outcomes to either working independently. Fusion skills will be needed in training, explaining, and sustaining activities (such as human judgment enabling improvement in the performance of machines); in expanding employees’ capabilities (such as machine intelligence enabling humans to make decisions); and in tasks in which humans and machines will jointly excel together (such as iterative processes in which each learns from the other).

AI-Skilled Workforce in Short Supply. In terms of developing an AI-savvy workforce, a plurality of manufacturers believe the biggest barrier to acquiring AI-skilled workers arises from an insufficient number of graduates with the needed knowledge and skills graduating from educational programs. This is closely followed by difficulty in attracting skilled candidates due to reputational issues revolving around manufacturing, and by a perceived lack of mechanisms to retrain existing workers with the requisite AI skills.

Learning and Development Vital to Unlocking AI Potential.

Manufacturers are pursuing several strategies to promote the development of AI-skilled workers.

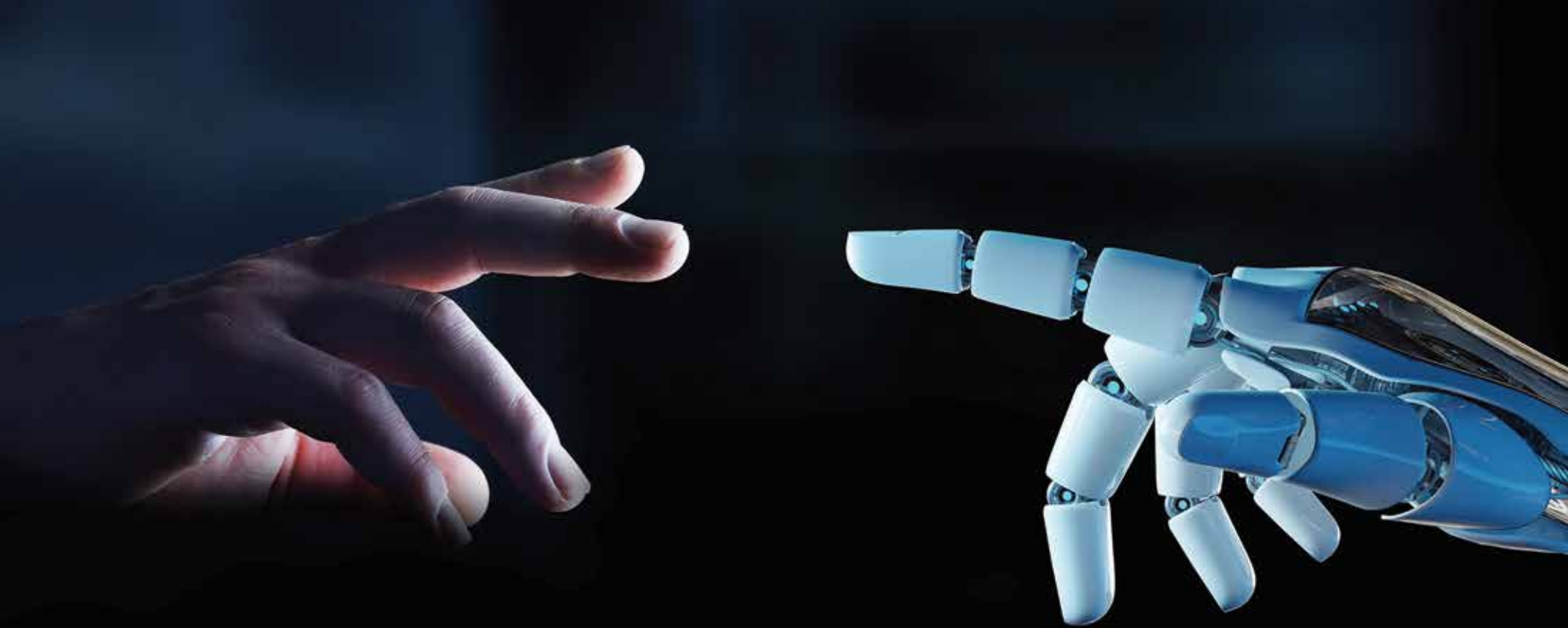
- A majority of companies expect to pursue a combination of both retraining and hiring employees with the needed AI/data science skills over the next five years
- Many are building relationships with local academic institutions (including high schools, community colleges, and universities)
- Some have turned to massively open online courses (MOOCs) and other forms of online education
- Some have developed internal training courses

At the same time, reflecting how early the application of AI is for many manufacturers, almost half are not yet supporting AI skills development for their workers.

SIX RECOMMENDED ELEMENTS OF THE MANUFACTURING EVOLUTION

A sustainable AI and workforce transformation will require a deliberate and comprehensive change management strategy. We have six recommendations for business leaders:

- 1 Create teams to drive digital transformation in the enterprise.**
 - The digitalization of manufacturing, including the application of AI-based solutions, heralds the most significant transformation to manufacturing in a generation.
 - Manufacturers will need dedicated teams to navigate this transformation, such as digital command centers and digital business teams tasked with leading the deployment of emerging digital technologies.
- 2 Define an “AI governing coalition” for AI transformation.**
 - Manufacturers should define their own AI transformation strategy to assess the company’s processes and operations and then evaluate how the application of AI-enabled systems could transform and improve them.
 - This “AI governing coalition” of business, IT, HR, and analytics leaders owns activities such as setting the direction of AI projects, analyzing problems to solve with AI, and managing internal change.
- 3 Evaluate AI and workforce transformation readiness.**
 - A workforce transformation strategy should consider what AI-specific jobs need to be created and how to provide relevant AI training to employees at every level.
 - Manufacturers need an inventory of what AI skills the company will need, to ascertain to what extent internal resources can fill these needs, or skills that need to be acquired externally, and develop a plan to train and upskill workers.
- 4 Set measurable objectives for digital and AI transformation.**
 - Companies shouldn’t deploy AI technologies for technology’s sake—all implementations of digital technologies should address a clear business need and be supported by a reasonable return on investment rationale.
 - Manufacturers should define annual objectives for how the application of AI can help meet key performance indicators such as overall operating efficiency and productivity growth.
- 5 Redefine digital and physical product innovation processes.**
 - The advent of digitally-based innovation creates a need to speed time to market, but this presents a challenge to the stage-gate models used to manage product development and innovation cycles.
 - Companies will have to modify their product development processes to accommodate digital transformation while still meeting key safety, reliability, and product quality standards for their finished products.
- 6 Overinvest in communication for change management.**
 - Effective practices include developing a communications process to explain the implications of AI applications and solutions to employees, customers, and partners.
 - Some companies have already set up worker councils to facilitate dialogue between the front office and the front line about how the advent of AI will change workers’ roles and responsibilities in the AI era.



Introduction


Artificial intelligence (AI) is a field of computer science devoted to creating computing machines and systems that perform operations analogous to human learning and decision-making.¹ Practically, AI refers to any activity previously conducted via human intelligence that can now be executed by a computer or software.² AI holds the potential to transform virtually every facet of modern manufacturing, from how products are designed, fabricated, and assembled to how factories operate and supply chains integrate to how products are sold, serviced, and consumed in the field.³ The proliferation of AI in manufacturing will likewise impact manufacturing workforces, creating entirely

new categories of AI-driven jobs while also transforming the roles performed and skills required for every manufacturing worker, from the factory floor to the front office. This report explores how manufacturing processes and workforces will be transformed by the coming era of AI expansion. It begins with a brief introduction describing AI applications in manufacturing and then examines the manufacturing workforce implications of the advent of AI. The report concludes with recommendations for both business executives and policymakers on how to successfully navigate manufacturing's transformation through AI.

From the manufacturing-enterprise perspective, this report finds that the advent of AI—a facet of the broader trend toward manufacturing digitalization—will reshape the source of value creation in manufacturing enterprises, facilitating the formation of new business models and the delivery of value-added services such as mass customization, predictive maintenance, and product “servitization” (i.e., selling products as services).

As digitalization becomes an ever-increasing source of value creation, manufacturers’ digital teams will grow. Information technology (IT) will increasingly integrate with operational technology (OT), which will give rise to an increasing number of entirely new digital jobs, many directly related to the application of AI-based solutions, such as AI applications developers, machine-learning engineers, and collaborative robot programmers. Indeed, an entirely new class of jobs will emerge in manufacturing enterprises devoted to creating and deploying AI-based solutions. Yet the coming AI transformation will impact every manufacturing worker; those on the factory floor might not need to know how to code an algorithm, but they will need to work in a facility with computers and AI-based systems as well as the ability to understand how AI-based solutions can be applied in value-creating ways. Frontline workers will increasingly work hand-in-hand with collaborative robots, using AI-enabled augmented/virtual reality (AR/VR) systems for training, to perform production or repair activities, and to interpret analyses or recommendations produced by machine-learning algorithms.

The advent of AI will lead to a significant reorganization of tasks in the manufacturing environment, displacing humans from repetitive and routine tasks, while creating new opportunities for them to focus on value-generating activities. Studies suggest that at least half the tasks now performed by humans in the manufacturing environment will be performed by AI or other automated systems within a decade. That doesn’t mean machines will replace half



From a public policy perspective, the single most important finding from this research is the need to dramatically increase America’s AI talent base.

of the manufacturing workforce, but it does mean that workers need to equip themselves with a largely different and more sophisticated set of skills if they are going to be able to add value in the manufacturing industries of the future. The individuals, and enterprises, which flourish during this transformation will excel at understanding how to reimagine existing business processes—and product offerings—in ways that uniquely combine the distinct capabilities of humans and machines.

From a public policy perspective, the single most important finding from this research is the need to dramatically increase America’s AI talent base. The United States already faces a shortage of AI talent, and extrapolating this report’s survey results to the entire U.S. manufacturing sector suggests that the demand for AI talent—particularly for workers with at least a bachelor’s degree in AI-related disciplines (e.g., computer science, math, or engineering)—will grow significantly going forward. In an era of talent scarcity, many graduates with AI skills are seeking employment in technology companies in desirable urban locations such as Austin, Boston, New York, Seattle, and Silicon Valley. It will be an enormous effort for a manufacturer in the American heartland to compete for this talent. As such, unless the federal government acts swiftly to expand college graduation rates for students with AI skills, and also immigration paths for individuals with AI skills, manufacturers in America will find themselves at a significant disadvantage compared with their global competitors.

Artificial Intelligence and Its Emerging Economic Impact

AI is a field of computer science devoted to creating computing machines and systems that perform operations analogous to human learning and decision-making. AI involves machines embodying many functionalities, the most important of which are:

1. **Learning**, which includes several approaches such as deep learning (for perceptual tasks), transfer learning, reinforcement learning, and combinations thereof
2. **Understanding**, or the “deep knowledge representation” required to execute domain-specific tasks, such as in accounting, cardiology, law, and manufacturing
3. **Reasoning**, which comes in several varieties, such as deductive, inductive, temporal, probabilistic, and quantitative
4. **Interaction**, with people or other machines, to collaboratively perform tasks and learn from the environment⁴

Within the manufacturing context, the most common form of AI entails machine learning, which is a branch of artificial intelligence that focuses on designing algorithms that can automatically and iteratively build analytical models from new data without explicitly programming a solution.⁵ (Machine learning represents the fastest-growing segment of AI in manufacturing, becoming more common due to the increased availability of large datasets, improved algorithms, and more powerful computer hardware.) Another

form of AI found in manufacturing is “deep learning,” a subfield of machine learning that structures algorithms in layers to create a “neural network” that can learn, recognize abstract patterns, and make intelligent decisions on their own.⁶

Accounting for its multiple forms, analysts expect AI to boost global economic output.

- A 2018 McKinsey Global Institute report estimates that, by 2030, applications of AI will boost global productivity by 1.2% annually, increasing the size of the global economy by \$13 trillion.⁷
- By 2035, Accenture estimates, AI will add \$8.3 trillion to the size of the U.S. economy.⁸
- In Germany, one government-sponsored study predicts that, from 2018 to 2023, AI applications will add €32 billion (\$36.5 billion) to the nation’s manufacturing output, an amount equal to one-third of the growth expected in Germany’s manufacturing sector over that period.⁹

Of course, these impacts will also be felt at the enterprise level. Accenture further estimates that companies “investing in AI and in human-machine collaboration” will boost their revenues by 38% between 2018 and 2022.¹⁰

Contextualizing AI Within the Digital Manufacturing Transformation Journey

Digital manufacturing (termed “Industry 4.0” in Europe) refers to the application of a suite of ever-more powerful information and communication technologies (ICT) to manufacturing processes. The technologies enabling digital manufacturing include the Internet of Things (IoT), cloud computing, wireless communications, big data analytics, and robotics, in addition to AI. Digital inputs now account for one-quarter of inputs used in U.S. manufacturing, a share that has risen to 40% in sectors such as electronics manufacturing.¹¹

Studies estimate that the application of manufacturing digitalization will increase factory productivity by 10% to 25% by 2025, with global output expected to grow by as much as \$3.5 trillion as a result of manufacturing digitalization over this period.¹²

- For its part, General Electric estimates that manufacturing digitalization could boost annual U.S. productivity growth by 1 to 1.5 percentage points and add \$10 trillion to \$15 trillion to the global gross domestic product (GDP) over the next 20 years.¹³
- A study from Finland estimates that fully half of all value in the global economy over the next decade will be created digitally.
- Similarly, a study by International Data Corporation (IDC) predicts that, by 2020, 60% of leading manufacturers will depend on digital platforms to support as much as 30% of their overall revenue.¹⁴
- IDC’s research further predicts that, by 2021, 20% of leading manufacturers will rely on embedded intelligence, using AI, IoT, and blockchain applications to automate processes and increase execution times by up to 25%.¹⁵

The essential point here is that AI is one of a suite of emerging digital technologies transforming modern manufacturing—and in many cases, successful applications of AI will depend on the proper antecedents being implemented in the manufacturing environment.

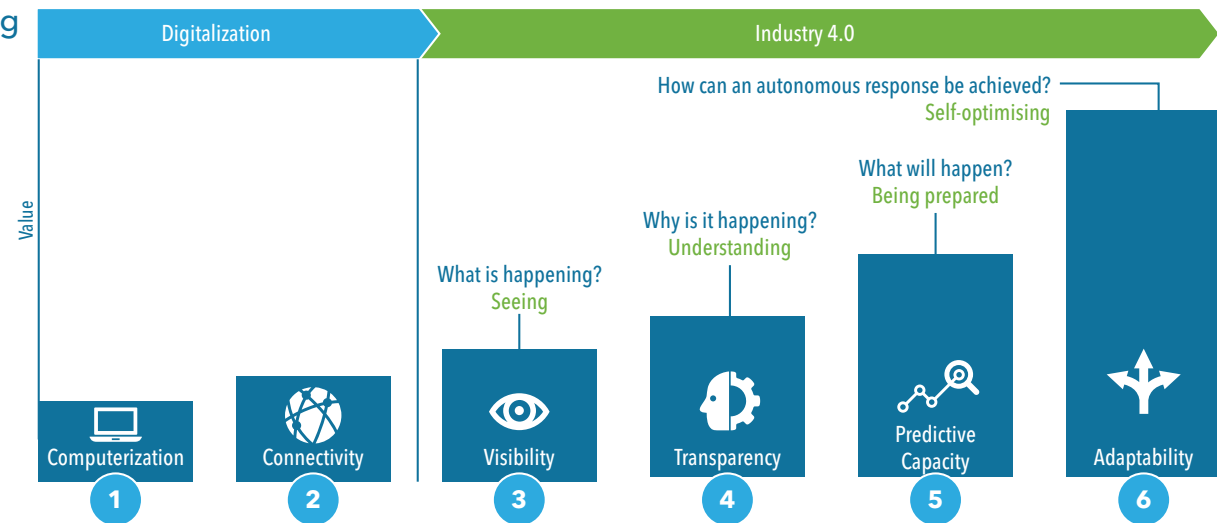
For instance, production equipment will need to be IoT-sensor-enabled in order to produce a real-time (and longitudinal) data stream and to create the datasets on which manufacturers can then run smart algorithms (i.e., AI) for the purpose of identifying patterns and detecting trends that facilitate predictive maintenance or make optimization decisions. In other words, AI is one (albeit a critical one) of a suite of tools facilitating manufacturing digitalization.

