
The workforce of the future

Advanced manufacturing's
impact on the global economy

April 2016



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1. Introduction

From 3-D printing to robotics, technology is rapidly transforming the manufacturing industry. What will this mean for the future of work? This paper seeks to define advanced manufacturing and the trends that shape it, quantify its impact on the world economy, detail implications for skills and workforce development, and outline recommendations for companies and governments to prepare for a new kind of human capital.

In the 1930's, economist John Maynard Keynes predicted a "new disease" that he dubbed technological unemployment, caused by "our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour."¹

Keynes was neither the first nor the last to argue that innovation would cause a substantial rise in unemployment; yet, since his prediction over 80 years ago, the global economy has not been inflicted with this disease. But is the fast pace of technological innovation that we are living through today going to make this Keynesian prediction finally come true?

Throughout the history of Industrialization, innovative business models, process improvements or

technological breakthroughs have brought into question job sustainability in certain industries. Globally, jobs transformed and workers adapted with new advances in automation and technology.

For example, mass picking techniques transformed agriculture, automation of assembly lines transformed automotive and textiles, and the dawn of the internet age transformed industries, the way we work, and the way we communicate with each other.

The disruptions brought about by these innovations have caused individuals with outdated skill sets to lose their jobs. But these disruptions have created opportunities for jobs that are more strategic or creative in nature. In turn, opportunities are provided to those

who have the expertise to service or maintain the moving parts of technology's new machines, or are willing to be flexible and learn new skills.

The lost jobs were repetitive in nature, easily replicable by automation, lower paying and often involved some degree of workplace safety concerns. They were replaced by higher paying opportunities requiring greater skills, creating a net positive for the labor force and global economy².

Most importantly, after over two centuries of innovation, the global economy has always proved able to provide more and better jobs, though transitions and adjustments have not been painless.

This type of workforce disruption is a necessary byproduct of innovation. GE's Global Innovation Barometer³ (GEIB), a survey of business leaders and the informed public in 24 countries, found that companies believe that the way to be the most innovative is to create new products, services and new markets.

And businesses don't just innovate because they want to. Innovation is like a living, breathing organism that feeds off the creativity of humans. Respondents to the GEIB said that they need to innovate or they will become obsolete. They fear being prey to "Digital Darwinism"⁴—technology is evolving faster than they can adapt. It's not just survival of the fittest; it's survival of the fastest.

Keeping the status quo to protect the current skillset of the workforce is suicide for brands in technology and manufacturing. While this technological disruption advances individual labor skills and salary requirements, it also stimulates the broader economy. Look at the farming industry. By automating crop reaping the efficiency of the agricultural production process increased exponentially and the real cost of food went down. Consumers were able to use the savings to buy other, manufactured goods.

By automating agriculture, overall economic growth increased and jobs in other fields were created. Those jobs required workers to have different skillsets than those needed for the jobs that had been displaced.⁵ Advances in agriculture have allowed us to feed a

rapidly growing world population—disproving the gloomy predictions of Thomas Malthus, who at the end of the eighteenth century predicted that population growth would inevitably outstrip food production.⁶

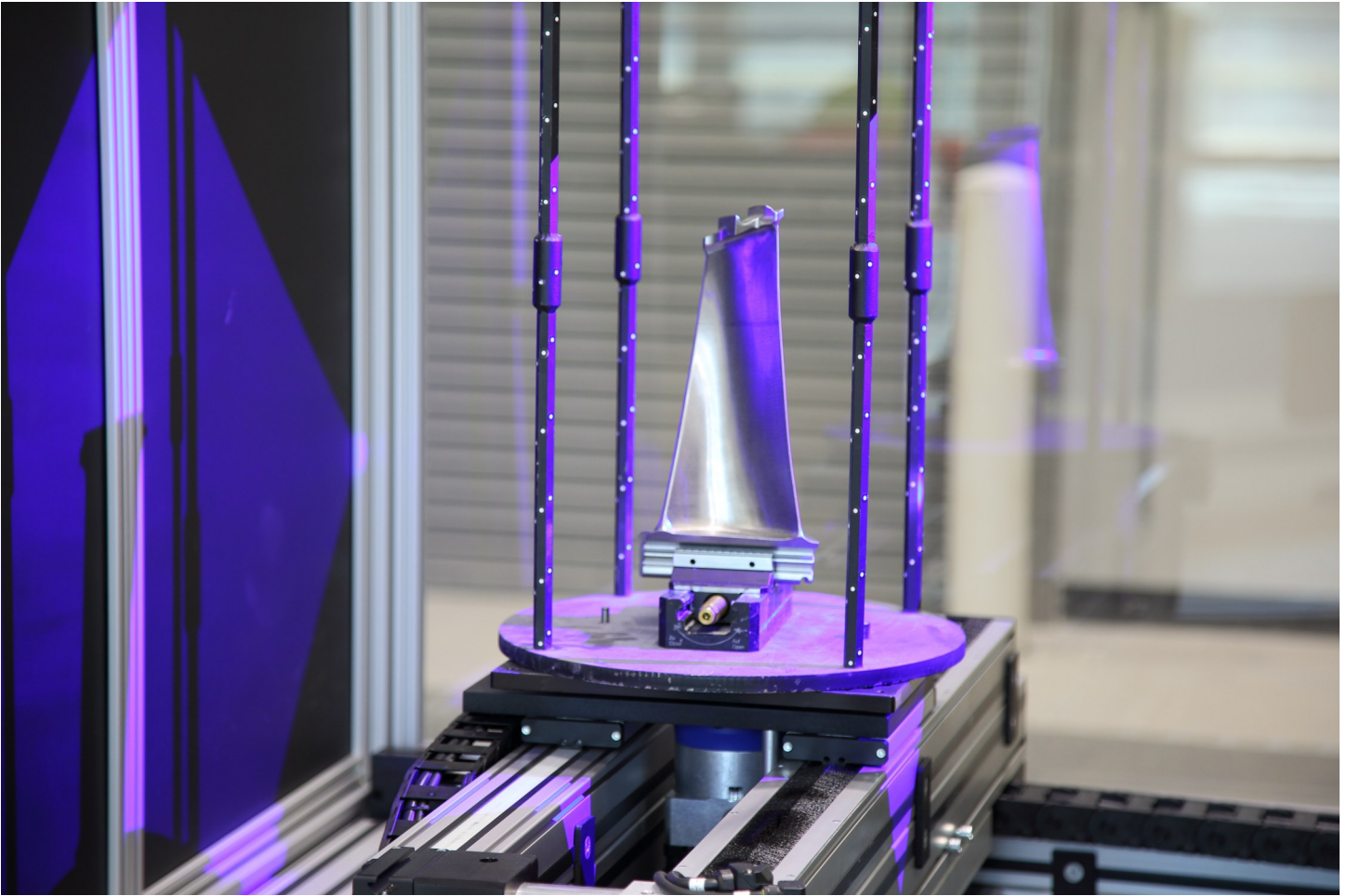
The need for firms to continuously innovate to win does not equate to a net job loss, **but rather a transition to the type of skillsets workers need.** The supply of available talent, and shrinking working age population in developed and some emerging markets means there will be jobs available for people who want them.

But the job descriptions over the next decade may be quite different than they are today.⁷ Those trained with the proper skills and willingness to adapt will more likely succeed. Workers understand this dynamic; research by Oxford Economics shows the greatest fear facing employees is obsolescence—they worry that their current skill sets will not measure up to the job demands of the near future.⁸

The need for firms to continuously innovate to win does not equate to a net job loss, but rather a transition to the type of skillsets workers need.

We may see a greater emphasis on human capital and less on physical capital. Social instability often arises from the mismanagement or underemployment of labor. As global issues of underemployment, post-retirement life span, mounting debt, and collapsing social systems all converge, **new ways to calculate the value of human labor to the overall society** and everyone's quality of life will be established.

By making an investment in transferrable skills, rather than just investing in building things, people getting those skills can take them wherever there are job opportunities. And as in the past, the transition will be challenging. Today more than ever, it is important to peer ahead to better understand what kinds of jobs will be created by new waves of innovation, and what skills will make workers best positioned to secure them.



2. What is advanced manufacturing?

Manufacturing today is digitally enabled, distributed, and democratized.

Multiple technologies are converging today to define “advanced” manufacturing. The blending of the physical and digital has led to a world where humans and computers communicate and collaborate. The proliferation of cloud and automation technologies will lead to more seamless and real-time simulation, workflow, and collaboration to transform the design of new products and accelerate the development process.

Products and devices are no longer sold on a one-off basis. Now, enabled with sensors and communications capability, manufacturers have the opportunity for longer-term and recurring service revenue streams.

Manufacturing is evolving to the point where **technological advancements and improvements will come from machines and systems themselves**, through predictive analytics, advanced controls, and smarter systems. Progressive automation technologies with advanced software platforms, robotics, and sophisticated new fabrication techniques, like 3D printing, are re-defining manufacturing for the future. The cloud enables real time transparency into operations in the factory and across the supply chain.

This flexibility promises the ability to react to an urgent situation or have machines or software automatically

adjust and respond. Manufacturing is concluding an era where centralized scale won the economic formula for cost and productivity. Customers and market needs are evolving faster, while disruptive technologies are redefining the nature of economies of scale: no longer just the production of very large numbers of identical products or parts, but the ability to manufacture custom products at the speed dictated by the customers' needs.

Disruptive technologies are redefining economies of scale.

