# ADVANCED TECHNOLOGY, ADVANCED TRAINING

## A NEW POLICY AGENDA FOR U.S. MANUFACTURING

MIT INITIATIVE FOR KNOWLEDGE AND INNOVATION IN MANUFACTURING
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# OVERVIEW

U.S. manufacturers report difficulties finding workers with the skills and experience they need. A common response is that workers need more "advanced manufacturing" skills to match the latest production technologies. But more skills alone will not solve the deeper challenges that American manufacturers face.

U.S. manufacturing productivity – after decades of lackluster growth – has declined since 2010. Inflation-adjusted wages for U.S. production workers have not grown in four decades. Manufacturing-related patents in the United States lag behind competitor nations like China and Japan. The Chinese government's Made in China 2025 initiative has received hundreds of billions of dollars in public funding, according to some estimates,[i] dwarfing the U.S. government's roughly $1 billion investment in the Manufacturing USA Institutes. Current policies lack the scope and the scale to help American manufacturing escape its current low-wage, low-technology equilibrium. More of the same will not produce better results.

MIT's Initiative for Knowledge and Innovation in Manufacturing (IKIM) offers a new analysis of the dilemma facing U.S. manufacturing and points the federal government toward new policy approaches. Our research and proposed policies address both the workforce challenges of large firms investing in advanced production, as well as those of small and medium enterprise (SME) manufacturers. IKIM identifies policies to improve the technological capabilities of SMEs, train more workers in advanced technology fields, and improve the efficiency of workforce training via regional networks and online platforms. The findings of the IKIM research, like those of the recent MIT Taskforce on Work of the Future (2020), show that the acquisition of advanced technology and advanced skills must proceed simultaneously. Both need to accelerate in parallel to achieve significant progress in the manufacturing economy.

In this study, we focus on workforce and acquisition policies that can deliver that change. The recommended policies fall in three categories: (i) stimulating demand for skilled workers, (ii) delivering training through partnerships and platforms, and (iii) developing new content and credentials. We propose a new Manufacturing Academy to put the recommendations of this study into action, coordinating and building on the existing workforce activities of the Manufacturing Innovation Institutes.

Implementing these policies will require the Manufacturing USA network – including the Manufacturing Academy – to grow dramatically in both the scope of its activities and the size of its budget. We propose that the workforce education programs at the Institutes, which are each focused on a particular technology domain, expand to meet regional needs across technology areas. Institutes should invest aggressively in programs to meet SMEs' training and technology challenges. Government agencies, Institutes, and the Academy will need to play the role of investor (funding promising models); convener (building regional coalitions); and standard-setter (endorsing new training content). Expanding the Manufacturing USA network in these ways will require a federal government commitment to the manufacturing economy that rivals that of U.S. competitors.

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## About IKIM

The Initiative for Knowledge and Innovation in Manufacturing (IKIM) aims to foster a thriving domestic manufacturing ecosystem by educating an agile workforce; creating resilient innovation in manufacturing processes; developing nimble organizations; and proposing transformative policies.

## Acknowledgements

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## Methodological Note

This study draws on the research team's 30+ interviews with U.S. manufacturing firms, as well as interviews with government officials, community colleges, and related organizations. The study also cites a variety of domestic and international data sources that measure the performance of the manufacturing economy over the past 70 years. This project builds on research and interviews from previous MIT initiatives on related subjects, including the 2020 Work of the Future Task Force, the 2013 Production in the Innovation Economy (PIE) initiative, and the 1989 Made in America study, each of which conducted interviews with an array of firms and other organizations to generate new knowledge and new policy recommendations about the future of U.S. manufacturing.

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# I. Vision: A New 'Arsenal of Democracy'

In the 1940s when American manufacturing was thriving, government initiatives combined with private action to make industry a driver of growth, military strength, technological innovation, and good jobs. By the late 1940s, U.S. manufactured goods comprised 30% of global exports, and the United States led the world in patent filings.[ii] The rapid growth of U.S. manufacturing jobs and output during this period followed the military's push to mobilize what President Franklin Roosevelt called the "Arsenal of Democracy" at American factories to support the Allied war effort.[iii]

U.S. manufacturers pioneered the development of industrial robots, electronic hardware, and machine tools. In each of these domains, the government provided funding for Research & Development that led to new technologies, and made markets for those new technologies through procurement.