The report “Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies” prepared by Acatech, (Germany’s National Academy of Science and Engineering) identifies six stages in the “digital manufacturing transformation journey.”¹⁶ They are:

- | | |
|--------------------|------------------------|
| 1. Computerization | 4. Transparency |
| 2. Connectivity | 5. Predictive Capacity |
| 3. Visibility | 6. Adaptability |

Stages in the Digital Manufacturing Transformation Journey¹⁷

Graphic based on a diagram from FIR e. V.
at RWTH Aachen University



- 1 **Computerization**, the basis for digitalization, which entails ensuring all key production equipment in the manufacturing environment has a digital interface—which is often missing for manufacturers, especially for machinery that is manually operated or has long replacement cycle times.
- 2 **Connectivity**, refers to manufacturing enterprises' ability to integrate their various technology systems and connect key production equipment into an integrated, enterprise-wide IT system.
- 3 **Visibility**, refers to the ability of enterprises to achieve real-time sensing of what is happening in the manufacturing environment. At this stage, "sensors enable processes to be captured from beginning to end with large numbers of data points," thus "making it possible to keep an up-to-date digital model of factories at all times."¹⁸ In effect, companies can create a "digital thread" or digital representation showing

what is happening across their manufacturing and enterprise operations so that management decisions can be based on real-time information.

- 4 At the **Transparency** stage, manufacturers can understand why things are happening and use this understanding to produce knowledge through root-cause analyses. Here, big data analytic applications are deployed in parallel to enterprise-level manufacturing execution systems (MES) or enterprise resource planning (ERP) systems.
- 5 At the **Predictive Capacity** stage, companies can predict failure modes for parts or machines, or simulate alternative future scenarios.
- 6 **Adaptability**, refers to self-optimizing factories in which autonomous responses can be achieved, and to "self-aware" machines capable of detecting and even fixing their own error modes.¹⁹

Progressing through these six stages of the manufacturing digitalization journey requires most manufacturers to make structural changes to at least four aspects of their company: their IT systems, organizational structure, resources (i.e., talent), and culture.²⁰ As noted, the Acatech report provides a comprehensive guide for how manufacturers need to evolve each of these structural areas across the six stages, and further provides a three-step guide for how manufacturers can identify:

1. Their current maturity stage
2. Specific capabilities needing development
3. Concrete measures they need to take²¹

This guide also quantifies the economic and productivity benefits manufacturers should expect to realize at each stage of digitalization.

Understanding the Stages

Roughly, Stages 1–4 are about deploying the underlying connectivity technologies: IoT-sensor-enabling production equipment to produce a real-time flow of information about their operation, RFID-enabling parts or components to track their status as they move through a work cell, and fully integrating ERP and MES systems into the enterprise’s IT architecture.

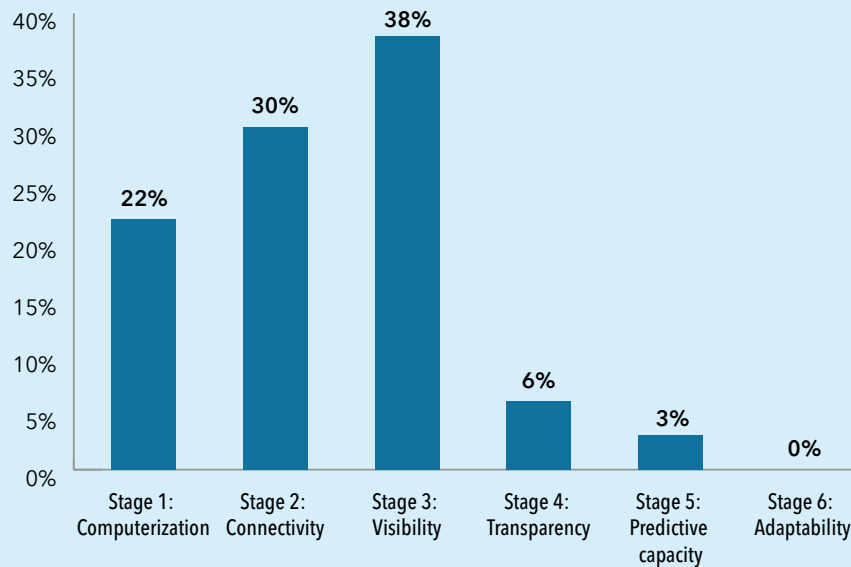
Stages 5 and 6 are more about beginning to leverage AI systems such as computer vision, machine learning, and collaborative robotics. As most AI-based systems learn by training on data, building companies’ data architecture and integrating their datasets represents a foundational step toward their capacity to deploy AI applications. The need to have an internal digital business unit or team—or at least the ability to outsource such skill sets—runs throughout the entirety of the digitalization process.

Managing organizational, talent, and cultural changes becomes especially important in Stages 4 through 6, for, as this report will elaborate, the advent of manufacturing digitalization, and AI in particular, will have a significant impact on manufacturing workforces. In terms of one company’s digital manufacturing transformation journey, a manufacturing executive interviewed noted that it’s useful to think about digital in three categories, “one focused on internal operations, one from a customer-engagement perspective, and one around taking data produced within our machines and using that to improve our product efficiency, optimization, and potential for monetization.”

The essential point here is that AI is one of a suite of emerging digital technologies transforming modern manufacturing.



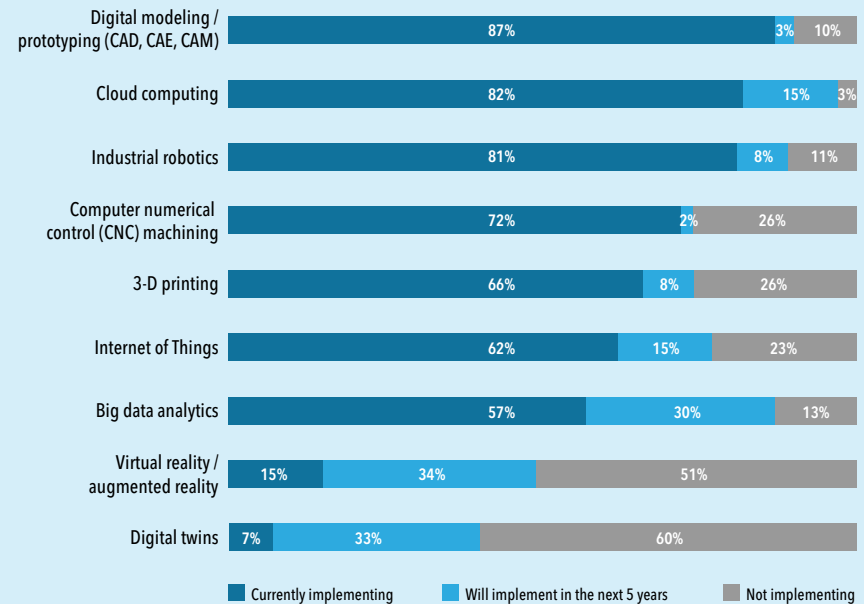
Most Manufacturers in Early Stages of the Manufacturing Digitalization Journey



To better understand how manufacturers in the United States are using digital technologies, especially AI, the Information Technology and Innovation Foundation (ITIF) surveyed 60 manufacturing executives who are members of the Manufacturers Alliance for Productivity and Innovation (MAPI).²² We evaluated how manufacturers mapped to the Acatec model in practice. Please see the [appendix](#) for full details on the survey.

Strikingly, over half of the respondents indicated their companies were just at the initial stages of the manufacturing digitalization journey, getting their enterprises computerized and connected. Almost two-fifths had progressed to a stage of having strong visibility into their manufacturing operations, while less than 10% had progressed to a stage of either achieving transparency or

High Variability in Implementation of Specific Digital Manufacturing Technologies



predictability in their manufacturing operations. No respondents reported being at Stage 6: Adaptability/self-optimization.

Reflective of this dynamic, most manufacturers in the survey are currently implementing more of the foundational digital technologies, before progressing to more sophisticated applications such as AI, digital twins, and AR/VR. This should not be a surprise, as these technologies are relatively mature, having been available to manufacturers for over three decades now. In contrast, 60% of respondents have yet to implement or consider implementing digital-twin applications, with 51% yet to implement AR/VR systems, and 26% 3D printing. In contrast to technologies such as robotics, these technologies are much less mature, and manufacturers have had less time to experiment with their implementation.

Applications of AI in Modern Manufacturing

Manufacturers are using AI to serve a wide variety of purposes, such as product design, production process improvement, quality control, predictive maintenance, supply-chain optimization, distribution, and AI-embedded products for workforce training.²³ The following section discusses several examples.

Generative Design

In product design, generative design (also called “algorithmic design”) allows product designers to enter into software the design constraints they desire for a part or product and AI algorithms embedded in the software generate thousands of iterations until an optimal design is found.²⁴ As one example, Airbus leveraged AI-enabled generative design techniques to create a bulwark that was 40% lighter, yet 50% stronger, than prior versions for the Airbus A320 aircraft. Deployed across an entire fleet of aircraft, the efficiency savings from the design change in that one aircraft

component alone could save an airline 465,000 metric tons of carbon-dioxide emissions annually, the equivalent of taking 96,000 passenger cars off the road for one year.²⁵

Similarly, Stanley Black & Decker’s Breakthrough Innovations team used generative design techniques to redesign hydraulic crimpers (used by electric line workers for the termination of electrical lugs, sleeves/fittings, connectors, wire ropes, and earth connectors) and attachments. Stanley Black & Decker’s new design reduced the weight of the hydraulic crimping attachment by 60%, making it much easier for workers to use. Moreover, the new design maintained the strength characteristics of the original tool, and permitted an additive manufacturing strategy to fabricate the new attachment.²⁶

Predictive and Preventative Maintenance

Manufacturers are also using AI to facilitate predictive and preventative maintenance and support quality-control activities. For instance, leveraging sensors, data, and machine-learning algorithms, the global electrical equipment manufacturer ABB can predict with 95% accuracy when one of its wind turbines is about to fail.²⁷

Siemens has installed smart sensors that use machine-learning algorithms on older motors and transmissions to detect subtle changes in vibration or energy use that may indicate that failure is imminent.²⁸ Computer vision (or “machine vision”) applications can detect microscopic defects in products such as circuit boards (or even in power lines or railroad tracks) at resolutions well beyond human vision, powered by machine learning algorithms trained on remarkably small volumes of sample images.²⁹



Supply Chain Optimization

Manufacturers are applying AI in order to optimize supply chains in numerous ways, including planning, warehouse management, logistics and shipping, natural language processing (i.e., processing datasets in foreign languages), and managing supplier relationships.³⁰ For instance, Procter & Gamble deployed an AI/IoT solution to automate warehouses and distribution centers, including the customized automation of product deliveries to 7,000 different stock-keeping units, helping the company reach its goal of cutting supply chain costs by \$1 billion annually.³¹

Operations and Inventory Management

AI will also play a prominent role in factory operations and inventory management. For instance, Toyota Material Handling's AI system can examine a shelf full of products, identify bar codes, and get the right products to the right places, with small robots swarming through factory floors using AI with visual recognition to navigate, constantly learning and then sharing that learning with other vehicles. As team leader Axel Wahle explained, "The swarm is for coordinated distribution, lean logistics, and continuous flow—the right truck, the right task, on time, every time by utilizing millions of calculations per second."³²

Employee Training

Manufacturers are using AI in conjunction with AR/VR to facilitate employee training. For instance, Honeywell has developed tools that utilize AI-powered AR/VR to capture the experience of work and extract "lessons" that can be passed on to new hires. As Honeywell employees wear AR headsets while carrying out their daily tasks, image-recognition technology captures a record of every step they take, which can be played back for trainees and new hires to experience their roles through virtual reality.³³

Support Production

AI-powered AR/VR is not just for employee training; it will also be used to support production activities. For instance, Boeing uses



AR to assist production workers with the wiring of the new 787-8 freighter.³⁴ Similarly, BAE Systems has created "interactive mixed-reality experiences" using AR/VR that guide frontline workers with step-by-step instructions that accelerate battery cell assembly.³⁵

Cobots

AI is empowering a new generation of industrial robots—cobots—that work more productively in tandem with frontline workers. Collaborative robots can sense their environment and comprehend, act, and learn, thanks to machine-learning software and other AI-related technologies. With collaborative robots, fixed assembly lines give way to flexible human-machine teams that can adapt on the fly. They represent organic teams that partner humans with advanced AI systems.³⁶ Ford has deployed cobots at one of its assembly plants to assist humans in fitting shock absorbers onto new vehicles.³⁷ Similarly, Hitachi has deployed AI to analyze

big data and workers' routines to inform robots in delivering instructions to employees to meet real-time fluctuating demand and on-site continuous improvement objectives.³⁸

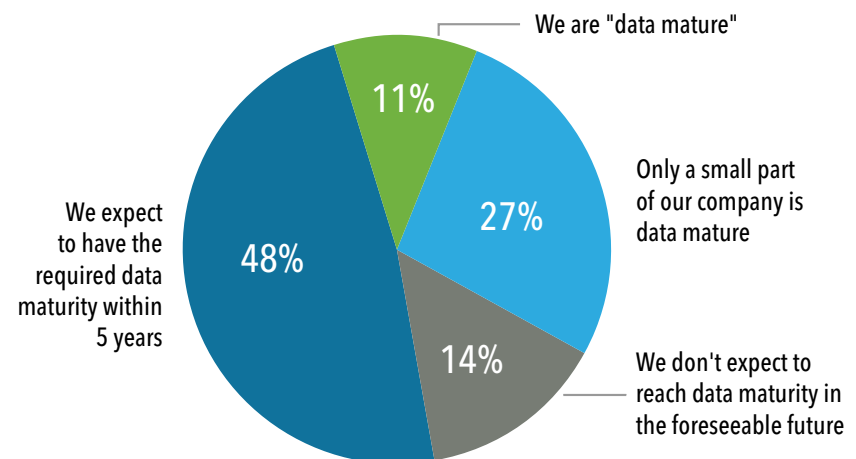
There are many more examples of discrete applications of AI in manufacturing, but the future will belong to enterprises that holistically knit AI applications together through every facet of their manufacturing enterprise, from demand and enterprise resource planning to operations on the factory floor and across entire industrial supply chains to uses in cybersecurity risk management. Consider one example of the future: Japan's robot manufacturer FANUC. At FANUC, robots actually build themselves, test themselves, and inspect themselves.³⁹ At one of the world's first truly "lights-out, 24/7 factories," FANUC's intelligent robots create computerized offspring capable, just like themselves, of machine learning and computer vision, with the robots constantly teaching themselves to perform tasks faster and more efficiently. FANUC found that what used to take one robot eight hours to accomplish can now be performed in one hour by eight robots learning together.⁴⁰ FANUC also teamed with Cisco to create a platform that identifies inefficiencies in manufacturing processes in order to improve production, which helped one major automotive manufacturer save \$20,000 per minute.⁴¹

Similarly, Siemens has constructed a model manufacturing facility in Amberg, Germany, that leverages over 1,000 networked manufacturing units automatically coordinating with one another to retrieve and fabricate components without human oversight. The facility is approximately 75% autonomous, allowing its human employees to focus on operating computer systems and monitoring the factory floor.⁴² While these examples provide a glimpse into the future, this degree of plant-level autonomous operation is currently a rarity—even within Siemens.