Technologies such as 3-D printing enabled this capability, along with new types of business models. Now a software-savvy employee can print a product onsite for a customer in real time—which is also leading manufacturing to become highly distributed and democratized.

What is the digital twin? ” ”

Q&A with Arnold Lund, PhD, Computational and Industrial Experience Labs Technology Leader, GE

What exactly is a digital twin?

The Digital Twin represents all of the digital information collected about that specific physical asset—we collect its history, the conditions under which it has been used, its configuration, who has touched it to repair it and more. The idea is to optimize analytics and maximize the life of the individual asset, optimize its performance, and optimize a set of assets across a fleet.

Will the digital twin eventually replace workers?

Definitely NOT. This is not about replacing workers. It is about enabling workers to be more effective, productive, and important to the business. It is about augmenting and enhancing the employees capabilities, and enabling them to keep up with the rate of change and leveraging it even more effectively.

How can today's workforce prepare itself for an environment where their "coworkers" will be machines or a Digital Twin?

This is actually a symbiotic relationship. Most fundamentally the machines need to be designed to send the signals that will let humans use them more effectively and the machines need to "read" humans more effectively. In the meantime, design needs to be simpler and focused on adapting to what people need so employees can focus on business outcomes and impact.

What will digital industrial companies going to look like 10 years from now? What differences will we see on the factory floor?

Human workers will be collaborating with intelligent devices more than controlling them, and will be supported by intelligent agents. They'll be using model-based human-system interfaces that let them focus on business transforming decisions rather than having to deal with the increasing complexity and scale of the systems they are using.

They'll be seamlessly connected to the industrial internet as they move from task to task, augmented by the technologies that they carry with them as well as the digital context that surrounds them, and the experiences will bring them what they need whether information, tools that adapt to them, expertise that has been harvested from others and helps them solve new problems they've never faced before, and support from communities of collaborators.

People will be living sensors leveraged by the analytics, and expertise will be captured and become a core asset for the enterprise as it continuously grows. The systems, processes, and organizational structures will evolve to respond to competitive forces, business needs and new technologies as they emerge; and entire complex systems will be optimized rather than just isolated devices and workstreams. Supported by the analytics building on the digital twin of the enterprise (incl. both workers and physical assets), this intelligence will light up the transformational enterprise.

3. Quantifying the impact

Measuring the value of advanced manufacturing to the U.S. economy.

Economists and pundits across the globe have speculated, researched, and forecast the potential impact on jobs and the economy as machines and factories become smarter with the inherent capability to displace human tasks. Some suggest unemployment will soar.

Recently, however, **the conversation has evolved from studying the elimination of jobs to the transformation of jobs.** Research from the World Economic Forum found that over five million jobs could be lost by 2020 as a result of developments in genetics, artificial intelligence, robotics and other technological change.⁹ But they also predict that two million jobs will be created and that 65% of jobs in the future will be in careers that are not yet invented.¹⁰

While the debate about whether advanced manufacturing will eliminate more jobs than it creates is ongoing, it is much more certain that companies will need people with new skills. There is no doubt that advanced manufacturing will impact the skillset required for laborers in the industry and its supply chain including engineering, sales, and field marketing. **The potential impact that this digital transformation in manufacturing will have on employment is significant to the jobs landscape, so we set out to evaluate the data and draw our own perspective.**

Together with economists from Oxford Economics, we examined North American Industry Classification System (NAICS) codes at a broad level to identify a set of industries that do or could employ Advanced Manufacturing technologies. We first grouped industries that required aspects of manufacturing to create a part or product. Next, we narrowed down the list by including only industries where the manufacturing process is or could be impacted by current digital technological

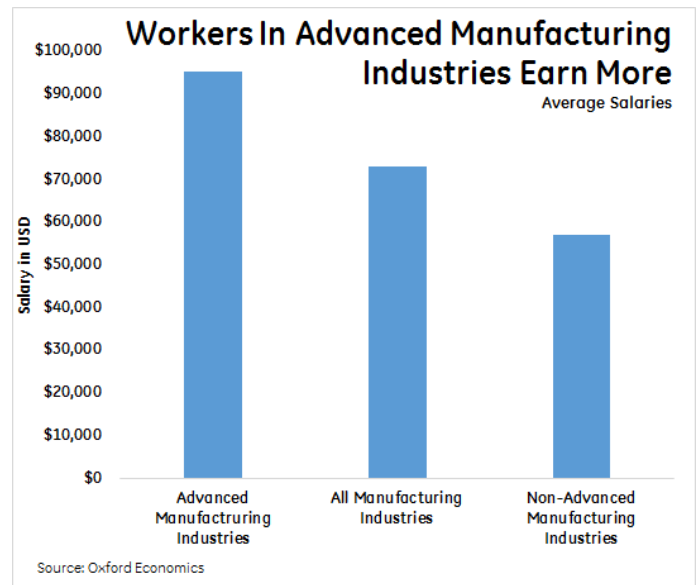
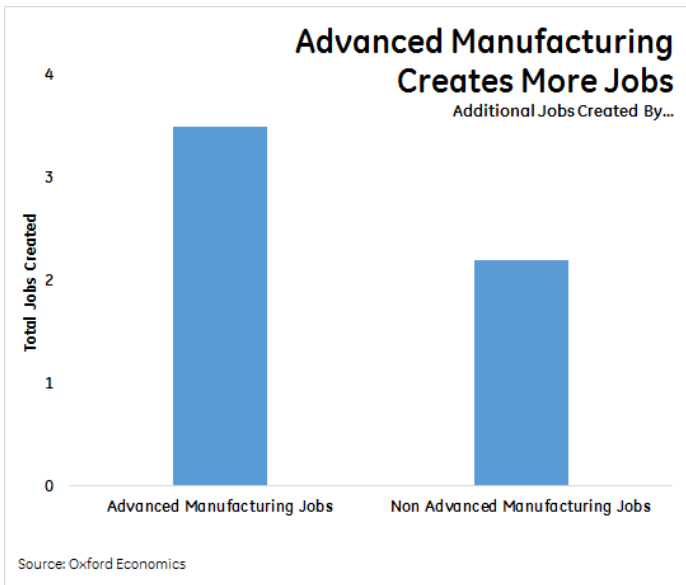
advancements such as 3-D printing, Big Data Analytics, and the Industrial Internet.

Oxford Economics provided this subjective, customized research focused on the U.S. national economic impact and structural workforce changes. The industries we deemed to be capable of adopting advanced manufacturing technologies include Petroleum and Coal Products, Industrial Machine, Engine, Turbine and Power Equipment, Semiconductor, Aerospace Products and other types of manufacturing. For the purposes of this paper, we have defined these industries as Advanced Manufacturing industries, or AM industries. To see a complete list of the industries included in the analysis, see the Appendix.

Each job in an advanced manufacturing industry supports another 3.5 jobs in the supply chain.

The research found that AM industries account for 13% of all jobs in the U.S.—**nearly 24 million people are employed in AM industries and they are compensated more highly than other workers.** The average worker in AM industries makes nearly \$95,000, compared to an average of about \$73,000 over all manufacturing industries. Workers in traditional manufacturing industries make only about \$57,000.

AM industries' overall impact on the economy is about \$3.1 trillion or 19% of US GDP. The value of jobs in AM industries can also be measured on their impact to the U.S. labor market. **Each job in an AM industry supports another 3.5 jobs through the supply chain** with a consumption multiplier effect, compared to non-AM jobs which only support 2.2 additional jobs.



4. The democratization of manufacturing

The rise of 3-D printing and robotics is disrupting traditional supply chains and distribution channels.

Technological advancements are transforming global supply chains and distribution channels. While the previous 10-15 years were defined by outsourcing and offshoring to find low cost alternatives for manufacturing, the rise of 3-D printing and cheaper energy domestically will cut into the overhead costs of manufacturing, and shrink labor costs.

The advantage in emerging markets may swing the pendulum back to domestic sourcing in the U.S. A local supply chain offers greater protection of intellectual property and a better ability to manage quality control.

Automation and robotics also level the playing field for input costs. As Stanford fellow Vivek Wadha said, "Our robots cost the same as their robots, and their robots work as hard as our robots. So why do we have to ship goods all the way over there?"¹¹

The increased use of 3-D printing, or additive manufacturing, will transform the supply chain. In

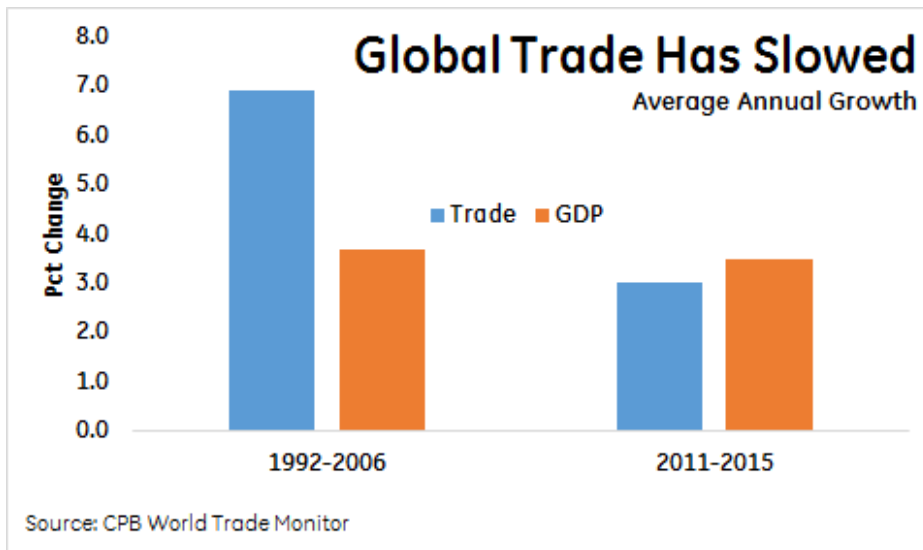
traditional manufacturing, each part of a machine is needed to be built somewhere as safely and inexpensively as possible. Offshore labor has been cheap enough to more than offset the cost of shipping parts across the globe.

Additive manufacturing is threatening that labor cost advantage. Also, in traditional manufacturing it is necessary to build several components that perfectly fit together to form the finished part or product. Additive manufacturing has shifted the paradigm. A part that traditionally needed several components can now be designed onscreen and printed out to the exact specifications needed. The 3-D printer can be housed in a much smaller factory (or even garage) as opposed to a traditional manufacturing line.

These improvements in automation and efficiency will decrease production costs and compel manufacturers to reassess the cost-benefit trade-off of offshoring. As

Advanced Manufacturing allows for the establishment of micro-factories that leverage local talent, **the democratization of manufacturing could slow the trend to more globalization of markets.**

This might already have played a role in the slowdown of global trade observed in the last few years. Prior to the 2009 global financial crisis, global trade used to grow at about twice the pace of global GDP; after 2009 it has been growing at just the same pace, and even slower over recent years.¹²



More research is needed to fully understand this phenomenon, but some analysts believe that new innovations such as advanced manufacturing might be playing a role. With localized suppliers and distribution, the existence of a global supply chain existing as we know it could be threatened.

While this has the potential to create a greater number of jobs locally, export dependent countries may need to accelerate efforts to rebalance economies to a healthier differential between exports and services.

The Democratization of Manufacturing may also be impacting China's dominance as a manufacturing hub. A 2015 poll conducted by Boston Consulting Group of U.S. manufacturers with sales of at least \$1 billion found that 53% of companies are considering bringing production back from China, up from 37% in 2012.

Seventeen percent of respondents say they are already in the process of reshoring, up from 7% in 2012.¹³ These executives felt that logistics, inventory costs, ease of doing business, and the risks of operating extended

supply chains are the factors impacting their decision.

Low wage costs will not have as large an impact for AM industries, threatening advantages that some export-driven countries have maintained. Instead several factors will weigh more heavily on factory location decision making: **proximity to the supply chain and customers, availability of skilled labor, energy cost efficiencies, quality of overall infrastructure, and an environment more conducive to business.**

The implications democratized manufacturing will have on supply chains is uncertain, but if the vision of localized sourcing becomes a reality, export-driven economies could feel the impact.

“Digital innovations of advanced manufacturing will augment the capabilities of workers at different levels of the skills distribution. Different and better skills will be needed, but technology itself will help in the process.”

—Marco Annunziata, Chief Economist, GE

5. Global financial crisis impact

Manufacturing industries took a significant hit, but AM is proving resilient.

When examining the impact advanced manufacturing technologies have recently had on jobs in the U.S., it is important to take into account the outsized impact on the labor market of the Global Financial Crisis of 2008 and subsequent extended time frame that was taken to get back all the lost jobs.

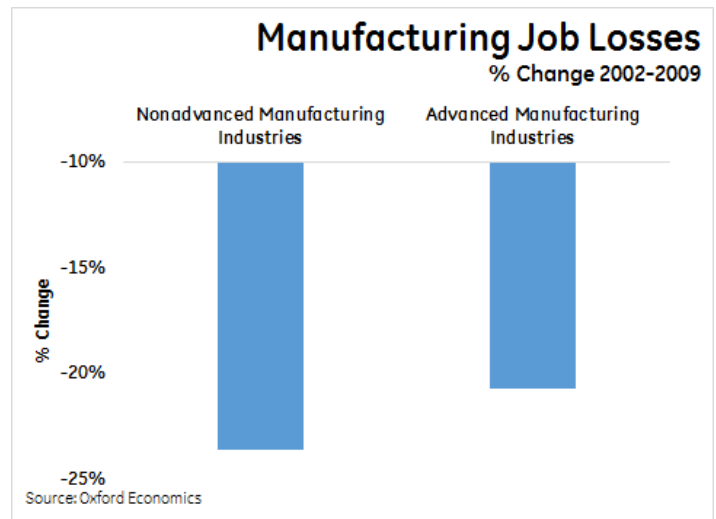
Very few industries were able to withstand the impact of the crisis unscathed. **But while most industries were negatively impacted, AM industries fared better than non-advanced sectors.**

Payroll employment in AM industries declined by 21%, or a loss of 1.3 million jobs. Jobs in non-advanced manufacturing industries, on the other hand, dropped by about 2 million jobs, or 24%. While most AM industries saw declines between 2002 and 2009, a few, including Aerospace, Mining, and Transportation, grew during this time period. Very few sectors were spared the pain of the Global Crisis, but AM industries were a bit safer.

The Global Financial Crisis also energized the technological great leap forward into automation that we are in the midst of now. **The need to achieve growth and remain competitive in a leaner environment pushed companies to fund technology in lieu of hiring, the substitution of capital for labor.**

Those who remained at work during the crisis had to do better at optimizing their time and were faced with the burden of increasing productivity demands to fill the gaps that were left by those who had lost their jobs.

As a result, workers created new processes and technologies. Those who were not working could not hone existing or acquire new skill sets while on the job. Though post secondary enrollment shot up as displaced workers tried to learn new skills, they were not able to do so in the real-world setting of the workplace.



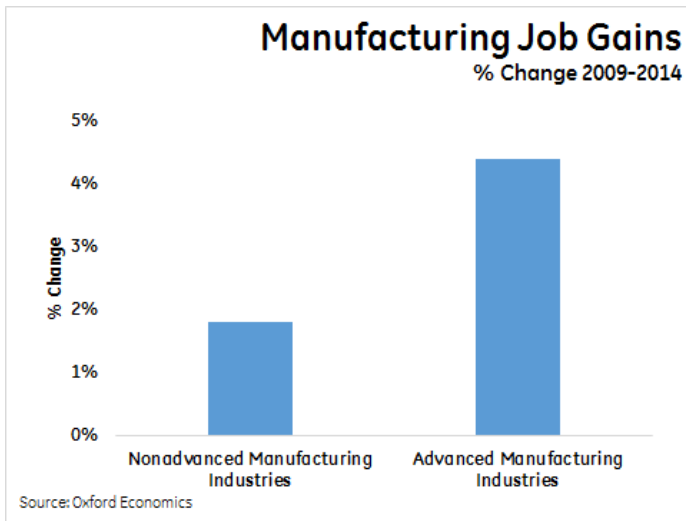
These issues helped to create an increase in long-term unemployment the U.S. is still saddled with nearly seven years beyond the height of the crisis. At the end of 2015 over 2 million people had been unemployed for at least 27 weeks. While this is down from the height of the crisis, when over 6.6 million Americans were among the long-term unemployed, pre-crisis the number hovered below 1.5 million¹⁴.

Two tides came together to create a perfect storm during and after the Global Financial Crisis—the era of technology speeding ahead coincided with an unemployment rate that was at a post-Depression high. This rendered skill sets of some workers obsolete.

Relative to previous recessions, it took the economy a long time to recover all the jobs lost following the Global Financial Crisis. It is taking traditional manufacturing even longer, and it is likely that some of these jobs may be lost for good.

But AM industries have seen a stronger recovery than traditional manufacturers. While 17% of the jobs lost between 2002 and 2009 in AM industries have been

recovered, only 10% of those jobs in traditional manufacturing have been recovered (through 2014).



The trend over the past couple decades has been a decline in manufacturing jobs, but there is a market for manufacturing talent. According to the Society for Manufacturing Engineers (SME), 600,000 manufacturing jobs in the U.S. went unfilled during the crisis years from 2009-2012 because skillsets of available workers did not fit job descriptions¹⁵.

And now the job market is getting tighter in places like the U.S., presenting challenges to all industries in need of more workers. The Bureau of Labor Statistics, in its Job Openings and Labor Turnover Survey (JOLTS), measures how many potential job seekers there are for each available job. In January 2016, there were less than 1.5 workers available for every open job, the lowest number since this data began being reported in 2000.

Meanwhile, the unemployment rate recently fell below 5%. Since 1990, the only time the U.S. unemployment rate has dipped into the 4's has been during economic bubbles—dotcom and housing. The increase of retirees has impacted participation in the workforce, providing room for the rate to fall further than the 5% inflection point that has been a signal of a bubble about to burst, but the country is nearing full employment.¹⁶

As job opportunities become more plentiful, competition for talent will heat up and employment costs will rise. This could help widen the gap between the demand for STEM workers and the supply of them in the market.

Adopting additive

Q&A with Kurt Goodwin, Executive, Advanced Manufacturing, GE Power

How is 3-D printing changing the culture at your plant?

Additive manufacturing is an extreme version of model-based manufacturing. For example, we have a machine with a computer that slices up a design model into a set of pass controls for the laser and you literally can't run the machine without some software knowledge.

When we launched our first additive manufacturing product line in our Greenville, South Carolina plant, there were a ton of employees who had never worked with computers, or even had an email address. But we are working to train these workers and they have been quick to adapt and learn. This new technology takes away parts of their jobs that they don't like. Instead of spending a chunk of their shift moving parts around in preparation for production, they can spend more time doing more value-focused tasks.