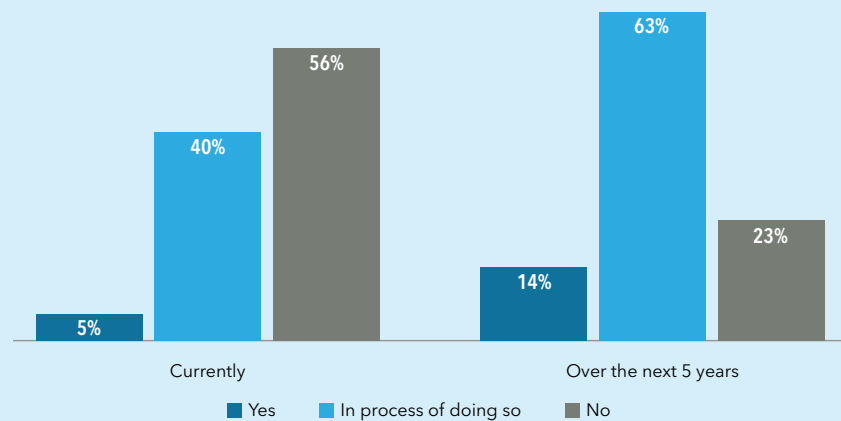
A CURRENT SNAPSHOT OF MANUFACTURERS' AI APPLICATIONS

The MAPI survey examined manufacturers' current and future expected uses of AI applications. One aspect of the AI future the survey made clear is that "data maturity" is a prerequisite for "AI maturity." For instance, as machine-learning algorithms depend on the ability to train on datasets (such as the current and historical operating condition of a product in the field or of a machine tool or other key piece of production equipment), that relevant data has to exist within the company in order to enable the AI application. However, only 11% of respondents believe their organizations are fully data mature, while slightly over one-quarter feel they are only partly so. About half of respondents believe their companies could become data mature within five years, but 14% feel their companies will not become so within the foreseeable future.

"Data Maturity" in Its Infancy for Most Manufacturers

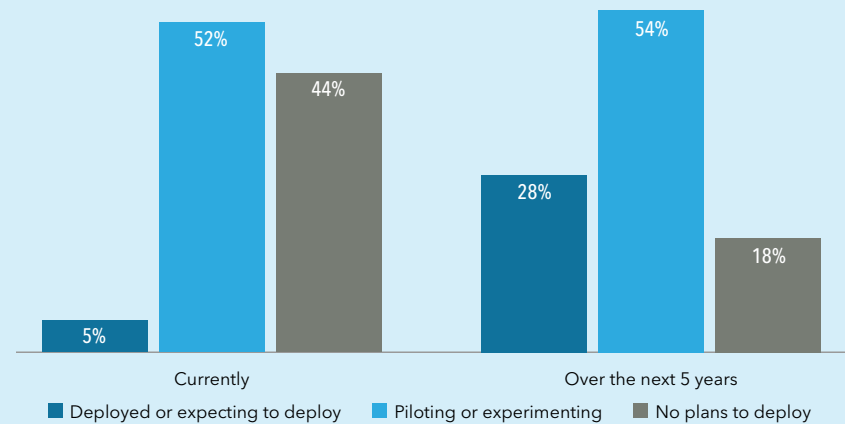


Expectations Rising for Mapping AI Opportunities and Data Requirements



Part of the challenge for many companies is that they have yet to identify where AI application opportunities exist within their companies, or to develop a clear strategy for how to accrue the datasets required to power those applications. Just 5% of respondents have mapped out where AI opportunities lie within their company and developed a clear strategy for sourcing the data AI requires, while 56% currently have no plans to do so. The picture improves over the next five years; by then, 14% of respondents are expected to have completed such mapping, while 63% are expected to be in the process of doing so.

AI Deployment Expected to Surge



In addition, the extent to which respondents' application and mapping of AI opportunities largely reflects their company's size. A majority of smaller companies, 61%, have no current AI solutions or pilots deployed, while the vast majority of larger companies in the survey, 92%, are currently piloting AI solutions (not shown). Over the next five years, both groups are predicted to progress significantly, as 67% of smaller companies expect to be piloting AI solutions, and 7% expect to have fully deployed AI solutions, compared with 33% and 58%, respectively, for larger companies.

AI applications that MAPI survey respondents have most commonly deployed to date include:

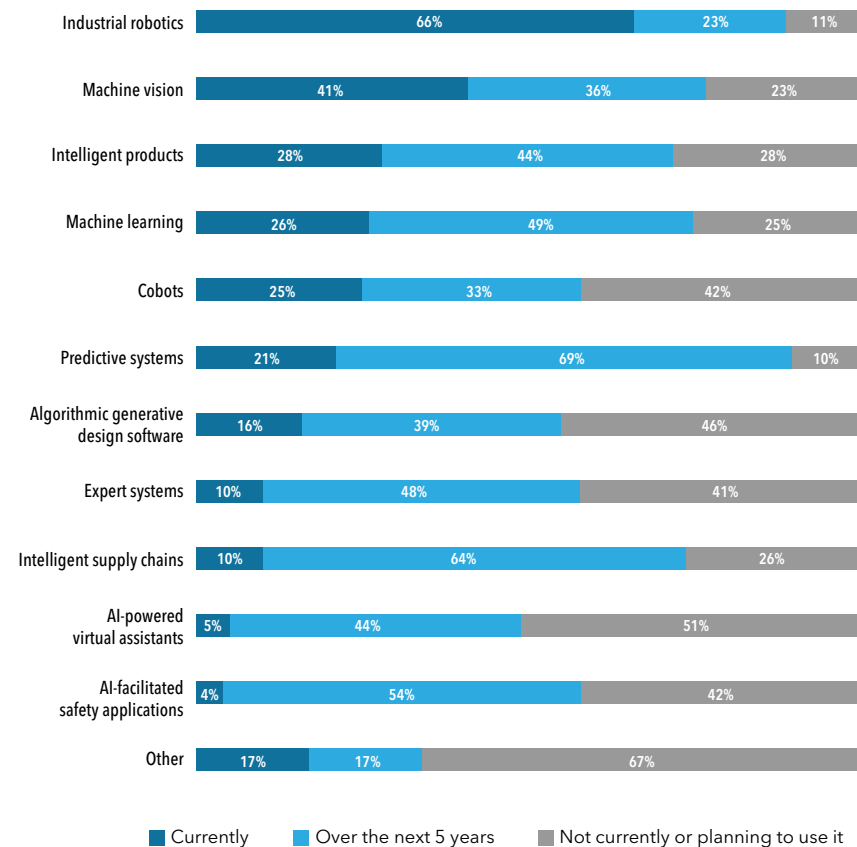
- Industrial robotics
- Machine vision
- Intelligent products
- Machine learning
- Cobots

However, over the next five years, respondents expect significant growth in their use of AI in predictive systems (growing to 90% penetration) and in their use of AI to manage intelligent supply chains, growing to almost three-fourths penetration, on par with their use of AI in machine learning, machine vision, and intelligent robotics. Here, survey and interview respondents also noted that they expect to see significantly increased use of robotic process automation (RPA) over the next five years.

RPA is the application of technology, governed by business logic and structured inputs, to automate (often back-office) business processes such as supporting warranty claims, executing customer service or support processes, and facilitating accounts receivable and payable transactions.⁴³ One company interviewed has completely automated how it processes invoices, using RPA to fully digitalize its entry and processing of invoices.

In our interviews, aside from RPA, the use of AI/machine-learning tools to facilitate predictive maintenance activities was the most common AI application encountered. Several companies also noted they were experimenting with AI-enabled chatbots to facilitate customer service interactions.

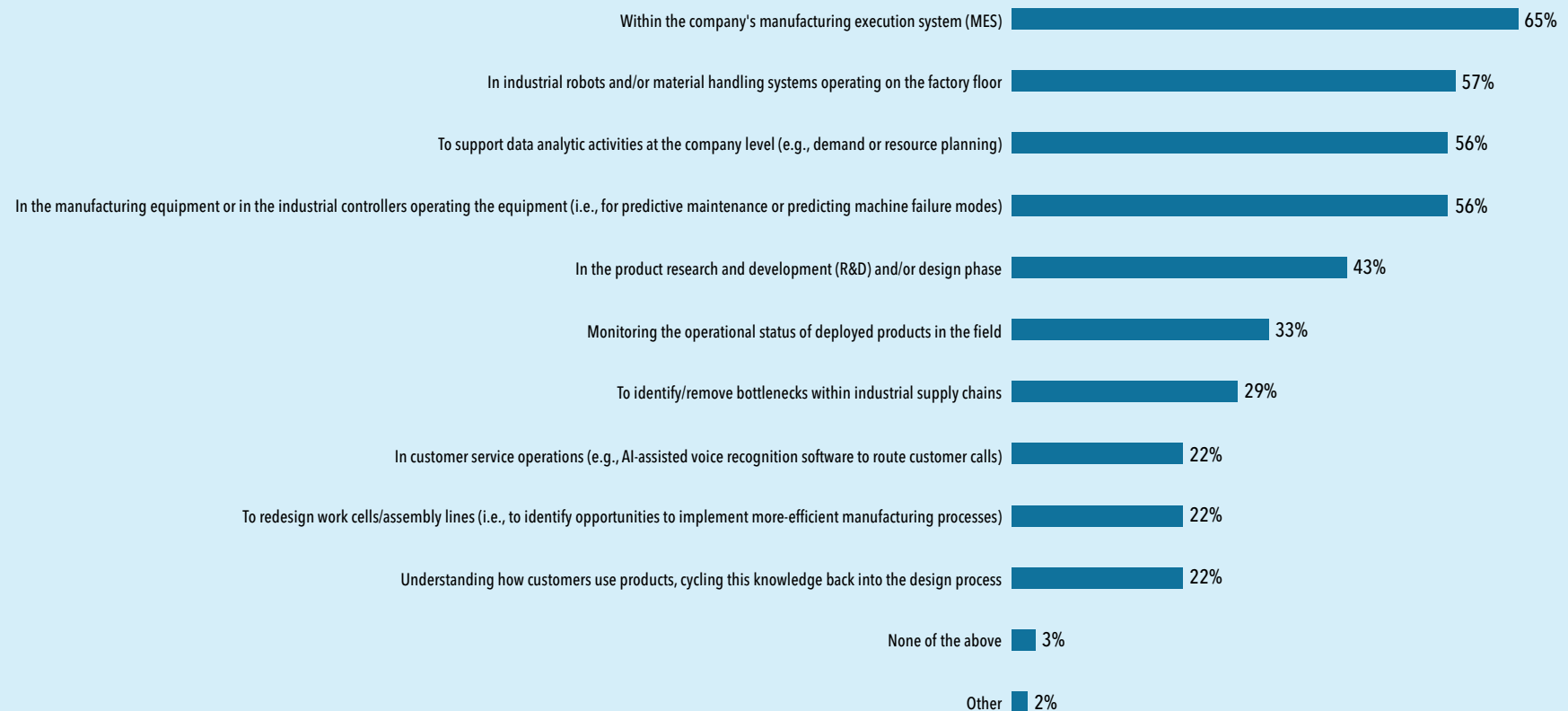
AI Deployment Levels Vary with Applications: Predictive Systems Expected To Overtake Robotics



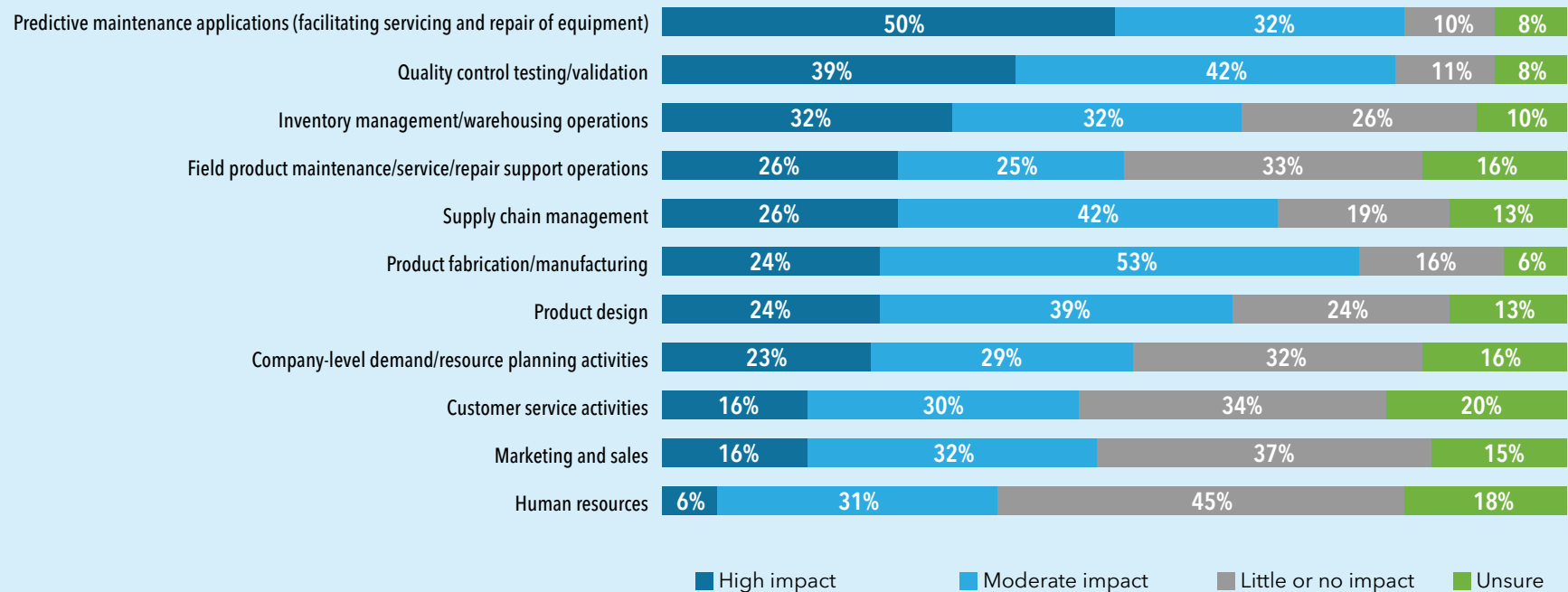
In terms of the specific operational domains in which survey respondents plan to deploy AI applications, the majority of respondents expect it to occur within production equipment or the software operating it on the factory floor. A smaller share, under one-quarter, currently intend to deploy AI applications in customer service operations, redesign work cells or assembly lines, or feed insights back into iterative product-development cycles.

Both smaller and larger manufacturers plan to deploy AI applications at similar rates with regard to manufacturing execution systems, industrial robots, manufacturing equipment, and research and development (R&D) activities. However, larger manufacturers are significantly more likely to use AI to address bottlenecks within industrial supply chains.

AI Applications Expected to Deploy Across Many Operational Domains



AI Impact Expected to Extend Across Key Business Processes



Predictive maintenance and quality control emerge as the top-two areas that stand to benefit the most from AI applications, with over 80% of respondents stating that AI will have a “moderate” to “high” impact on these processes over the next five years. This is followed by product fabrication/ manufacturing (77% expecting “moderate” to “high” impact over the next five years), supply chain management (68%), and inventory management/warehousing operations (64%). As one executive observed:

The advent of artificial intelligence means companies can't go to market the same way or try to compete the same way as before. You've got to create a different value proposition than

your competitors have. With predictive analytics, predictive maintenance, and telemetry, powered in some ways by machine learning, we've been able to change our business model to move from a flat fee to a per-use basis. As our product is a key input for final products made by customers in a wide variety of B2B and B2C industries, it means we've been able to align our interests with those of our customers: When they sell more, we do as well. Digitalization has enabled us to transform our go-to-market business model.

In other words, AI will have as large an impact on business models as business processes.

Preparing the Manufacturing Enterprise for the AI Future

Digitalization of manufacturing, including through the application of AI solutions, heralds significant changes for manufacturing enterprises. This includes how value is created for customers within the manufacturing enterprise, how manufacturers can distinguish and differentiate their products (and value-added services), where financial and human resources should be allocated to create value within firms, and, of course, how manufacturing workforces will be transformed and upskilled. **Innovation is a dynamic process that, by definition, necessitates change.** Accordingly, many companies that lead in innovation are also the best at change management.⁴⁴

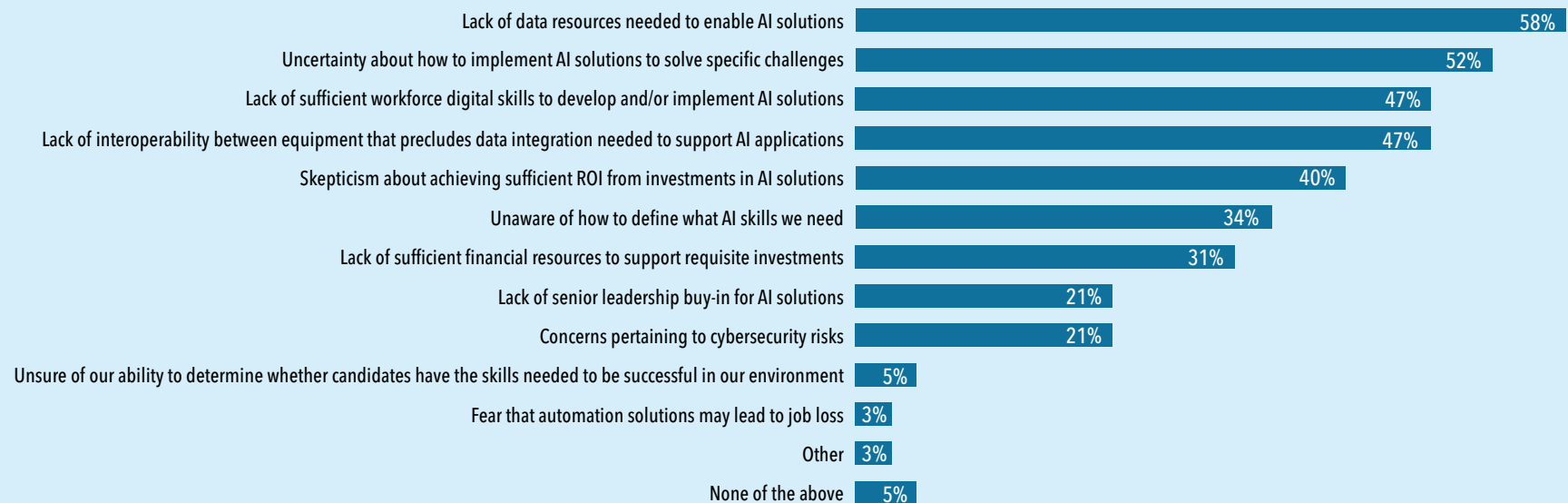
Thus, successfully navigating the coming AI revolution will require manufacturing enterprises to develop effective change management strategies, and to overcome key hurdles to AI adoption. The rewards are clear. For instance, one Keystone Strategy study (of companies with revenues over \$3 billion) found that organizations that take steps to embrace digital transformation generate an average of \$100 million more in operating income each year than those that lag behind.⁴⁵ Yet despite the fact that companies were expected to invest \$1.7 trillion in digital transformation technology initiatives in 2018, as many as 20% of executives “secretly believe” these digital transformation projects are a waste of time, in part due to challenges in changing their corporate culture or in adopting new ways of working.⁴⁶ Overcoming these types of challenges will be vital to realizing the promise of AI.

BY THE NUMBERS

MAPI survey respondents reported that the most significant barrier to deployment of AI solutions pertained to a lack of data resources (58% of respondents), while the third-biggest barrier concerned a lack of interoperability between equipment that precluded the data integration necessary to support AI applications (47%). The second-most-significant barrier was also technical in nature, in that respondents were unclear about how to implement AI solutions to solve specific manufacturing challenges (52%).

The skills gap also represents a significant barrier, with 47% of respondents indicating their companies’ workforces lack the digital skills needed to implement AI solutions; and 34% reporting they simply don’t know how to define the AI skills needed. Other concerns pertained to skepticism about achieving sufficient return on investment (ROI) from AI solutions (40% of respondents), a lack of financial resources to support requisite investments (31%), a lack of senior leadership buy-in (21%), and concerns about cybersecurity risks (21%). Significant barriers exist to AI adoption in manufacturing.

Top Barriers to AI Adoption Focus on Data, Know-How, and Talent



Responding companies addressed some of the change management practices they are developing in response to the coming era of AI transformation, considering both organizational and workforce aspects of change management. Forty-two percent of respondents have commissioned an internal team or working group tasked with researching, developing, and deploying AI solutions, while 37% have formally explored how AI applications can help their companies reimagine their existing business processes and operations. The survey indicates there is more to be done to reimagine the workforce skills composition in the AI era. Only 18% of respondents have comprehensively re-evaluated job roles, work titles, employment levels, and pay scales, recognizing the need to attract employees with AI skills. And only 8% of respondents have either developed internal retraining programs to upskill existing workers with needed AI and other digital skills or

developed a communications process to explain the implications of AI applications and solutions to employees, customers, and partners. Overall, more than twice as many smaller manufacturers than larger manufacturers reported not having implemented a workforce change management strategy (50% versus 23%), and were much less likely to have explored AI applications' ability to redesign existing business practices (11% versus 62%) or to have developed an internal team focused on AI (17% versus 54%).

Strikingly, 35% of respondents have yet to implement any form of change management strategy whatsoever. However, these numbers are not too dissimilar from what's seen elsewhere in corporate America, as a recent McKinsey study found that "only 8% of firms engage in core practices that support widespread AI adoption."⁴⁷

CASE STUDY: MICROSOFT

Change management is difficult, even for the largest of companies. However, research has yielded useful examples and best practices to facilitate transformation. For example, Microsoft isn't just a software developer; it's also a manufacturer, having manufactured and sold over 30 million Xboxes.⁴⁸ As Greg Shaw explains in *The Future Computed: AI & Manufacturing*, Microsoft's Xbox manufacturing centers are scattered throughout the world, and "the data from assembly lines [that saunters] into various databases and spreadsheets [is] often old and unactionable."⁴⁹ To address this challenge, Microsoft's leaders asked one specific question—how could they get smarter, faster—and set about that challenge by developing three clear strategic goals: get connected, become predictive, and grow to be cognitive.⁵⁰ Note that this technique directly mirrors the manufacturing digitalization transformation journey referenced previously.

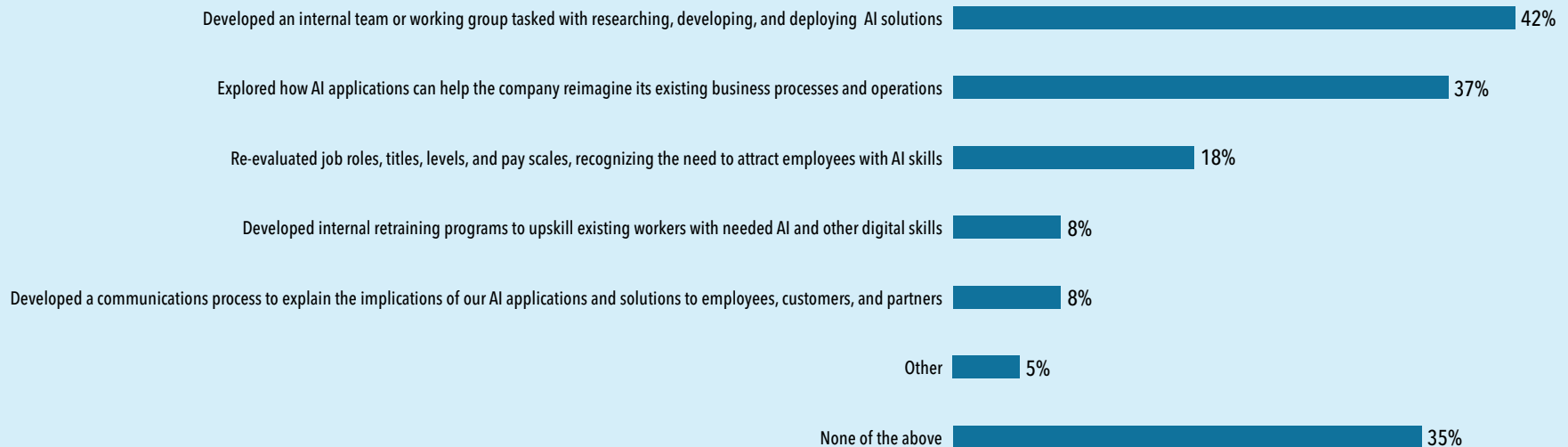
As Shaw wrote, Microsoft's first step was "to connect as many devices, instruments, tools, and people as possible," creating a data lake that represents "one single source of truth" about the state of the enterprise's manufacturing environment. Second, engineers built algorithms converting the massive amounts of data the connectivity enabled into predictive insights, using analytics to produce data visualizations and dashboards that ensured plant managers and supervisors alike were all seeing the same information at the same time. As Shaw explained, "The dashboards funnel all the telemetry data that's collected, such as cycle rate and the pressure of a particular press, into a model to detect shifts and drifts so they can respond before a part fails or a line has to shut down."⁵¹ Finally, Microsoft's engineers trained the model to become cognizant—that is, to think—of solutions that could augment human capabilities, and to rapidly transmit these insights to frontline workers.



The results have been impressive. Microsoft moved from being able to commit 40% of orders in five days to 95% of orders within 48 hours. Further, the company has since experienced a \$50 million reduction in errors and omissions year over year; saved another \$10 million in just one year due to scrap reduction, yield improvements, and process optimizations; and can now develop demand forecasts that are 15% more accurate. Moreover, Microsoft's experience with implementing AI solutions in its Xbox manufacturing operations gave rise to a suite of AI-powered tools Microsoft now sells as software to other manufacturers. But, through it all, change management processes proved essential. As project leaders Mark Klinkenberg and Darren Coil observed, "The culture will fail long before the technology does."

One of the greatest benefits has been a more engaged workforce from top to bottom. But the cultural change won't happen through a webinar or reading a manual. It must be a combination of top-down and bottom-up change. In our case, the corporate vice president in charge decided to lead by example [and that] executive role modeling was key.⁵²

Change Management Strategies for AI Transformation Already Underway



A good example of effective change management is ZF Group, a Germany-based auto parts manufacturer with plants near Detroit, Michigan, which has been a pioneer in developing data algorithms to detect and predict mechanical failures on the manufacturing line and to optimize energy consumption in manufacturing processes.⁵³ Like at BAE Systems and Honeywell, ZF's "XReality" is a combination of augmented and mixed reality in which wearable devices such as Microsoft's HoloLens helps workers identify machines and parts and access data, while also assisting workers and floor supervisors with solving problems. The advent of AI applications has significantly altered the skills and job performance requirements for ZF's employees. The company formed worker councils that manage the process

of establishing communications between frontline workers and management regarding the coming changes AI-based solutions will introduce to job roles and also what types of skills workers will need to develop in order to remain productive.⁵⁴

In summary, if companies are to optimize the potential of AI, the entire manufacturing sector must work together to embrace change, break down silos, and create seamless information supply chains within companies. Strong leadership, combined with engaging workers at all levels in the process, is also essential for success.⁵⁵ But perhaps the most important change management issue will be for companies (and societies) to transform their manufacturing workforce in anticipation of the coming AI era.

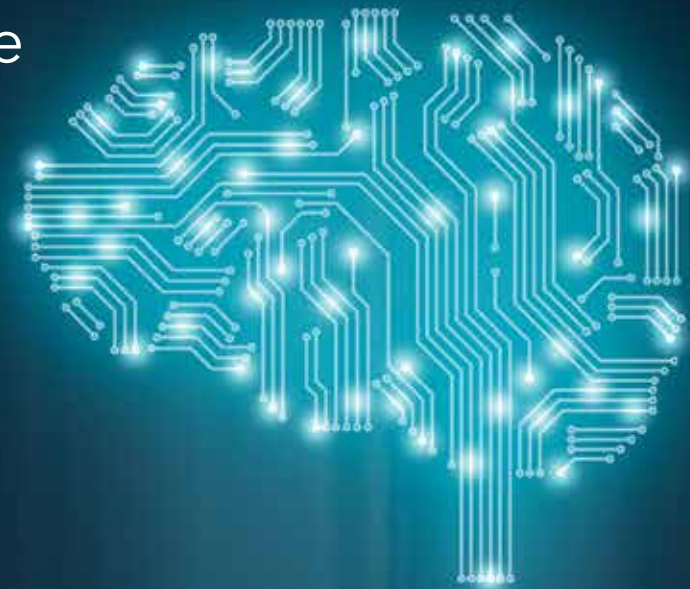
The Manufacturing Workforce in the Artificial Intelligence Era

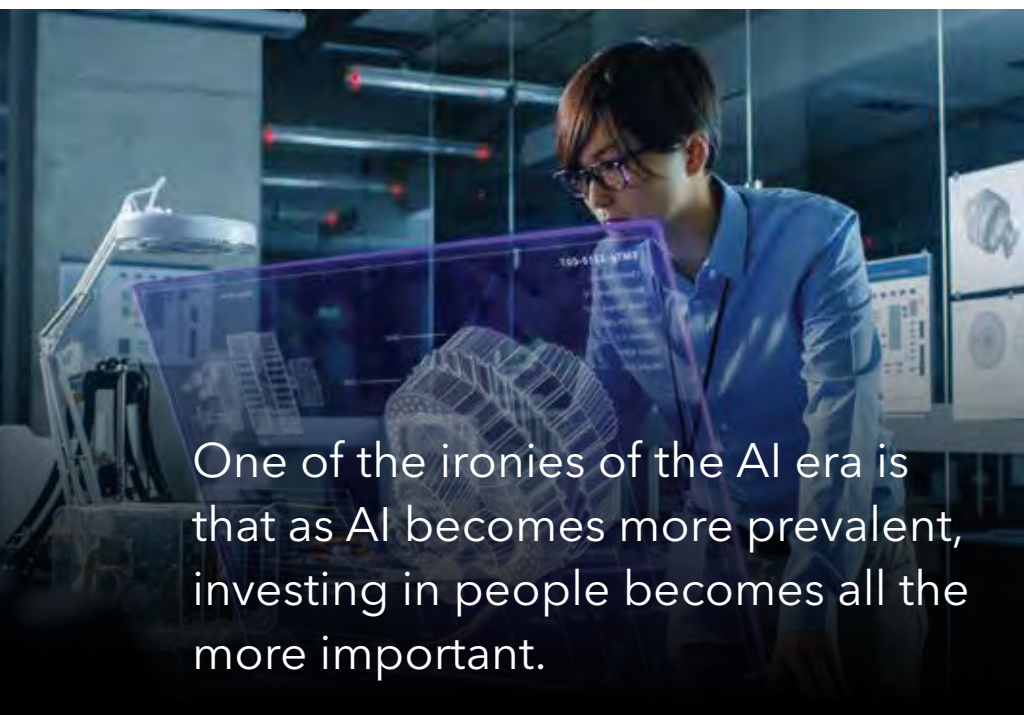
The following examines how manufacturing workforces will be transformed in the AI era, beginning with a broad overview of the transformation before examining the new types of jobs and roles that will be created, how manufacturers can acquire the requisite AI-skilled talent they will need, and what the aggregate impact of AI on manufacturing employment is likely to be.

AI AND THE FUTURE OF THE MANUFACTURING WORKFORCE

AI will benefit manufacturers and society, and will create an opportunity for workers to add new skills to bolster their potential to add value to manufacturing organizations. As research and interviews made clear, the companies that best ascertain how to empower their manufacturing workforces through AI applications will create the greatest value going forward.