This transformation of our production and preparation process has started to free up workers from some more repetitive and boring tasks, and allows them time to apply more creative solutions.

Does this create a safer working environment too?

Absolutely. Though we are not yet fully automated, the number of recordable safety incidents has dropped. The workplace is safer and more productive, with the same population of people in our factory now with added automation and digitization.

For example, think about a part that has to withstand high temperatures in use. These types of high value parts need to be coated with a type of insulation. Each time we need to coat a different part, mechanical engineers need to go onto the floor and re-program and reconfigure the coater. But now, thanks to automation, we just need to scan the part number, select the right program, and the machine is automatically reconfigured. Productivity is increased without the safety risks formerly associated with reconfiguration.

What about the bigger macro picture? Does additive usher in an advent of reshoring jobs?

I think it's bigger than that. Yes, additive manufacturing is going to bring jobs back to local suppliers. But the same concept that applies to bringing manufacturing back inside a country's borders could be applied to bringing manufacturing back inside a firm's wall. Companies like GE could bring a great deal of outsourced part manufacturing back in-house.

What types of workers are going to succeed in this new stage of manufacturing?

We are looking for problem solvers who will thrive in an environment where they may be working on one thing Monday afternoon, and something totally different by Thursday morning. The type of people that will succeed will be those that are flexible, who want to be challenged to create something that has not been done before.



Surviving in the crosshairs of technology: The bank teller

The banking industry provides a clear example¹⁷ of a technology that, by its very name, was innovated to replace tasks completed by human beings—the ATM.

Some early versions in certain regions of the U.S. were given a more benign name, like MAC machines or Money Access Centers, but the name that caught on held a foreboding forecast for the human bank worker—The Automated Teller Machine, a machine that was created to dispense and deposit cash or checks and provide instant information about one's financial situation.

These were exactly the services that a human teller provided. The ATM also held benefits that a human teller was unable to provide. First, ATM's provided customers access to their accounts 24 hours a day, seven days a week, something physical bank locations could not compete with. Second, as society grew more protective about its private affairs, the ATM offered the illusion of confidentiality. There was no human teller seeing your account information and how much money you had every time you entered a bank.

So why did the ATM not eradicate tellers from the employment market? ATM's are machines that breakdown. They need to be replenished with money and receipt paper. We have all experienced a time where we go up to the ATM machine, it is not working, and we have to go inside the bank to transact with a human teller.

Safety concerns are another issue that has kept the human teller employed. The opportunity for thieves to steal money from people using ATM's, or to steal ATM cards and decipher pin numbers has caused banks to limit the amount of money that can be withdrawn from ATM's. Lastly, older generations who are not as comfortable with technology or who simply appreciate the human interaction they get inside a bank branch have ensured the survival of the human teller.

Actually, ATM's created new job opportunities within the bank, and have also had a positive impact on the broader economy. Before ATM's, human tellers were transactional. They deposited money into accounts or withdrew it from accounts. Now they are more knowledgeable and able to offer advice on the various products banks offer.

The ATM also helped establish a new paradigm for point of sale purchases. Prior to ATM's, bank customers had passbooks that they would bring into a bank branch. But ATM's made it necessary to have a bank card to access funds through the machines. Retailers then updated their systems to accept these debit cards and consumers suddenly had access to their cash anywhere at any time. Regulatory changes also permitted banks to open more locations, across state lines. All of these changes allowed for the job of the human teller to survive the advent of the ATM.

While technologies will continue to improve the utility of the ATM, the workforce will in turn adjust. **New markets will be created and new opportunities for more creative and strategic kind of work in the banking industry will be established.**

6. Divergent thinking

Perspectives vary widely on whether technological advances pose an opportunity or a threat—depending on where you come from.

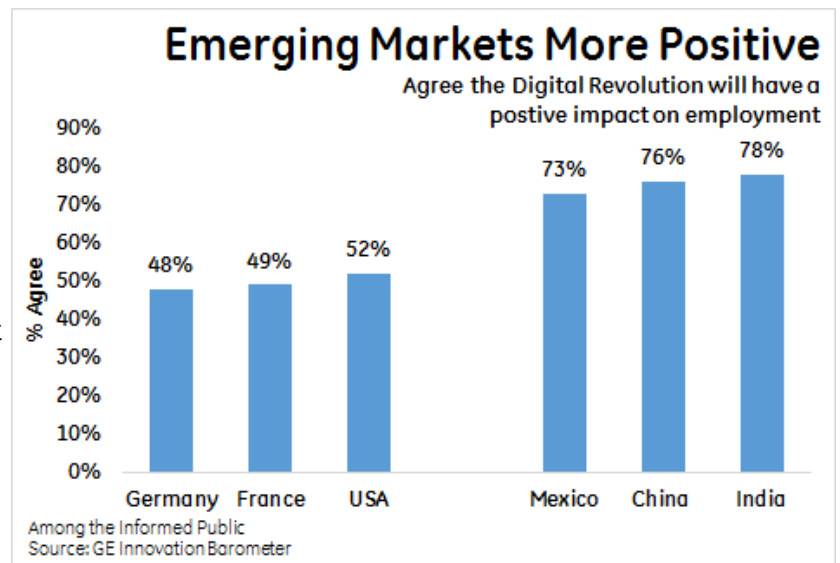
The Global Innovation Barometer showed us that the informed public is actually not too concerned about job displacement from technology. 60% of the informed public feel the net impact of the digital revolution will have a positive impact on jobs, and only 14% feel it will have a negative impact.

Yet displacement and job loss is still a major part of the broader conversation. Confusion and concern over technology erupts because this net impact does not happen immediately. A lag occurs between the onset of early technological advances and full integration.

During this lag, compensation inequalities expand between the early adopters, in this case those who have the skill sets in demand, and the laggards or luddites. Those late to the party are likely to have a less favorable view of the impact of technology on the workforce.

The GEIB shows us that yet another divide exists between developed and emerging markets. In places like Germany, France and the United States, only about half of the informed public feel the digital revolution will have a positive impact on employment. In emerging markets like China, India and Brazil, on the other hand, about 3 out of 4 feel it will have a positive impact.

This could be attributed to the “leapfrog” theory. Despite the fact that emerging markets have a lack of infrastructure in place in certain sectors, **these technologies could help Emerging Markets (EM) leapfrog Developed Markets into adopting widespread use of new technologies.**



Without the traditional telecommunications infrastructure in place, emerging markets were quick to adopt mobile technology. With no oil pipeline or transportation infrastructure in place, the adoption of renewable energy sources like solar, wind and hydro are more likely to take hold. The adoption of virtual health care is more easily established when the expectations of traditional health care—seeing a doctor in person, reactive vs. preventative care—are not yet in place.

Concerns about job displacement are different in emerging markets too. **As populations in EM's expand, the goal is more basic than worrying about whether or not technology will displace jobs. The goal is to create any type of job for an expanding workforce.**

In this way, the Leapfrog theory will apply to the workforce in general. Emerging markets could leapfrog the fear that technology will displace jobs if there are few repetitive, task-oriented jobs in existence to replace.

Minds and machines: GE Aviation's Bromont Facility

Q&A with Alain Oullette, Manufacturing Engineering Executive, GE Aviation

GE Bromont opened in the early 80s. The facility has had a strong history of productivity and innovation. It has a nontraditional management system called socio tech, where employee and business wellness are equally considered and open communication between leadership and workforce is essential. We spoke with Alain Oullette, Manufacturing Engineering Executive, at GE Aviation Bromont.



Can you provide some examples of advanced manufacturing technologies in use at the facility?

We originally looked at robots to help in harsh environments like forging and forming. Initial adoption of the technology was slow and difficult. We quickly learned that robots, like we use them today, dislike variation. However, we needed consistency for our processes. As the team struggled to achieve an acceptable yield, we were able to start building robustness and repeatability. The robustness improved as we learned how to apply the technology and now, we have groups of robots, working as a team. They each handle different features and move a part through multiple process steps.

When these technologies were put in place, how was the local GE workforce impacted?

We initially encountered the anticipated human reaction to the robots: employees were worried jobs would be eliminated. But it did not happen. The facility leadership group was able to show the team that robotics was a technology evolving the way we work to help people. The promise of the robots was to help reduce injuries, improve quality and costs by reducing variation due to manual operations, improve overall flow of hardware through the facility and result in lower manufacturing costs—thus making our products more competitive on the market. We installed automated processes on all of our forging equipment and the employees quickly saw the benefit. So much so, that in 2004, when a new extrusion machine came in for our forging operations, the employees asked that we make sure we get the robots to go with it.

What type of training or support did GE provide for those workers who had to transition to new roles?

Standard work scope of an employee drastically changed from a heavily physical operator in part processing to an equipment manager of a group of robots that would produce parts. This required automated processes be robust to keep the operator interaction with the robot to an acceptable level. In addition, we needed adequate training for the workers to become comfortable with this new role. Operators were given basic robot operating skills through training, with the ability to do adjustments within a certain work envelope. The maintenance crew on all shifts is now capable to intervene if needed, which takes care of most if not all situations. An estimate of our forging and forming operations shows that with today's production rhythm, well over 45 million non-ergonomic movements have transitioned to the robots.

Are there enough workers available with the type of skills needed to navigate new advanced manufacturing technologies?