Thus, the question isn't so much, "Will AI replace workers?" Rather, it's, "How can AI applications empower workforces?" Consider the field of medicine, wherein research finds that clinicians, radiologists, and pathologists are making better diagnoses and prescriptions when they work in concert with AI applications.⁵⁶ And so it will be in manufacturing. For instance, as Markus Schaefer, head of production planning at Mercedes-Benz, observed, "We're moving away from trying to maximize automation, with people taking a bigger part in industrial processes again." As Schaefer explained, "When we have people and machines cooperating, such as a person guiding a part-automatic robot, we're much more flexible and can produce many products on one production line. The variety is too much for the machines to take on."⁵⁷





One of the ironies of the AI era is that as AI becomes more prevalent, investing in people becomes all the more important.

Similarly, as author Will Knight writes, “BMW determined that human-robot interactions in the automotive factory are about 85% more productive than either humans or robots working on their own.”⁵⁸ As Paul Daugherty and James Wilson write in *Human + Machine: Reimagining Work in the Age of AI*, “AI systems are not wholesale replacing workers; rather, they are amplifying our skills and collaborating with us to achieve productivity gains that have previously not been possible.”⁵⁹ The future belongs to manufacturers that ascertain ways to leverage technologies such as AI to empower their workforces.

Thus, one of the ironies of the AI era is that as AI becomes more prevalent, investing in people becomes all the more important. Yet there is a disconnect here. For instance, even though almost half of

business leaders surveyed identified digital skills shortages as a key workforce challenge in a recent Accenture study, only 3% reported their organizations had plans to significantly increase investment in training programs over the next three years.⁶⁰ **Perhaps one of the challenges here is that employees are actually more ready for the AI transformation than their employers think they are.** In the same study, only one-quarter of executives believe their workforce is ready for AI adoption. However, 68% of highly skilled workers and nearly half of the lower-skilled workers were enthusiastic about AI’s potential impact on their work, while 67% of workers considered it important to develop their own skills to work with intelligent machines.

Moreover, a separate Accenture survey done in conjunction with World Economic Forum found that while nearly all (92%) workers believe the next generation of workplace skills will be radically different from the prior one, 87% believe that, within the next five years, new technologies such as AI will improve their work experience.⁶¹

In other words, there’s evidence that America’s workforce, including in manufacturing, is ready to be led on a value-adding, AI-driven transformation journey—which would be fortuitous, as it would coincide with a generational shift in America’s workforce, especially in manufacturing. More than one-quarter of U.S. manufacturing workers are over the age of 55 today, yet baby boomers are retiring from all sectors at a rate of 10,000 a day in the United States, taking their institutional and technical knowledge with them into retirement.⁶² At the same time, it’s estimated that a manufacturing skills gap may result in as many as 2.4 million U.S. manufacturing jobs going unfilled between 2018 and 2028, at a potential economic impact of \$2.5 trillion to the U.S. economy.⁶³ Amid these changes, many manufacturers “worry that millennials will not be attracted to manufacturing” or that they will “see manufacturing

as something they don't want to do for a career.”⁶⁴ As Microsoft's Çağlayan Arkan argued in “The Workforce of the Future: Insights around disruption, transformation, and the role of AI,” the way to circle this square is for manufacturers to “lure in tech-savvy talent to harness new and disruptive manufacturing technologies. Companies should look for a new generation of employees that possess the hybrid skills and comfort with innovation to adopt new technologies and those not yet invented.”⁶⁵ This suggests that the manufacturing workforce of the future will be younger, more creative and solution-oriented, and skilled and empowered to leverage technology, including AI, to create new forms of value for their organizations.

The chief technology officer of an automation systems developer described how AI will change the responsibilities of frontline workers and require them to become much more solutions oriented:

*The implementation of AI and some of the newer digital technologies is changing how the workforce in a factory interacts with machines. If they are used to pushing buttons and calling maintenance people when the machine fails, that's yesterday. Tomorrow they're going to have to be more focused on information coming in from AI systems that they will have to interpret. They will need to have the ability to dig deeper, to double click on information, to look at root causes and be able to extrapolate from root causes to keep machines running longer and more productively. The future is going to be a handheld device like a phone or iPad where one has information about the machine, performance parameters, and also comparisons to the overall operating efficiency of one's machine compared to other machines, so one can compare performance and use AI methods to find out what's going wrong and then fix it. Front-line workers are going to have to be comfortable with using these types of digital tools.*⁶⁶

WHAT DOES THIS MEAN FOR MANUFACTURING JOBS?

The digitalization of manufacturing will have a significant impact on the skills manufacturing workers will need in the future. For instance, according to the Brookings Institution report “Digitalization and the American Workforce,” while only half of U.S. manufacturing jobs required a “medium- to high-digital skill level” in 2002, that percentage has jumped to 82% today.⁶⁷ The advent of digital manufacturing has introduced not just new skill requirements and responsibilities, but even entirely new types of jobs. For instance, “[The Digital Workforce Succession in Manufacturing](#)” recently identified 165 completely new job roles pertinent to digital manufacturing and design.⁶⁸

Likewise, quite a large number of new-to-the-world AI-driven jobs have emerged in the manufacturing environment. These include roles such as:

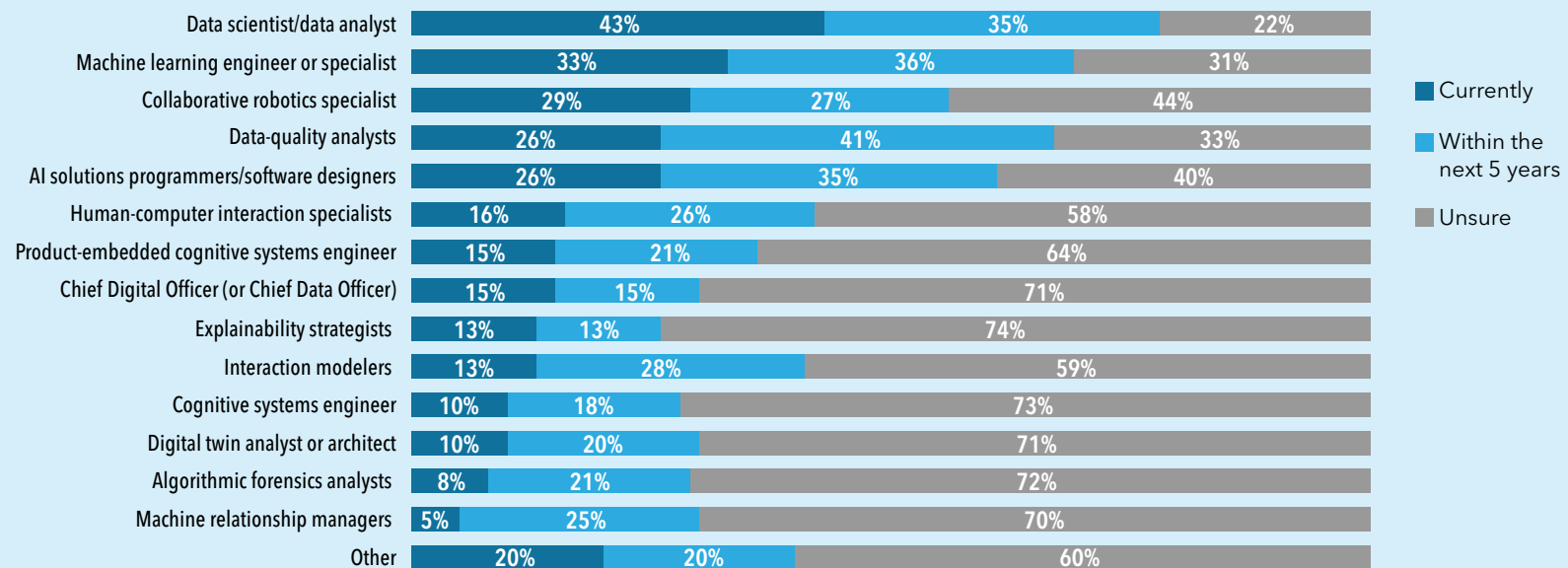
- Data scientist/data analyst
- AI applications developer
- AI applications engineer
- Cognitive systems engineer
- Machine-learning engineer or specialist
- Collaborative robotics specialist
- Digital twin analyst or architect
- Data-quality analyst
- Interaction modeler
- Algorithmic forensics analyst
- Human-computer interaction specialist
- Explainability strategist⁶⁹

The most common emerging AI-related job title that surveyed companies have introduced is data scientists/data quality analysts, with 43% of companies having already introduced it in their organizations, and 35% more expecting to do so within the next five years. This was followed by machine-learning engineers or specialists (33% today, almost 70% in total within five years), collaborative robotics specialists (29% today and another 27% within five years), and a tie for fifth between data-quality analysts and AI solutions programmers/software designers (with 26% of firms already having created such jobs and at least a total of two-fifths expecting to have done so within five years).

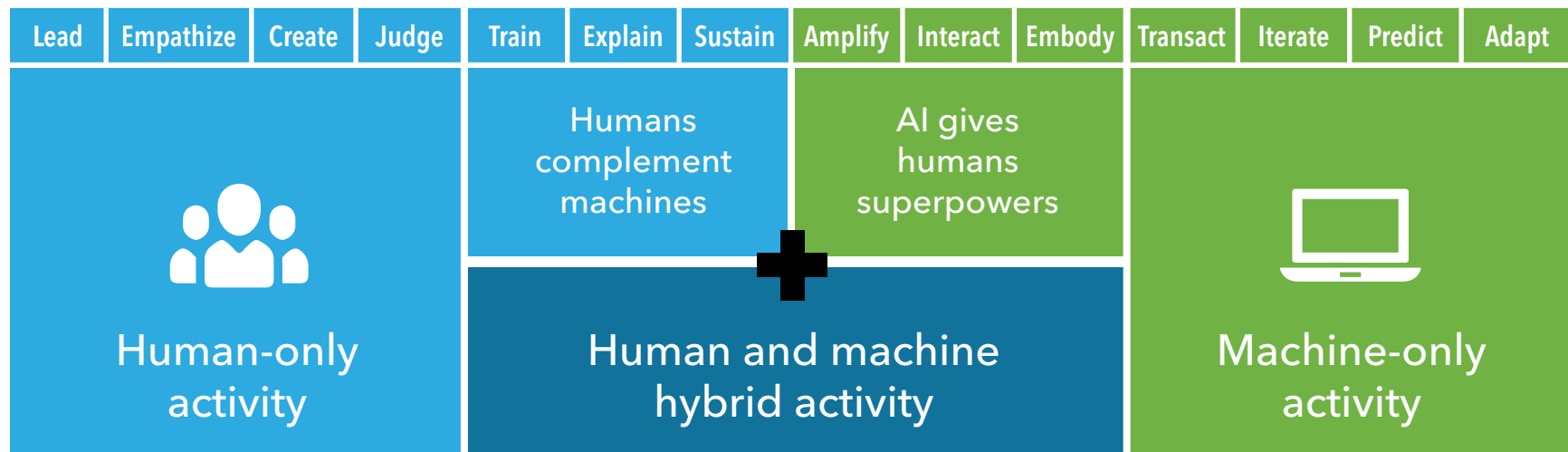
Daugherty and Wilson identified a set of roles wherein human capacity will remain supreme (tasks such as leading, empathizing, creating, and judging) and a set of tasks wherein machines

are likely to outperform humans (such as transacting, iterating, predicting, and adapting). Yet in the middle lie a set of tasks where humans will enable machines—in functions like training, explaining, and sustaining—and ones where “AI will give humans superpowers,” thus augmenting human capabilities—in functions like amplifying, interacting, and embodying.⁷⁰ It’s in this “missing middle,” as Daugherty and Wilson contend, wherein humans and machines complement and extend the potential of one another—and give businesses significant potential to reimagine their existing work processes “to take advantage of collaborative teams of humans working alongside machines.”⁷¹ As they argue, “The simple truth is that companies can achieve the largest boosts in performance when humans and machines work together as allies, not adversaries, in order to take advantage of each other’s complementary strengths.”⁷²

AI Spurs Introduction of Multiple AI-Related Job Titles



Roles of Humans and Machines in the AI Era⁷³



Graphic based on diagram from Daugherty and Wilson, *Human + Machine: Reimagining Work in the Age of AI*

Of particular importance are new roles AI will give rise to for individuals who will act as “trainers, explainers, and sustainers.”⁷⁴ In other words, people will be needed to train machines to perform tasks, explain the machine outcomes, and maintain the machines in a responsible manner.⁷⁵

Trainers

Trainers are individuals who will teach AI-based systems how to perform certain tasks—or even how to act more human. For example, new flexible robotic systems working alongside people will need to be programmed for and trained to handle different tasks. Similarly, AI software, such as customer service chatbots, will need to be trained to detect the complexities and subtleties of human communications or to help natural-language processors and

language translators make fewer errors. Specific types of training jobs that will be created include:

- **Empathy trainers**—individuals who teach AI systems to display compassion
- **Personality trainers**—individuals who teach AI systems to behave in a more human-like way
- **Worldview and localization trainers**—individuals who teach AI systems such as chatbots about local tastes or idioms and global differences (i.e., so AI systems can adopt to regional differences)
- **Interaction modelers**—individuals who help train the behavior of machines by using expert employees as role modelers⁷⁶

In AI systems, trainers will perform tasks such as cleaning and preparing data for uploading, discovering relevant data and datasets, training machines on human decision-making behaviors, and working with human resource departments to inform the design of workplace retraining initiatives. Trainers will also assist AI systems in developing “humanness attributes,” including by training them on aspects of language, gestures, and empathy; defining and developing personalities; and refining machines’ performance by correcting errors and reinforcing successes.⁷⁷

Explainers

“Explainers” refers to a new category of AI-inspired jobs that will help bridge the gap between technologists and business executives, helping executives understand algorithms and how AI-based systems make decisions. Explainers will interpret the results of algorithms to improve transparency and accountability for their decisions, helping to strengthen the confidence of both customers and workers in AI-powered processes. Specific roles for explainers will include:

- **Algorithmic forensics analysts**—individuals responsible for holding algorithms accountable for their results
- **Transparency analysts**—individuals responsible for “classifying the reasons a particular AI algorithm acts as a black box” (in other words, recording why and how AI-based algorithms make specific decisions in specific cases)
- **Explainability strategists**—individuals who ascertain which AI technologies are best deployed for certain applications and circumstances, and who manage trade-offs between accuracy and explainability⁷⁸

Specific tasks for explainers include algorithmic testing and editing and interpreting their output (i.e., such as by explaining to stakeholders how AI systems work).⁷⁹

Sustainers

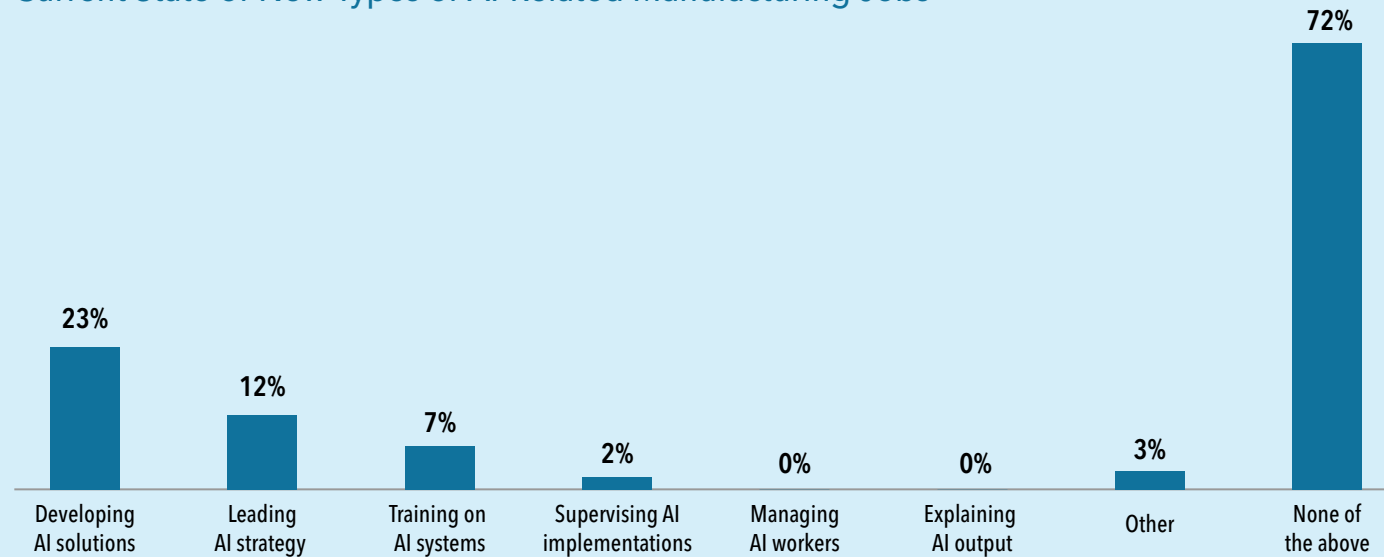
Finally, AI will give rise to a set of sustainer roles, individuals who work to ensure AI systems are functioning properly. Sustainers will ensure intelligent systems stay true to their original goals without crossing ethical lines or reinforcing biases.⁸⁰ Sustainer roles will include:

- **Context designers**—individuals who take into account a variety of contextual factors in the design of AI systems, such as the business environment, cultural issues, internal processes, and the interests of individual users
- **AI safety engineers**—individuals who anticipate possible unintended consequences or actions of AI systems and then instantly remedy them
- **Ethics compliance managers**—individuals who monitor AI systems to ensure they uphold generally accepted norms of human values and morals⁸¹

Tasks for sustainers will include functions such as applying critical evaluation to AI performance and reviewing output quality; identifying opportunities to improve algorithms and the performance of AI-based systems; and setting limits on or overriding the output of AI systems in the event they contravene legal or ethical standards.⁸²

Conversely, there will be a set of jobs created or empowered by the capabilities AI systems will endow humans with. For instance, machines can amplify human insight and intuition by leveraging data and analytics, enabling them to generate powerful, real-time data-driven insights. AI systems will facilitate interaction, such as AI-based systems capable of immediate language translation or natural language processing to facilitate customer service activities. Finally, “embodiment” refers to the application of AI in physical spaces in order to augment human capabilities, such as cobots on the factory floor, wherein the robot becomes an extension of workers’ bodies, thereby extending their capabilities.⁸³

Current State of New Types of AI-Related Manufacturing Jobs



The MAPI survey asked about these new types of AI-driven jobs and roles companies expect to create going forward. Twenty-three percent of respondents anticipate introducing roles related to the development of AI solutions, 12% to leading AI strategies, and 7% to supervising AI implementations. However, showing how nascent AI remains for many manufacturing enterprises, 72% of companies reported they have yet to introduce such new types of AI jobs into the organizations.

The AI era will give rise not just to entirely new jobs but also to entirely new forms of “fusion skills” that build on the combination of human and machine talents within a business process to create outcomes that are superior to either of the two working independently.⁸⁴

In Daugherty and Wilson’s formulation, the first three fusion skills relate to training, explaining, and sustaining activities:

- **Rehumanizing time** refers to the ability to increase the time available for distinctly human tasks such as interpersonal interactions, creativity, and decision-making to create a reimagined business process. Rehumanizing time suggests freeing humans from menial tasks, permitting them to engage in higher-value-added activities, such as performing more complex machine repairs, conducting blue-sky research, and increasing customer satisfaction.
- **Responsible normalizing** refers to responsibly reshaping the purpose and perception of human-machine interaction as it relates to individuals, businesses, and society; for instance, managing the task of responsibly integrating AI-based systems such as autonomous vehicles into society.
- **Judgment integration** refers to the judgment-based ability to determine a course of action when a machine is uncertain about how to proceed.

"Fusion Skills" Reflect Human and Machine Hybrid Activities⁸⁵

Human and machine hybrid activities					
Humans complement machines			AI gives humans superpowers		
TRAIN	EXPLAIN	SUSTAIN	AMPLIFY	INTERACT	EMBODY
Rehumanizing time			Intelligent interrogation		
Responsible normalizing			Bot-based empowerment		
Judgement integration			Holistic melding		
Reciprocal apprenticing					
Relentless reimagining					

Graphic based on diagram from Daugherty and Wilson, *Human + Machine: Reimagining Work in the Age of AI*

Three of the fusion skills pertain to AI giving people new powers:

- **Intelligent interrogation** refers to knowing how best to ask questions of AI systems across levels of abstraction in order to extract insights; it also includes knowing when the output of an AI-based system doesn't make sense or when certain data inputs might be skewing results.
- **Bot-based empowerment** refers to collaborating with AI systems to extend capabilities, whether by using automated scheduling agents such as those produced by Clara Labs, or having demand planning forecasts facilitated by AI.
- **Holistic melding** refers to the development of robust mental models of how AI agents can improve process outcomes; in other words, it refers to the ability to reimagine a company's existing business processes with knowledge of how AI-based systems work, learn, and interact with workers.

Finally, two fusion skills cover the entire spectrum of tasks within the "missing middle."

- **Reciprocal apprenticeship** refers to performing tasks alongside AI agents so they can learn new skills, as well as to on-the-job training for people so they can work well within AI-enhanced processes. Essentially, it refers to an iterative, cyclical process in which machines learn from humans, and humans, in turn, learn again from machines.
- **Relentless reimagining** refers to a discipline of creating new business models from scratch, rather than simply automating old processes. As such, it represents "a fundamental skill that lays the foundation for other fusion skills like intelligent interrogation or bot-based empowerment."⁸⁶

Essentially, these fusion skills refer to an individual's (or an enterprise's) ability to combine the relative strengths of a human and a machine together to create better outcomes than either could achieve alone.

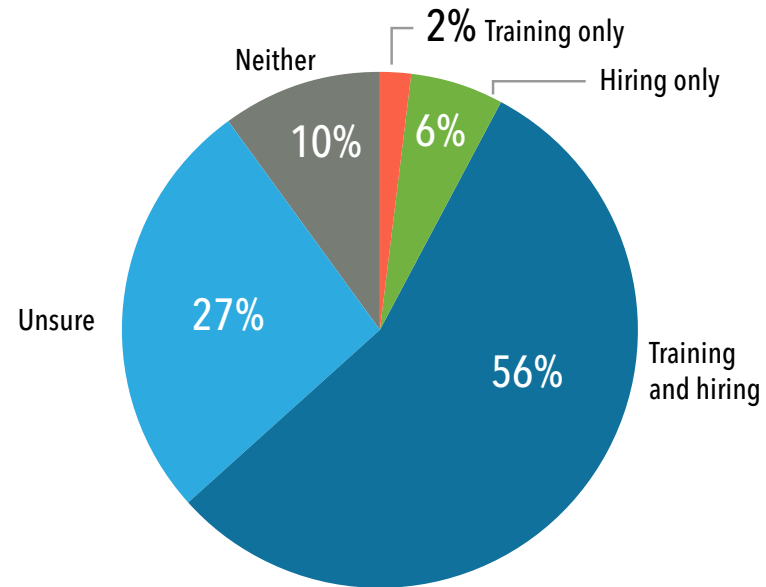
DEVELOPING AND ACQUIRING AI TALENT

Manufacturers recognize the need to get individuals with the requisite AI skills into their organizations. In fact, according to the [LinkedIn AI Skills Penetration Index](#), manufacturing is now the fifth-most AI-skill-intensive industry. That report also found that AI skills are among the fastest-growing on LinkedIn, experiencing a 190% increase from 2015 to 2017.⁸⁷ Yet, as Rockwell Automation's Director of Advanced Technology David Vasko observes, the challenge is that, "There's a lack of AI-related skills in the marketplace; demand for data and AI skills will continue to outstrip supply."⁸⁸ Indeed, Deloitte found that the leading cause of America's manufacturing skills shortage is "shifting skill set due to the introduction of new advanced technology and automation."⁸⁹

Our survey found that 56% of respondents expect to pursue a combination of both retraining and hiring employees with the needed AI and data science skills over the next five years, while 6% expect to pursue new hires only and 2% to only retrain existing workers. Twenty-seven percent of respondents reported their organizations were unsure about how to source needed AI talent.

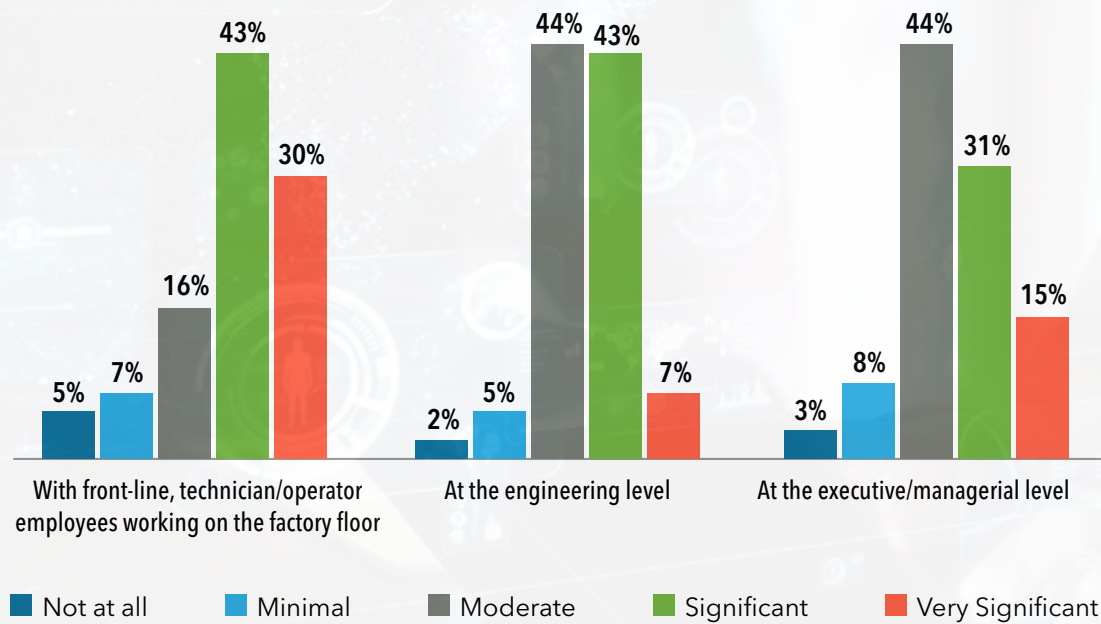
Respondents acknowledged an AI skills gap at virtually every level of their organizations. Almost 75% reported facing "very significant" (30%) or "significant" (43%) gaps with frontline, technician, or operator employees working on the factory floor. At the engineering and solutions-development level, the gap was not perceived as quite so acute. Nevertheless, over two-thirds of respondents perceived a "moderate" (44%) to "significant" gap (43%). Interestingly, almost half of respondents felt there were "very significant" (31%) to "significant" (15%) gaps at the executive level, suggesting there may be an executive-level gap in understanding the potential and impact of AI applications. That's concerning, for one of the leading causes of failure of companies' AI initiatives is "the lack of a foundational understanding of AI among senior executives."⁹⁰

Companies Pursuing a Mix of Hiring and Training to Source AI Talent



For frontline operational workers, there are several facets to the AI skills gap. But the most significant one pertains to a lack of data literacy. While respondents feel their frontline workers possess the basic necessary computer and math skills, 57% believe there are gaps in employees' ability to understand statistical output and analysis, and 49% perceive gaps in employees' ability to work with applied mathematical concepts, such as algorithms. Interestingly, almost half of respondents identified distrust with the analysis or recommendations arising from AI-driven systems as a challenge, suggesting frontline workers harbor skepticism of AI systems, and significant cultural challenges persist in this regard. (It's possible this distrust was actually a reflection of distrust of managers or of what managers might do to workers' jobs based on the capabilities of AI-based systems). But that actually gets back to the fusion skills

Skill Gaps Appear Across All Levels of the Manufacturing Workforce



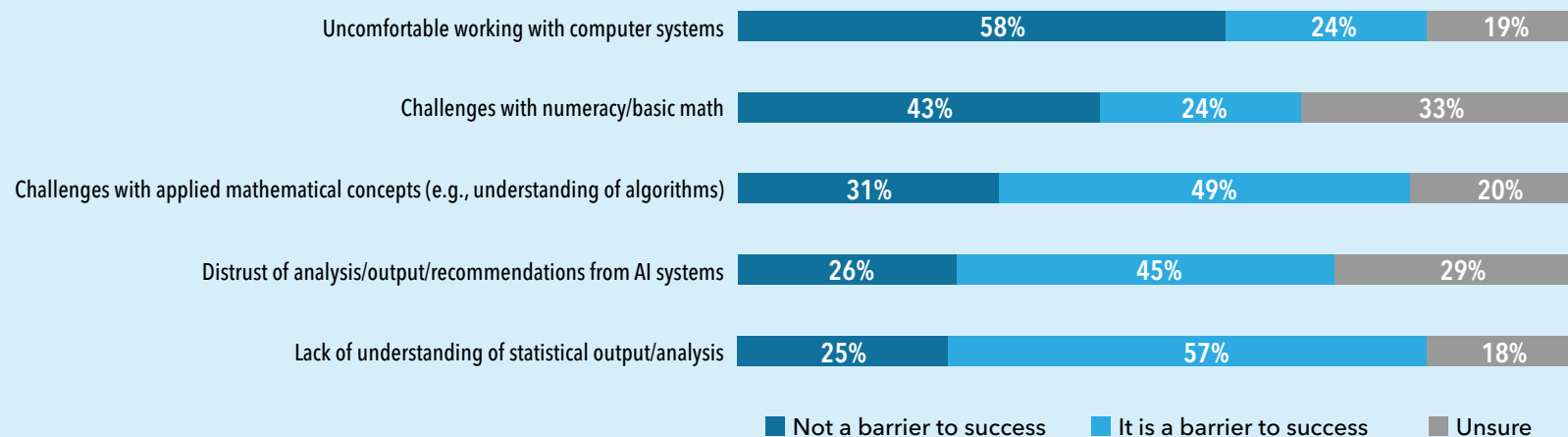
discussed earlier, particularly the need for workers who can engage in *relentless reimagining* to visualize how they can work in tandem with AI-based systems to augment their own capabilities and produce new forms of value for their organizations.

The survey data makes clear that manufacturers believe a significant AI skills gap persists, raising the related questions of what the biggest barriers to acquiring workers with the needed AI skills are, and what strategies will prove best in order to close the AI skills gap. Thirty-eight percent of respondents believe the largest barrier arises from an insufficient number of graduates possessing the needed AI knowledge and skills, closely followed by difficulty in attracting skilled candidates due to reputational issues (i.e., the attractiveness of working in manufacturing) (36%), and by a perceived lack of mechanisms to retrain existing workers with the requisite AI skills (35%). Other notable challenges identified include difficulty in attracting workers due to remote geography, the

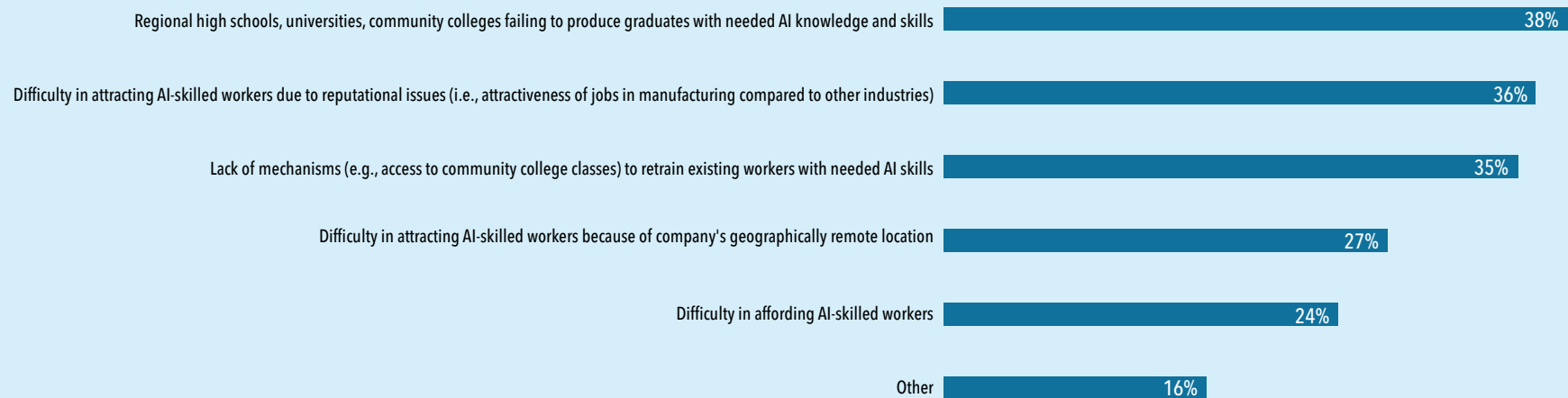
increased cost of hiring workers that are AI-skilled, and competing firms regularly “poaching” other firms’ AI-skilled workers.