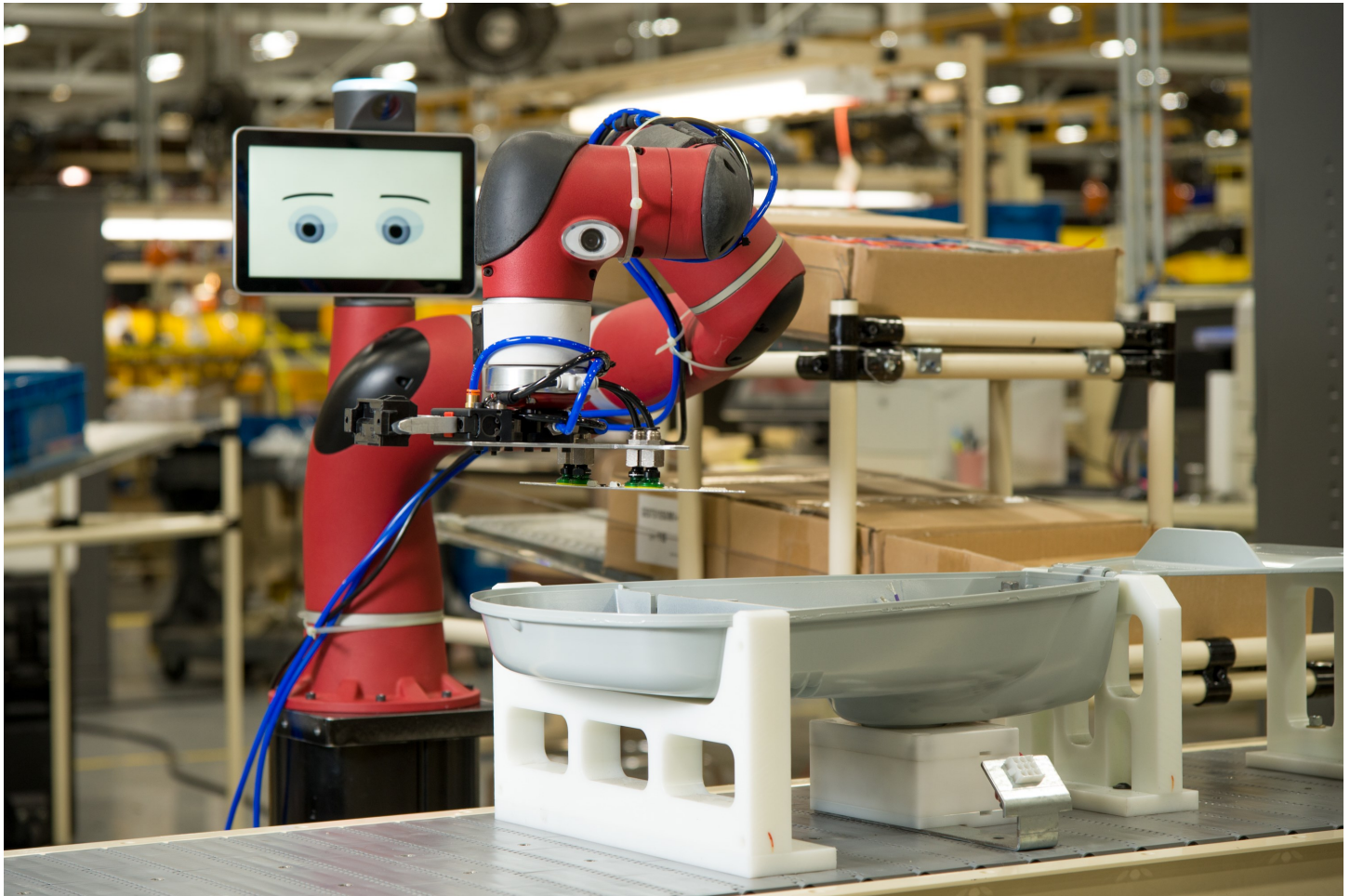
The evolution of the last fifteen years would make me say yes. The key will be striking a balance between the engineering effort to make automation solutions robust enough and the compatibility with the workforce. A critical element of success is the ability and willingness of our workers to adapt to change, so the training will go a long way.

Are universities training workers with the proper skills to succeed in advanced manufacturing careers?

On the technical and engineering front, we have been able to sustain the pace up to now. However, with more companies embarking on this journey, I expect a situation where skilled resources are going to become higher in demand. I am confident the schools and market will adapt to the need. We see many initiatives to raise awareness on STEM careers at a young age. One good example is FIRST (For Inspiration and Recognition of Science and Technology). This competition makes science exciting for young people and has seen a significant growth in popularity since it started in the 90s.

And what about women; how can companies that use advanced manufacturing technologies promote female participation in these industries?

I would say this is an area of needed improvement. I am encouraged in the level of participation I see at FIRST events; it gives me confidence we are making strides that young women can see a career path for themselves.



7. Shifting demographics

Countries need to prepare changing workforces for the jobs of the future.

As the global population ages, many developed markets (DM) are faced with a larger burden on the workforce and on government programs to support their aging populations. In Germany, it is estimated that there is a deficit of 150,000 births each year.¹⁸ According to UN Population Projections for Japan, the dependency ratio—the number of those of young and old age as a percentage of the age 15-65 working-age population—will be nearly one to one by mid-century.¹⁹

This will put a huge strain on not just workers, but also on the government to provide services to the growing population that is too old to work.

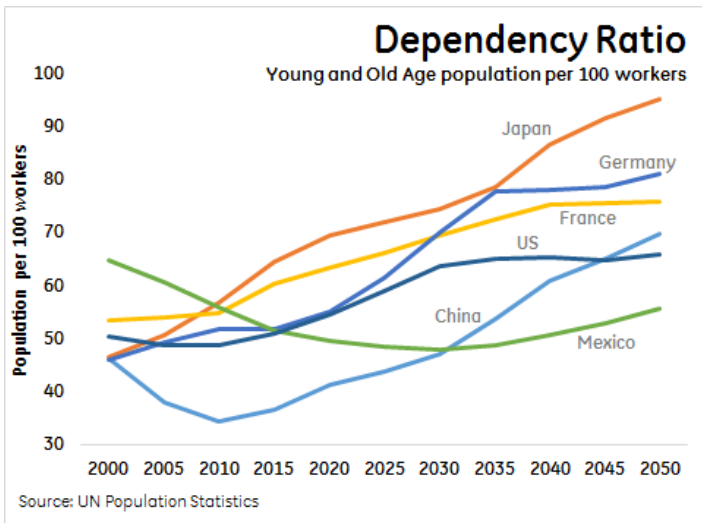
In the U.S., though the dependency ratio will continue to rise over the next two decades, there is an inflection point in the data where the ratio levels off to about 10 workers for every 6 dependents.

That inflection point is the “sunsetting” of the baby boomer generation in the decade between 2030 and 2040. As a group, the Baby Boomers have moved the economic needle throughout their lives. That trend will not change as they progress through old age.

But this is not just a phenomenon taking place in DM. Some emerging markets (EM) are also coming to terms with an aging workforce. China is a prime example,

where the one-child policy has resulted in a declining working-age population.

Though China's one-child policy has recently been reversed, there are indications that having just one child has become a social standard.²⁰ But even if the more liberal child policy has its desired effect and birth rates increase, **it will take decades to reverse the trend of a shrinking workforce.**



Other EMs are not facing the same challenges. Birth rates remain strong in Mexico. According to UN population statistics the working age population there is projected to increase until about 2050.

Many other emerging and developing markets are experiencing this “younging of the population.” For instance, both India and the Middle East have tremendous youth populations—with a significant portion of their population not just under the age of 24, but 17. This will be critical when it comes to attracting a new, fresh labor base.

The future is increasingly going to pivot around sub-Saharan Africa as well. Africa is expected to go from having roughly 1 billion people today to 4 billion by the end of the century. Africa contains some of the world's fastest-growing economies. Plus, over one million Chinese have moved to Africa in the last two decades.

Entrepreneurship is transforming Africa, helping to create an African middle class. Skilled youth will excel in and benefit from such an environment. Plus, enormous

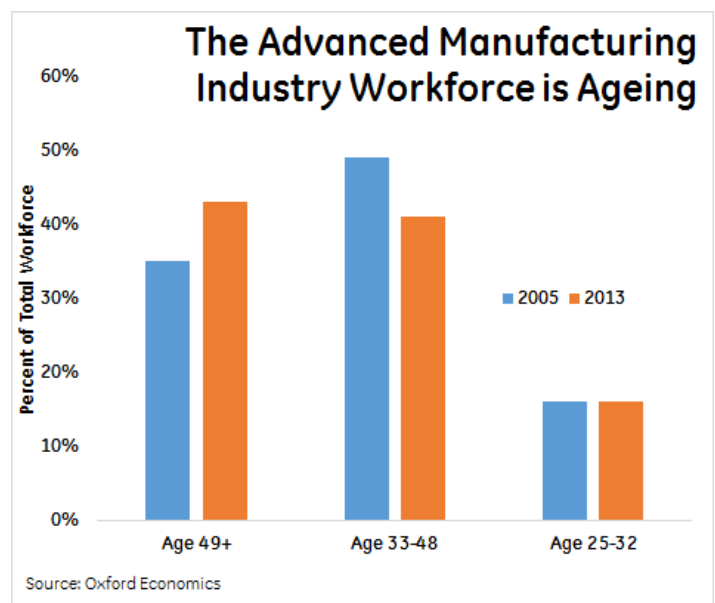
advancements in digital infrastructure are allowing many to participate in the global economy.