To address these challenges, manufacturers have pursued a number of strategies to promote the development of AI-skilled workers. Thirty-seven percent of respondents have looked to build relationships with local academic institutions (including high schools, community colleges, and universities), 22% have turned to massively open online courses (MOOCs) and other forms of online education, and 20% have developed internal training courses. Only 10% of respondents reported working with their local Manufacturing Extension Partnership (MEP) partner to implement digital or AI-based solutions. This appears to represent a potential missed opportunity, though it’s not surprising. One study found that only two in ten manufacturers actively partner with government, and just three in ten partner with private institutes in training their workforce.⁹¹ However, reflecting how early the application of AI is

Discomfort with Computer Systems Tops List of AI Skills Gap of Frontline Workers



Significant Barriers Remain to Recruit Employees with Requisite AI Skills

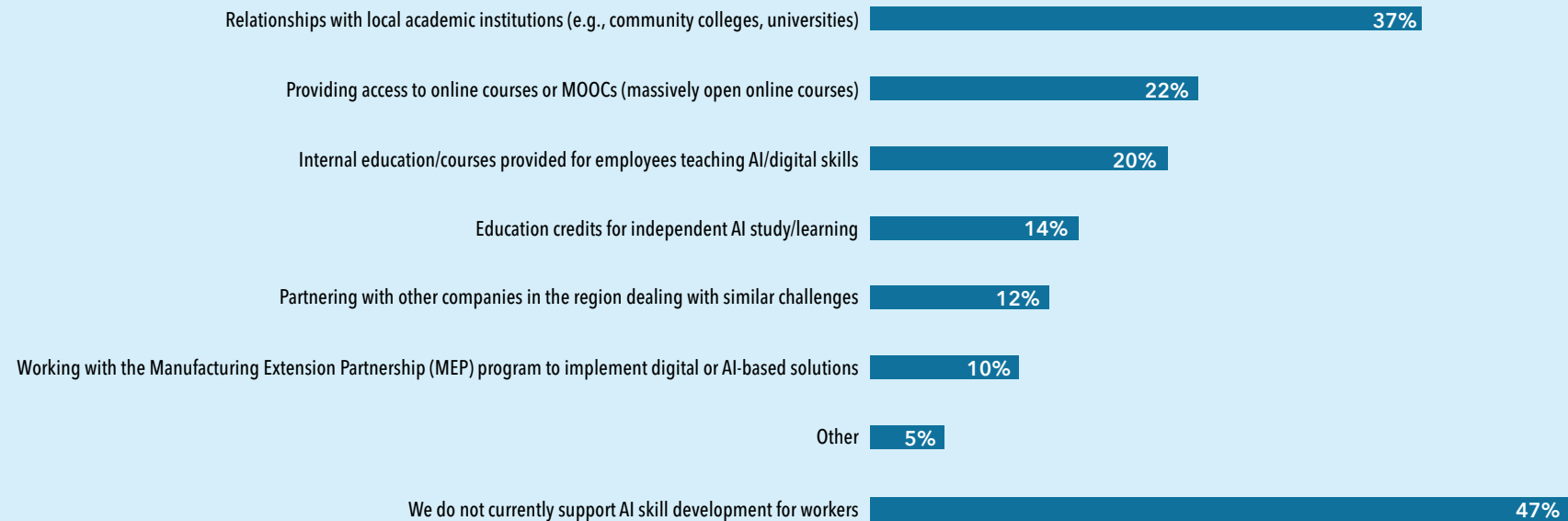


for many manufacturers, almost half (47%) of respondents reported that they are “not currently supporting AI skills development for their workers.”

While an AI skills gap certainly exists, channels are emerging to help close that gap. For instance, Microsoft has created the [Microsoft Professional Program](#), which offers certifications in data science, AI, AI applications development, and data-analyst roles. These certifications help individuals gain technical, job-ready skills and accrue real-world experience through online courses, hands-on labs, and expert instruction.⁹² Similarly, Microsoft has also created the [AI Business School](#), an online masters-level curriculum that educates executives on how to lead their organizations on an “AI transformation journey.”⁹³ Similar AI education courses for executives are available from a number

of leading U.S. universities, including [Georgetown](#), [MIT](#) and [Stanford](#).⁹⁴ Another source for relevant online education is [Tooling U-SME](#), a web-based, cloud-delivered, massively open online university that offers over 500 online classes related to manufacturing technology, including for AI-related skills, breaking down the training into 9 functional areas and 60 competency models to identify gaps, define requirements, and provide specific guidance for individuals’ AI skills development.⁹⁵ Another online learning platform, [Coursera](#), also offers a number of AI-related courses. Several companies have launched their own internal AI academies, which typically incorporate classroom work (online or in-person), workshops, on-the-job training, and site visits to experienced industry peers. Most companies that have established “internal AI academies” offer four broad types of instruction focused on leadership, analytics, translators, and end users.⁹⁶

Partnerships With Local Institutions Create a Path Forward for Developing AI-Skilled Workforces



But if the United States is to close its AI skills gap, industry and government will have to do more to work with academia to ensure the latter is graduating students with in-demand skills. For instance, the [Harrisburg University of Science and Technology](#) is a new, private university focused on responding to the needs of employers in the region and for producing graduates educated and trained in applied science and technology-related fields.⁹⁷ Another example is the [Olin College of Engineering](#), which has reimagined engineering education and curriculum to prepare students “to become exemplary engineering innovators who recognize needs, design solutions, and engage in creative enterprises for the good of the world.” Olin’s results have been impressive. Its new method of teaching engineering has been widely praised among engineering firms, and on a per-student-graduated basis, Olin graduates start

more new businesses than even MIT graduates.⁹⁸ Olin represents a compelling model for how the United States can transform its colleges into entrepreneurial factories while encouraging the development of completely new schools based on the needs of the current workforce.⁹⁹ These types of solutions are needed, especially when just one in four Americans are confident that the country’s higher education system is doing enough to address the need for career-long learning and retraining in the AI era.¹⁰⁰

Other nations are experimenting with similar solutions. Italy’s high-value-added SME manufacturing clusters leverage relationships with community and polytechnical colleges to collaboratively research technical hurdles and train workforces with relevant skills.¹⁰¹ [Canada’s Polytechnics System](#) features publicly funded



“There’s a lack of AI-related skills in the marketplace; demand for data and AI skills will continue to outstrip supply.”

– David Vasko, Director of Advanced Technology, Rockwell Automation

colleges and institutes of technology that offer four-year degrees, advanced two-year diplomas, certificates, and in-class training for apprenticeships.¹⁰² Singapore offers an interesting **AI apprenticeship program** that includes two months of supervised AI coursework, seven months of on-the-job training on a real-world AI problem, and a monthly stipend of SGD 3,500 to SGD 5,500.¹⁰³ For its part, Finland has launched a national strategy to train 1% of its workforce (55,000 employees) in the basic concepts at the root of artificial technology through a university-level course, codeveloped by industry and academia, which teaches “**The Elements of AI.**”¹⁰⁴ The class—now required for all employees at such Finnish companies as Elisa and Nokia—introduces the basics of AI, not teaching individuals to code, but seeking to raise awareness of the opportunities and challenges of AI among individuals who are strangers to computer science.

One reason ensuring sufficient access to AI-skilled talent in the United States matters is that the lack of qualified graduates is

driving up costs for companies to acquire workers with the data skills necessary to make AI solutions a reality. One company interviewed told the story of hiring an undergraduate data scientist out of Carnegie Mellon University and finding that the starting salary rate was \$150,000, which only senior executives were making at the time. But the company understood the value added the individual could provide—and recognized that the value-added services wrapped around products were increasingly a key source of value creation for the firm—and so managers went to the human resources department and received hiring approval. The story was actually an example of how AI and the digitalization of manufacturing has compelled manufacturers to reassess the source of value creation in their companies and to adjust compensation packages, incentive programs, career and promotion pathways, and human resources activities in light of this. Nevertheless, deep shortages of talent mean bidding wars for the scarce talent that does exist, which results in many companies simply not being able to afford to hire the talent they need.

AI'S IMPACT ON EMPLOYMENT

The employment impact of AI in particular, and automation technologies in general, has been much debated. Some believe the advent of AI heralds a technological dystopia of mass unemployment. Moshe Vardi, a professor at Rice University, predicts the AI revolution will cause global unemployment to reach 50%.¹⁰⁵ Stuart Elliott, in a paper for the National Research Council, extrapolated Moore's Law and argues that in 23 years computers are likely to displace 60% of jobs.¹⁰⁶ In the *Rise of the Robots: Technology and the Threat of a Jobless Future*, Martin Ford counsels policymakers to expect unemployment rates approaching 75% in Western societies

by the year 2100.¹⁰⁷ Likewise, MIT professors Erik Brynjolfsson and Andrew McAfee in their book *The Race Against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*, write that workers are "losing the race against the machine, a fact reflected in today's employment statistics."¹⁰⁸

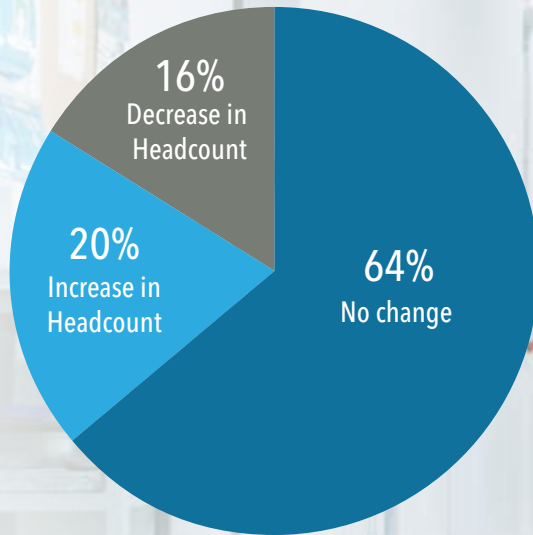
There are many reasons these dire predictions are misguided, but the most significant is that they fall prey to what economists call the "lump of labor fallacy"—the notion that there are only a fixed number of jobs to do in an economy and that if a person is replaced by a machine, that job is lost irrevocably.

"Historically, the income-generating effects of new technologies have proved more powerful than the labor-displacing effects: technological progress has been accompanied not only by higher output and productivity, but also by higher overall employment."

– *Technology, Productivity and Job Creation: Best Policy Practices*



Employee Headcount Unlikely to Change with Advent of AI



Moreover, such predictions miss the second-order effect from productivity growth: creating new demand that in turn creates new jobs.¹⁰⁹ That is why virtually all academic studies on the topic have found that productivity increases do not decrease the number of people working or raise the unemployment rate. As a definitive report from the Organization for Economic Cooperation and Development found, “Historically, the income-generating effects of new technologies have proved more powerful than the labor-displacing effects: technological progress has been accompanied not only by higher output and productivity, but also by higher overall employment.”¹¹⁰

Another critical point is that AI and machine-learning applications don’t affect the occupation as much as they affect the tasks performed in an occupation. For instance, one study found that, by 2022, machines and algorithms will contribute 42% of total task hours, compared with 29% in 2018 (across all industries).¹¹¹ But as the McKinsey Global Institute concludes, “Very few occupations will be automated in their entirety in the near or medium term. Rather, certain activities are more likely to be automated, requiring entire business processes to be transformed, and jobs performed by people to be redefined.”¹¹² In other words, AI will lead much more to job redefinitions and opportunities to add more value, not to outright job destruction.

This explains why one study found that, while 46% of traditional job descriptions will become obsolete as machines take on routine tasks and people move to more project-based work, only 16% of jobs examined are at risk of displacement across five production industries (automotive, textile and apparel, chemicals, consumer electronics, and industrial equipment).¹¹³ And so while some have predicted that robots will steal up to 20 million manufacturing jobs worldwide by 2030, jobs in the manufacturing sector posted to the ZipRecruiter marketplace actually grew 84% in 2018, outpacing growth of those in finance, insurance, and business and professional services.¹¹⁴ In fact, ZipRecruiter's 2019 *"The Future of Work"* report found that many of these jobs will be in traditional manufacturing roles. Machine operators showed the largest net gain in manufacturing job postings on ZipRecruiter from 2017 to 2018, with flexographic printing press operators, a skilled position, being the fastest-growing specialization.¹¹⁵ The report notes that part of the reason for this manufacturing job growth is that, "AI has fostered the growth of small manufacturing businesses in the U.S. by introducing efficiencies to production and business development that were never thought possible."¹¹⁶

Another important point is that AI and automation will make possible entirely new forms of value creation that don't displace people but combine their capabilities in new ways to create new forms of value and new opportunities. Consider Waze, a GPS navigation service that provides turn-by-turn navigation information,

travel times, and route details. It would take thousands of people to do what Waze's AI does every morning, but one never would have thought about going out and hiring all of those people; the service creates efficiencies and value, but replaces no one. A factory environment could provide a similar dynamic, for instance, in using AI to predict when one out of every several thousands of parts or components might break in a production machine, or in a product such as a jet engine or wind turbine. As Rockwell Automation's Dave Vasko notes, no manufacturer would ever hire 1,000 people to inspect every element every hour in order to detect failures. AI will enable new forms of work such as predictive maintenance that previously could only have been performed by 1,000 people—but it doesn't necessarily replace 1,000 people.¹¹⁷ In other words, AI will make entirely new forms of value creation possible, often in ways that don't replace workers, but rather actually create new opportunities for them.

Perhaps because of these dynamics, survey respondents anticipate AI to exert a neutral impact on overall headcount. Almost two-thirds of respondents expect no net change in employment, and 20% believe the advent of AI will actually increase employee headcount, while 16% expect a decrease. Companies, regardless of size, were close to evenly split between AI increasing or decreasing employment, but only 31% of larger manufacturers do not expect AI to impact their employment, compared with 72% of smaller manufacturers.

A Path Forward for Manufacturers

Manufacturers must prioritize preparing their enterprises for the coming age of AI transformation. The following section provides several recommendations for manufacturers to prepare for the coming AI transformation.

Create teams to drive digital transformation in the enterprise.

The digitalization of manufacturing, including through the application of AI-based solutions, heralds perhaps the most significant transformation to manufacturing in a generation. As this report has argued, it will affect every facet of manufacturing operations, from how new products are researched, developed, and designed; to how they are fabricated and assembled; to how factories and entire supply chains integrate and operate; to how products are sold, consumed, and serviced in the field.

As such, manufacturers will need dedicated teams to navigate this transformation. One company in our research established a Digital Command Center (termed their “DCC”) and two others had created digital business units or teams tasked with leading the deployment of emerging digital technologies. As one manufacturing executive explained, “Our emerging digital technologies team identifies use cases in part by holding ‘use-case workshops’, conducts technology mapping and internal landscaping, finds business value, and builds a corporate digital IQ that becomes the broader digital strategy for the enterprise.” The first step these digital business units should take is to plot their position along the manufacturing digitalization transformation journey, and then leverage resources such as Acatech’s “Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies,” which provides a step-by-step, how-to guide to progress along the digital manufacturing maturity index.



The digitalization of manufacturing, including through the application of AI-based solutions, heralds perhaps the most significant transformation to manufacturing in a generation.

Microsoft framed its approach nicely in its aspirational formulation of “Get Connected; Become Predictive; Grow to be Cognitive.” Manufacturers’ digital business units will need dedicated resources, both financial and personnel, and will need to be connected directly to C-level executives, for these units will increasingly become the value creation centers within manufacturing enterprises.

Define an “AI governing coalition” for the organization.

Artificial intelligence applications are poised to transform every facet of manufacturing organizations, from financial, customer service, and back office functions through AI systems like robotic process automation, to enterprise resource and demand planning activities, to employee training, to manufacturing operations itself. Thus, every manufacturing enterprise should define its own AI transformation strategy, which should have a core mission

of evaluating the company’s current processes, procedures, production systems, and operations and evaluating how they could be transformed and improved through the application of AI-enabled systems. In the development and execution of the strategy, companies should establish an “AI governing coalition” of business, IT, human resources, and analytics leaders who own the responsibility for activities such as setting the direction of AI projects, analyzing problems the company seeks to solve through the use of AI, building the algorithms, designing the tools, testing them with end users, managing internal change, and creating the supporting IT infrastructure. However, several interviewees averred that companies should “learn to walk before they run” with AI, suggesting manufacturers start with specific projects that can build proof points and confidence, and which can then be subsequently scaled up across the enterprise.

Evaluate AI and workforce transformation readiness.

One element within the organization's overall AI transformation strategy should be a workforce transformation strategy—and it should give consideration to both what AI-specific jobs will need to be created within the organization and providing relevant AI training at every level of the organization. As noted, tailored programs exist at universities (executive online short courses) or can be accessed through IT vendors (i.e., the Microsoft AI Business School) to specifically train executives on the implications and requirements of, and potential for, AI transformation. Similarly, a variety of tools, such as the aforementioned Microsoft Professional Program, exist to provide technical, job-ready skills and real-world experience to engineers or frontline workers through online courses, hands-on labs, and expert instruction on roles in data science such as AI developer and data analysts. Manufacturers need to create an inventory of the AI skills they need, ascertain to what extent these needs can be filled by internal resources or where external talents will need to be acquired, and develop a plan to train workers. Another best practice is setting up worker councils to manage the process of establishing communications between frontline workers and management about both the coming changes AI-based solutions will introduce and what types of skills workers will need to acquire in order to remain productive and competitive.

Set measurable objectives for digital and AI transformation.

It's important to remember that companies shouldn't deploy digital technologies such as AI for technology's sake. Rather, all implementations of digital technologies should address a clear business need and be supported by a reasonable ROI rationale. That said, the power of these technologies to transform organizations is immense. Digital transformation is about driving continuous improvement. One manufacturer we spoke with noted that the company's senior executives have set a baseline goal of increasing their company's productivity growth by 4% to 5%

annually—and the company's application of digital technologies, including AI, is viewed as key to meeting that objective. All manufacturers should define similar annual objectives for how the application of digital technologies can help them meet key performance indicators such as overall operating efficiency, productivity growth, more effective service and support, etc.

Redefine digital and physical product innovation processes.

Several companies interviewed explained that the advent of digitally based innovation means they need to speed their time to market, which presents a challenge to the stage-gate models their companies have historically used to manage product development and innovation cycles. They noted that the digital model is "more agile, experiment, iterate, fail fast, learn fast, and improvise as we go forward." These companies modified their product development processes to accommodate digital transformation while still meeting key safety, reliability, and product-quality standards for their finished products.

Overinvest in communication for change management.

It's universally acknowledged that change is hard. Enterprise-level change of digital transformation requires extensive changes within technology, systems, processes, and often company culture. Change is required of employees, partners, and sometimes customers as well. It is comprehensive, and solutions must address it holistically, not just at the point of a new robotics system implementation or iterative change happening at a point in time.

Companies that excel in AI transformation use several techniques, including setting up worker councils to facilitate dialogue between the front office and the front lines (or shop floor) on how AI will change workers' roles, responsibilities, and growth paths in the AI era. Continued open dialogue, even if there are no new answers to challenges, allow workers at all levels to be invested in the change and perhaps be the catalyst for change at all levels of the organization.

Policy Recommendations

Successfully managing the transition to an AI economy will not be easy for companies, workers, or even societies. That's why at least two dozen nations, including the United States, have introduced national AI strategies—to perform functions such as smoothing workforce transitions, facilitating technology deployment, and providing pools of capital to assist companies with upgrading plants and equipment to incorporate digital technologies, including AI.¹¹⁸ If American industry is to successfully reskill its workforce for an AI era, it will need much more assistance from effective public policies. In particular, the United States needs to prioritize building an AI-prepared workforce, just as other countries such as Finland have done. Our policy recommendations follow.

Congress should invest in cultivating AI talent. Countries such as Canada, Finland, and the United Kingdom have launched initiatives to do just that, and the United States should adapt similar approaches. For example, Canada's AI strategy funds the creation of AI research institutes and programs to attract and retain AI talent in Canadian universities. Similarly, the United Kingdom's AI Sector Deal describes how the government will fund at least 1,000 AI Ph.D. students by 2025. Congress should fund and direct the National Science Foundation (NSF) to create a competitive AI fellowship program for at least 1,000 computer science students annually—and could go further by authorizing and funding a NSF program to provide competitive awards for up to 1,000 academic AI researchers for a period of 5 years. These awards would incentivize more AI researchers to stay in academia and help U.S. universities meet the demand for AI skills.¹¹⁹

Congress should establish an incentive program for universities to expand their offerings in computer science, and prioritize retaining American students interested in majoring, minoring, or simply taking courses in computer science. At 2015 graduation rates of 50,962 bachelor's degrees, 22,777 master's degrees, and 1,826 Ph.D.'s in computer science, the supply of computer-science knowledge coming out of America's universities is insufficient to meet growing demand.¹²⁰ To increase the number of computer science graduates, schools need to work on generating interest in computer science classes among a broader and more diverse group of students, improving the quality of computer science classes, and expanding the number of available seats in computer science classrooms at both the high school and university level.¹²¹ Congress could create an incentive program (perhaps slightly increasing available federal research dollars) for universities that expand computer science course offerings and produce more computer science graduates.

Expand Section 127 tax benefits for employer-provided tuition assistance. Section 127 of the federal tax code allows employers to provide employees up to \$5,250 per year in tuition assistance; the employer deducts the cost of the benefit but the employee doesn't have to report it as income.¹²² While it's an important benefit, Congress has not increased the eligible amount since 1996. Congress should increase Section 127 to at least \$8,700 (the rate of inflation since 1996) and index the amount to the annual rate of inflation going forward.¹²³ As the *Economic Report of the President* finds, the proportion of workers that received employer-sponsored training dropped by 42% from 1996 to 2008.¹²⁴ Expanding the Section 127 benefit could help address this challenge, as U.S. corporate investment in workforce training as a share of GDP fell by 30% from 1999 to 2015.¹²⁵

Establish a knowledge tax credit that would allow firms to take a tax credit for expenditures on both R&D and workforce training.

While firms invest less in R&D than would be optimal from a societal or economic perspective—because the benefits spill over beyond their ability to capture all of them—the same can be said of their investments in workforce training. Thus, just as there's a compelling rationale to incentivize firms' investing in R&D through R&D tax credits, there is an incentive to encourage investment in workforce training. Accordingly, Congress should consider turning the research and experimentation credit into a knowledge tax credit by allowing qualified expenditures on both R&D and workforce training to be taken as a credit and expanding the rate from 14% to at least 20%.¹²⁶

Expand and make permanent funding for Manufacturing USA Institutes. America's Institutes of Manufacturing Innovation within **Manufacturing USA**, such as **MxD** in digital manufacturing, have played pivotal roles in keeping the United States at the global forefront in advanced manufacturing products and processes, developing relevant curricula, and fostering the development of workforce skills. The **Revitalize American Manufacturing Innovation Act**, which authorized Manufacturing USA, specified that federal program funds may not be awarded to an institute more than seven years after its first award. But comparable programs in other countries, such as Germany's Fraunhofer Institutes, receive core institutional funding from government on a permanent basis. Such funding in the United States could provide flexibility to institute managers and confidence to industry members, while limiting the influence of the largest industry members, including foreign-headquartered firms that might otherwise dominate an institute's agenda. Congress should consider a permanent program of support for the Manufacturing USA institutes, perhaps at an ultimate level of no more than 20% or 25% of their budgets, while maintaining incentives for them to seek industry members, ensure they remain industry-led, and undergo evaluations for continuation on a regular basis.¹²⁷

Conclusion

While we are still in a nascent phase, AI is poised to add important new capabilities to American manufacturing. Manufacturing enterprises will need to implement effective change management strategies in order to prepare themselves for the challenges and opportunities wrought by manufacturing digitalization. Individual manufacturing workers and broad national manufacturing workforces alike will need to acquire entirely new skills if they are to add value in the coming AI-transformed manufacturing environment. Companies, and societies, will need to enact serious strategies to educate, upskill, and train workers for AI. The stakes are high for both companies and countries, as the advent of AI and other digital technologies reshapes the landscape of global manufacturing competitiveness, advantaging those most prepared to leverage digital technologies, such as artificial intelligence, as platforms for innovation and the adoption of more-efficient and productive manufacturing processes.

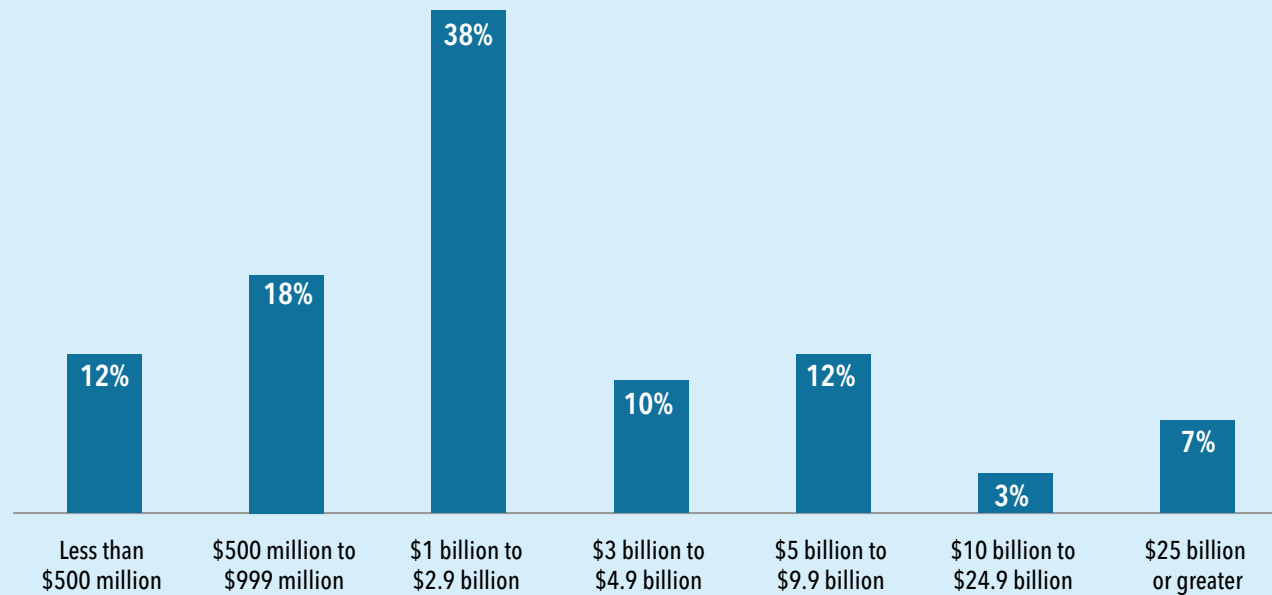


Appendix

ABOUT THE SURVEY

Surveys were sent to over 200 MAPI member executives between March and June of 2019, yielding over 60 usable results.¹²⁸ The respondents were manufacturers in the United States, generally with sales of between \$500 million and \$10 billion, with the full distribution shown here.¹²⁹

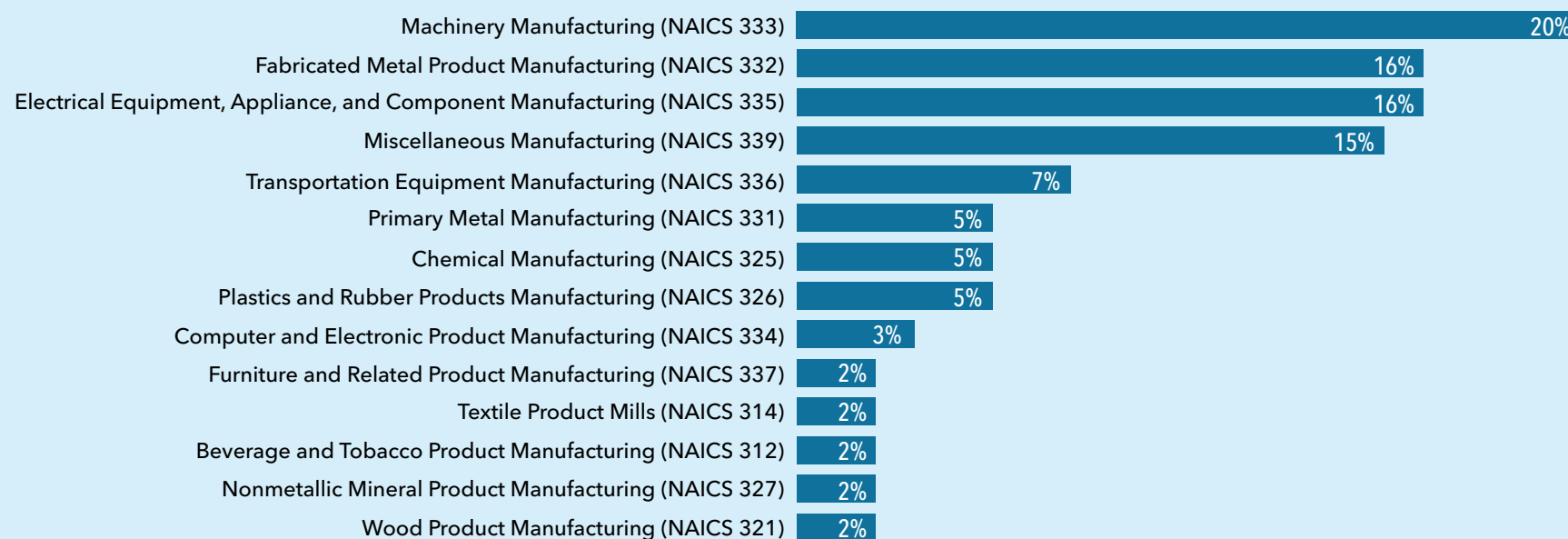
Distribution of Survey Responses by Company Size



The respondents tended to concentrate in industrial manufacturing sectors, with 20% of them in machinery manufacturing. The chart below shows the full distribution of respondents by manufacturing sector.

Note: Responses in some of the charts and graphs in the preceding report may not sum to 100% due to rounding.

Distribution of Survey Responses by Respondent's Manufacturing Sector



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As founder and president of ITIF, recognized as the world's top think tank for science and technology policy, Robert D. Atkinson leads a prolific team of policy analysts and fellows that is successfully shaping the debate and setting the agenda on a host of critical issues at the intersection of technological innovation and public policy.

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