Across the globe, demographic trends like these will shape the future of work. But manufacturing workers are mainly in graying professions. The three main occupational groups for AM industries are Business and Financial, Computer and Math, and Architecture and Engineering. These three groups are highly comprised of workers with advanced degrees—nearly 70% have at least a Bachelor's degree and 25% have a Masters.

The U.S. is facing the mass retirement of the Baby Boomer generation, which started in 2011. As noted above, countries like Japan and some in the Eurozone will face a dependency crisis in the coming decades. The impact of these issues is more direct on AM industries. Nearly 40% of AM industry workers in Business and Financial Operations and Architecture and Engineering are aged 49 or older.

Across the globe, demographic trends are shaping the future of work.

One major challenge faced in certain AM industries is the gender gap. While female workers in Business and Financial Operations occupations make up over half of



workers as well as half of college graduates, the percentages in Computer and Math and Architecture and Engineering are staggering.

Less than one quarter of AM industry jobs in Computer and Math are held by women, and in Advanced Manufacturing architecture and engineering jobs, only 13% of workers are women. Women represent an increasing majority of enrollment in higher education institutions globally; but the major challenge remains converting this enrollment into the formal pursuit of STEM disciplines.

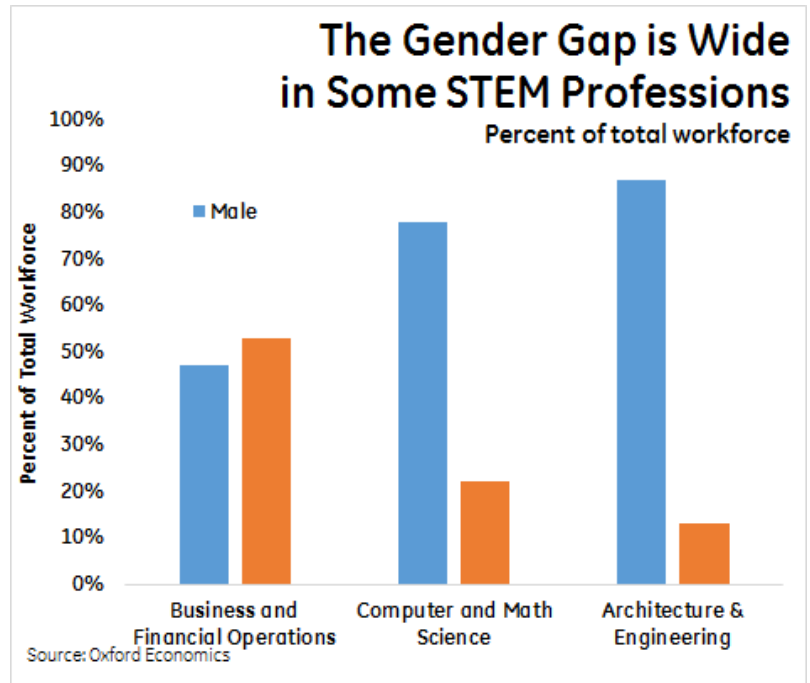
Without shrinking this gender gap and targeting glass ceiling compensation imbalances between genders, the drive to increase the talent pool of STEM professionals cannot succeed. AM industries need to make this a priority.

Employees in the Computer and Math profession also have another common trait – they are much more likely than employees in other professions to be non-US citizens. Though only 12% of those employed in Computer and Math are non-US citizens, that is about double the number that are employed in Business and Financial and Architecture and Engineering.

Companies need to expand the search horizons beyond borders for people with these skill sets.

Amending U.S. rules restricting the number of H1B visas could quickly increase the pool of talent of Computer and Math professionals in country.

Japan has been mired in two lost decades, thanks in part to social norms which discourage females in the workforce and prevent immigrants from working in the country—norms that Prime Minister Shinzo Abe attempted to address (with little success) in his Three Arrows to improve the Japanese Economy. Other developed markets like the U.S. should learn from the lessons taught by the Japanese situation and work to avoid similar long term economic stagnation.



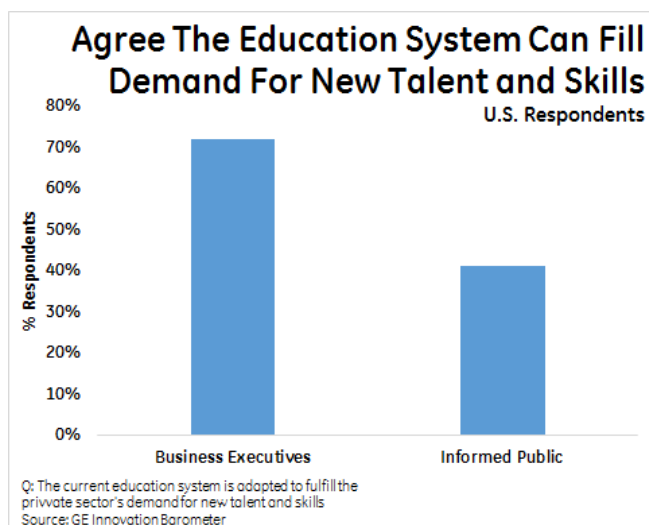
8. A new kind of human capital

Creating generations of educated, resilient, and flexible workers.

As we've established, having an appropriate skillset and being adaptable are two essential traits for working in AM industries, especially given the shifting demographic dynamics detailed above.

But GE's Innovation Barometer found that innovators across the globe do not feel their education system is prepared to answer the future skills challenge. Globally less than 60% of respondents were confident that the current education system is adapted to fulfill the private sector's demand for new talent and skills.

In the U.S. there is a major gap on this subject between business executives, of whom 72% feel the education system is up to the task, and the informed public, of whom only 41% feel similarly. In this section we examine whether universities, businesses and governments are training students to succeed in today's workforce.



Many of the workforce challenges detailed in the last section can be addressed by **enticing young people to take up STEM career paths**. Governments need to renew an early-education focus on science and math. At the college level, AM firms need to work with educators

to establish curriculums that align the skills students are learning with the skills businesses will demand.

In order to fill new types of work in AM industries and to provide a future for younger generations of workers our universities should increase the number of required STEM courses that must be taken in the first or second year in order to qualify for graduation.

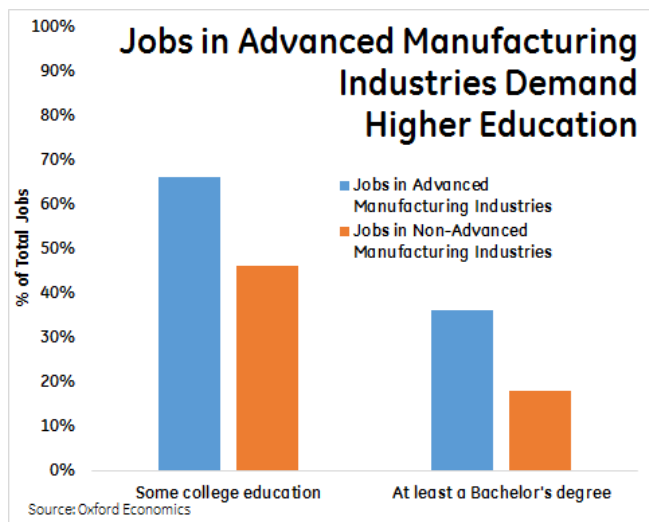
According to a 2014 STEM report by the Brookings Institute, as of 2011, 26 million U.S. jobs (which is 20 percent of all jobs) required a high level of knowledge in at least one STEM field²¹. Furthermore, the U.S. Department of Labor reports that jobs related to STEM are projected to grow by more than 9 million between 2012 and 2022.²²

In addition, by 2018, 63 percent of all jobs will require some kind of postsecondary education and training.²³ This is especially true in AM industries. Architecture and Engineering, Computer and Mathematical Sciences, and Business and Financial Operations account for over 15% of all AM jobs—and these are all typically held by professionals with advanced degrees.

Meanwhile, when looking at the time period from 2002 to 2014, production occupations and office and administrative support occupations saw the largest drop in jobs in advanced manufacturing industries. **So while we do see jobs that require less education and training being phased out in advanced manufacturing industries, careers that require advanced education are increasingly in demand.**

It is the responsibility of a consortia of governments, educators and the private sector to provide applicable training and education to those whose jobs will be transitioned by technology. The worker also is responsible for making sure she adapts his or her skills to capitalize on these new opportunities.

And **we won't be able to close the skill gap with the current costs of education.** The size of student debt has already skyrocketed to surpass that of auto loans²⁴. Providing financial incentives to students who undertake STEM training will help. Companies could offer student loan forgiveness packages to new hires in lieu of or in addition to stock options or 401k matching. They could also offer housing assistance to allow recent graduates who are burdened by their student debt to leave their parents' nest.



Generational dynamics

Even with such burdensome costs, **the workforce does seem to be adapting, attaining higher levels of education than previous generations.** A survey undertaken by the Pew Research Center demonstrated that in previous generations, more people ended their education once they received a high school diploma than went on to receive at least a Bachelor's degree. While one-third of Gen Xers in 1995 quit their schooling after earning a high school diploma, only one-quarter had a bachelor's degree. This level of college education had held steady since the 1970's.²⁵

But millennials are flipping this on its head; as of 2013, thirty-four percent of respondents now had a Bachelor's degree while only 25% ended their education after high school¹⁸. AM technologies are poised to cause a rise in demand for skilled workers and the rise in college educated Millennials will help close the skills gap.

This sea change in educational attainment could have various causes. Some students may have understood the shift in skillsets that are in demand. The poor job prospects during the Financial Crisis may have led people to continue education or stay in school longer to avoid the unemployment line. The increased availability and access to student loans could also have enticed students to expand their education.

Higher education levels are necessary to compete in the new digital world of advanced manufacturing.

And coming up quickly behind the Millennials is Generation Z, or those born from the late 1990s through the early 2010s. Early research points to a generation that is industrious, collaborative, entrepreneurial, community-oriented, and financially prudent.

This is also a generation that will be highly-educated, but places less value on traditional higher education. They will likely attain high levels of education (which is good), but are jaded about whether those degrees will translate into real world value based on how much education currently costs.

Many in this generation also place a higher premium on high-tech literacy and skills. They are the new engineers, programmers and developers. They represent an enormous talent pool. Some are choosing to forego higher education, in favor of being directly hired as teenagers.

This generation – similarly to millennials, but even more so – is entering an educational pipeline that is struggling to modernize. Many may seek to attain relevant and transferrable marketplace skills outside the bounds of a traditional academic setting.

Whatever the reason, the higher levels of education being achieved by today's younger demographics are necessary to compete in the new digital world of advanced manufacturing.

Kelli Wells, executive director of education programs at GE Foundation, on STEM education:

GE appreciates the need to invest in STEM education for pipeline and economic development. In 2013, we invested in MC2, a STEM High School, after years of intensive collaboration between the Cleveland Metropolitan School District, KeyBank Foundation and Cleveland State University.

The high school is located in Nela Park, Cleveland (also headquarters for GE's lighting and industrial unit), and gives students the experience of both business and higher education. The campus resembles a stately college and has an MIT Fab Lab to support an immersive learning environment with use of the digital fabrication tools across the school's curriculum.²⁶

And students are excelling. Student test scores at MC2 increased from the 43rd to 78th percentile in math. Even more surprising, test scores in reading increased from the 38th to 75th ranking, a testament to the power of differentiated instruction in liberal arts as well as STEM subjects.

However, this impact generated by MIT Fab Lab users is far beyond improving test scores in STEM education. Stories abound of students who had never imagined going into a STEM-oriented career, now entering engineering and science degree programs.²⁷

On a wider scale, GE Foundation invested more than \$250 million in STEM development and thousands of hours from GE Volunteers to support student achievement and professional development for teachers in K-12 public schools across the country, impacting 10,000 educators and 1.3 million students spanning more than 2,000 K-12 public schools. Its goal is to ensure that students graduate from high school, college- and career- ready, with a special emphasis on developing STEM capabilities.

A few results highlighting the success of the initiative include: Jefferson County Public Schools, in Kentucky, achieved a 14-point gain on student mathematics assessments, compared to an overall state gain of six points. Cincinnati Public Schools achieved a rank of 13th out of 609 school districts in Ohio in student achievement.



Bridging the skills gap

Despite the fact that today's graduates matriculate with more advanced degrees, the types of skills they are learning during their extra years of education are not matching what the skills of today's Advanced Manufacturers are looking for.

A 2014 expose in the New York Times magazine looked at 14 recent graduates from across the U.S. whose low salary combined with burden of college debt had them still living in their parent's homes. None of the 14 had STEM degrees.²⁸

In addition to the skills gap, **colleges and universities are not educating enough students to fill even the current available positions in manufacturing.** In addition to the previously mentioned shortage of engineers during the Global Financial Crisis reported by SME, Boston Consulting predicts that by 2020 there will be a shortage of 875,000 manufacturing workers in the U.S.²⁹

The problem is not getting better. For those people directly employed in a manufacturing environment characterized by 3D-printing technology, an advanced skill set will surely be necessary. "Machinists" will go from being a blue collar profession to one where advanced technical skills will be required.

One solution is **for firms to begin working with students and universities earlier in the education process to help craft curriculum that would allow graduates to have a better base of knowledge coming out of school.** Some firms are even foregoing college grads, hiring workers with less formal schooling, and training them in applicable skills.

This strategy has the potential to build a long-lasting loyal relationship with talent, create a pipeline of workers that will enable manufactures to keep product costs lower thanks to lower labor costs, and ensure that talent is steeped in the culture of an organization.

In the near future, we may very well see a greater blending of the human resources and information technology functions within an organization. More of

the “labor force” will consist of smart machines, systems, software and robots.

Who will “hire” these smart technologies? And beyond this, those technologies are going to work seamlessly, side-by-side, with human labor as part of more efficient structures than ever before.

The nomadic workforce

Meanwhile, the sharing economy so embraced by millennials and Gen Z—think Uber, Airbnb and others—has for the most part been driven by consumer facing industries and start-ups. As this sharing economy trends into the B-to-B world, it has spawned companies like Hourly Nerd, GLG and others.

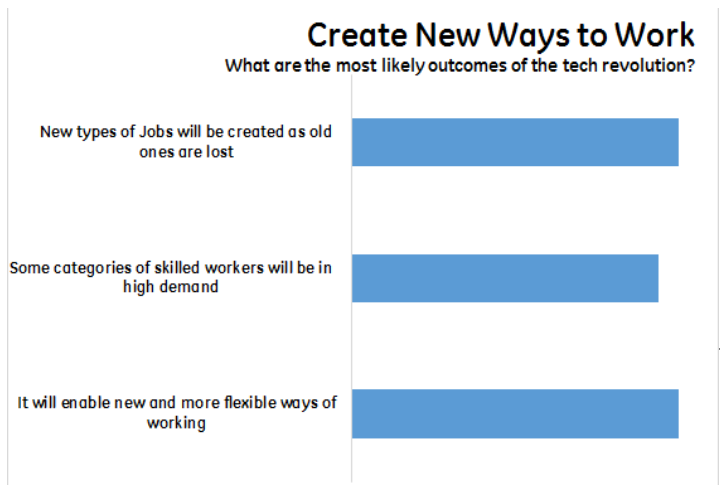
This has created both **an opportunity for workers, but also a challenge for corporations with traditional business models**. 48% of the informed public interviewed in the GE Global Innovation Barometer believe the digital revolution will enable new and more flexible ways of working.

This nomad workforce, the ranks of workers who want to have flexibility in their regular work routine, is rising thanks to the benefits of personalized scheduling, which is becoming an expectation. **This type of scheduling flexibility, combined with mobile and social platform adoption, created a new cultural expectation within the workforce**. The flexibility to set one’s own “shift,” to try out different industries and careers, and to supplement core income sources with part time or temporary gigs is becoming an increasingly important benefit to workers.

Flexibility is one of two key components driving the Nomad workforce. Benefits are the second component. “Hard” benefits include financial incentives like 401k plans, stock options, health care and life insurance, and something as simple as a regularly dependable recurring paycheck. “Soft” benefits include quality of life factors and the flexibility of location and time management: not being required to go into the same office every day at the same allotted time.

Soft benefits are becoming more important for the younger generation of workers, and may even be driving career decisions.

The Pew Research study mentioned earlier also looked at other traits of the millennial generation that could be driving this prioritization of soft benefits over hard ones. Pew reports that people are not getting married until they are older. In 2013, only 26% of people aged 18-32 were married. This number has dropped steadily with each generation. In 1997 36% of this age group were married, in 1980 it was 48% and in 1960 a majority of 18-32 year olds, 60%, were married²⁰.



Additionally, medical advances have made it increasingly likely that children born to older adults are healthy. Life expectancy is also increasing. The UK Office of National Statistics reported that 1 out of every 3 children born in 2012 would live to be 100.³⁰

In previous generations, marriage and children were typically all life events that occurred in the 20’s or early 30’s. That no longer needs to be the norm. With families not in the equation until potentially 10 to 15 years into a career, a tectonic shift in the balance between the need for hard and soft benefits has occurred.³¹

These life events pushed people to take jobs and start careers with one focused goal in mind: to provide hard benefits for their families.

One of the hard benefits that workers needed to provide their families has traditionally, in the United States, been

health benefits. With the expansion of universal health care, the need for this hard benefit has been minimized. **Health care is now available to all, and should help to unleash potential business innovators that were trapped** by “Entrepreneur Lock.”³²

This theory posits that some workers, especially those with pre-existing health problems, were locked into staying with firms that provide health benefits. But Craig Garthwaite, professor of management and strategy at the Kellogg School of Management, estimated that implementation of the Affordable Care Act could move 500,000 to 900,000 people to leave the labor market. Dane Stangler, vice president of research and policy at the Kauffman Foundation, estimates that about 25,000 new business could be created each year.³³

The sheer pace of change is making it difficult for the formal workforce to play ‘catch-up.’

We also suspect that those of or approaching retirement age will become a significant demographic of the Nomad workforce. Many people facing retirement want the same things as the younger generation – scheduling flexibility for a higher quality of life and time to accomplish things they never had time to do while maintaining a full time career.

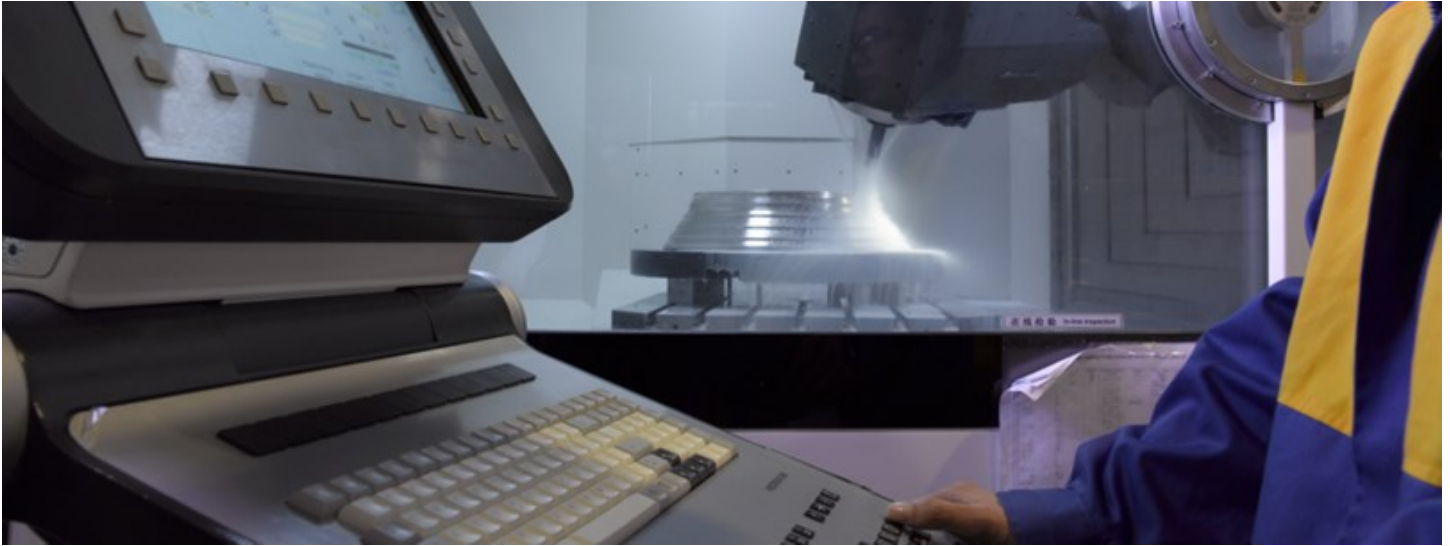
However, **with the rising costs of healthcare to support longer life expectancy rates, fewer companies offering pensions, and more volatility in markets where 401K investments reside, retirees need to subsidize retirement with income.** Nomadic work offers them career choices and a more balanced lifestyle, while companies can continue to leverage their expertise.

While the flexible scheduling and working environments help workers with their career choices and a more balanced lifestyle, it has some negative effects as well. Companies could lose control over a significant amount of domain experience.

The challenge in manufacturing (not just in advanced manufacturing industries) is how to adapt to attract workers who do not want to be full-time employees.

Identifying specific roles on the factory floor that do not require full time employees will be an avenue to allow the Nomad workforce entrance into manufacturing while also allowing managers at plants to ease their way into understanding how to lead this demographic.

It will take a reimagining of the workforce to provide an environment that Nomad’s will accept. Failing to adjust to their needs may push them into other careers.



Planning for tomorrow's workers

Q&A with James Gallman, Strategic Workforce Planning Leader, GE

How concerning is the skills gap between what young professionals bring to the table and what manufacturing businesses need?

The biggest concern is about the speed of change. Students are being trained in traditional educational frameworks that are not modernizing quickly enough to reflect the evolving manufacturing landscape. For example, there are far too few programs in techniques such as additive manufacturing. The counterbalance is that many students come in with a wide variety of interests and mental agility that allows them to adapt quickly. Also, younger workers come to the company with a native understanding of technology and how it can be used and integrated into life and work.

How will the Nomad workforce—those individuals that do not necessarily seek full time employment but favor free-lancing or contracting mode—impact manufacturers?

Actually, this workforce could be quite beneficial for advanced manufacturing. Having a set of highly skilled and globally mobile employees will help companies to do short-term expert work such as factory shutdowns and equipment changeovers. They would also fit in as part of the service repair and installation workforce, which is growing in size and need for skill. Both of these types of work demand higher skills but do not require long-term company affiliation.

What role should universities play in better preparing students for the skillsets needed in Advanced Manufacturing?

This answer is probably going to be a little bit surprising. Rather than push, as many others have, for a reduced emphasis on a liberal education, it might be better to complement the advantages of this education with more exposure to manufacturing. It would help the students in their ability to see alternate points of view and help menu factoring by bringing a broader set of skills into the workplace.

The other more obvious answer, of course, is that manufacturing matters. We have to get universities to continue to share with students that there's more to the world than the app economy. In fact, this could play well for certain students who are going to be better suited in a manufacturing world than in a software world.

STEM roles are traditionally male-centric. How can more women be attracted to this type of role?

The most important way to remove this barrier is by showcasing female role models in manufacturing. The one factor that we often talk about is the ability of women to maintain their independence financially via a STEM job. This is meaningful work that has impact. Talking candidly about this message happens to resonate well in the developed and developing world.

Will automation and robotics cost people their jobs?

Yes and no. The jobs that will be lost are more mundane and routine work. The jobs that will be gained will be those that require higher skills and thus higher pay. The actual challenge here is when the job is not lost - but transformed. In this case, we actually need a better skilled worker than we have hired for the older techniques in manufacturing. This is where all of our internal skills-based training and our partnerships with local community colleges really come into play.

9. Conclusions

Daniela Rus, a computer scientist and professor at MIT, wrote that “robots are better than humans at crunching numbers, lifting heavy objects, and, in certain contexts, moving with precision. Humans are better than robots at abstraction, generalization, and creative thinking, thanks to their ability to reason, draw from prior experience, and imagine.”³⁴

For those people that crunch numbers or lift heavy objects, there may be a disruption from automation in jobs. **But human creativity will still be needed to understand the meaning of those crunched numbers, to determine where to move those heavy objects—and more importantly, to decide for what reason they are being moved.** And it will be up to humans to continually improve upon the precision with which automation works and to find new uses for automation.

The transition the workforce needs to undertake to adapt to advanced manufacturing technology is not one that will happen overnight. While the transition is already underway, some jobs will be eliminated and wages will need some time to adjust. Early adopters to the skillsets in demand in the digital age will benefit, but the wage gap could expand until the skillset gap closes.

So what can today's workforce do? Be a driver of change, a change agent. Constantly grow their skill set, be adaptive and curious. Never be content; Digital Darwinism will feed not just on slow-to-adapt companies, but will also feed on slow-to-adapt workers.

But it is not just the responsibility of the workforce. GE's Innovation Barometer asked respondents if they felt businesses had to increase their responsibility for providing educational support to their employees to update their skill sets. Globally only 32% of business executives agreed. We feel firms need to do more.

Businesses must provide training and opportunities to their workers to help them adapt to the new jobs being created by AM technologies. This in turn will create loyalty. As technology continues to develop, workers will

trust that employers will look at them as partners for growth and provide opportunities to grow their skillsets to best take advantage of ever changing technology.

Business leaders fear falling behind. They can prevent this from happening by having a tech-savvy, adaptive, educated and loyal workforce. Leadership must encompass a digital savviness—not only to understand the Information technology, but also to understand the new business models that go with it. Data is very valuable. More so than ever, leadership needs to be able to innovate and think differently.

Governments need to promote innovation by supporting students who get into STEM career paths. Providing tuition assistance, relieving student debt and ensuring state school systems have curriculum that prepares students for jobs in AM industries.

Governments can also promote entrepreneurs and innovative companies by creating tax structures that are attractive to business and permit local manufacturers to stay competitive in the global marketplace.

New technologies are augmenting the capabilities of existing workers at all skill levels. Workers will have to adapt their skill set to a future where we will see collaboration between humans and machines; a collaboration that will create a safer, more efficient working environment.

Technology is always advancing. It is not an extinction level event for workers. Though certain tasks can and will be automated, that automation is Version 1.0.

The opportunities exist for human beings to create the next versions—better, faster, more customer-centric. Competition will ensure jobs will be there for the innovators, the designers, the creators, the technicians, the marketing and sales people. **Companies need to promote an environment that prepares the workforce to adapt to win in the ever changing Future of Work.**

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Advanced manufacturing defined industries

- | | | |
|--|--|--|
| 1) Aerospace Product and Parts | 11) Engine, Turbine, and Power | 22) Other Electrical Equipment and Component |
| 2) Agriculture, Construction, and Mining Machinery | 12) Transmission Equipment | 23) Other General Purpose Machinery |
| 3) Alumina and Aluminum Production and Processing | 13) Foundries | 24) Other Miscellaneous Manufacturing |
| 4) Audio and Video Equipment | 14) Household Appliance | 25) Other Transportation Equipment |
| 5) Basic Chemicals | 15) Industrial Machinery | 26) Petroleum and Coal Products |
| 6) Commercial and Service Industry Machinery | 16) Iron and Steel Mills and Ferroalloy | 27) Pharmaceutical and Medicine |
| 7) Communications Equipment | 17) Medical Equipment and Supplies | 28) Railroad Rolling Stock |
| 8) Computer and Peripheral Equipment | 18) Motor Vehicle | 29) Resin, Synthetic Rubber, and Artificial |
| 9) Electric Lighting Equipment | 19) Motor Vehicle Body and Trailer | 30) Synthetic Fibers and Filaments |
| 10) Electrical Equipment | 20) Motor Vehicle Parts | 31) Semiconductor and Other Electronic Component |
| | 21) Navigational, Measuring, Electromedical, & Control Instruments | 32) Ship and Boat Building |
| | 21) Other Chemical Product and Prep | |

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