Government customers bought the initial microchips that Texas Instruments and Fairchild Semiconductor produced.[iv] Between 1955 and 1960 when the first semiconductors were produced, government customers made 36% to 45% of all semiconductor purchases. During the same period, the government invested resources in boosting the market for early numerically-controlled machines. The U.S. Army built 120 units and leased them to American firms.[v]

American manufacturing workers benefited from the expansion of public high schools to build skills in math and machining. Vocational schools multiplied during the two World Wars and included machine shops, forges, and foundries to train new manufacturing recruits. In wartime, branches of the military coordinated with vocational schools to boost local training capacity.[vi] And when students with machining or welding skills graduated high school, the jobs that they entered frequently paid higher wages than the national average.[vii]

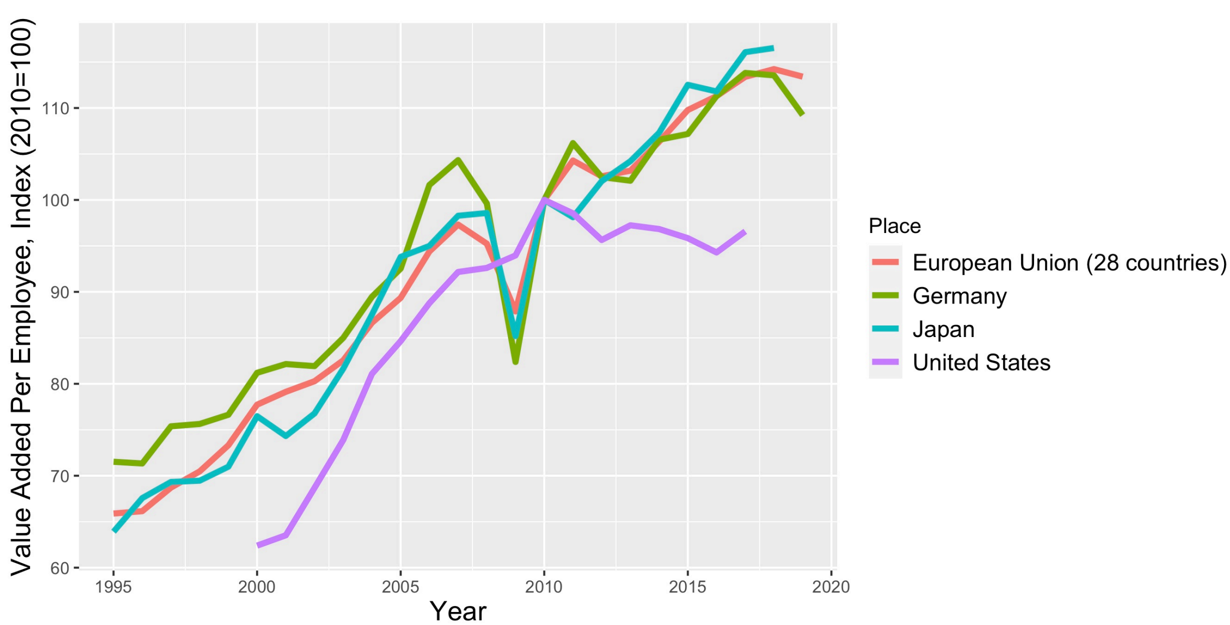
In the decades that followed, the manufacturing economy has changed dramatically – in size, focus, and competitiveness. The share of world exports coming from U.S. manufacturers has dropped from 30% to 9%.[viii] The number of U.S. manufacturing jobs is 40% lower than its peak.

American factories have shifted from specializing in low-cost, high-volume manufacturing, to higher-cost, higher-variety production. Original equipment manufacturers (OEMs) with headquarters in the United States now frequently manage distributed global supply chains to produce their final products – a far cry from vertically-integrated firms of the past.[ix]

And while many individual American manufacturers have thrived during this period, American manufacturing as an industry has lagged behind competitor nations like China, Germany, and Japan. In global data on manufacturing productivity, the United States is losing ground (see Figure 1).

The COVID-19 pandemic has underscored the value of speedy, flexible, domestic manufacturing. When demand for PPE, ventilators, and other goods spiked, manufacturers across the world scrambled to produce much-needed equipment. Many factories had to produce large batches of products they had never made before – and fast. With shipping delayed and trade stalled, supply chains that were global months before became domestic. The places that were able to produce and distribute essential goods became the places better prepared to fend off the spreading virus.

FIGURE 1. THE PRODUCTIVITY PROBLEM IN U.S. MANUFACTURING[x]




Note: since 2010, U.S. manufacturing productivity has declined as peer countries and regions have experienced productivity growth.

Despite these transformations, the value of the manufacturing economy remains the same: providing goods to consumers domestically and globally; reliable and advanced equipment for the military, innovation for the broader economy, and upwardly-mobile jobs for American workers. The goal of this study is to identify ways that the government can help U.S. manufacturing workers – as well as their employers – to realize these aims.

The federal government already invests in a variety of programs and policies that support U.S. manufacturers. Examples include the Manufacturing Extension Program (MEP), which focuses on improving the productivity of small manufacturers, and the Small Business Innovation Research (SBIR) program, which seeks to stimulate technological development across industries through investments in research and technology development.

The most significant recent federal industrial policy is the Manufacturing USA network of Innovation Institutes. Over the past decade, the Department of Defense, the Department of Energy, and the Department of Commerce have established 16 Institutes, each focusing on a particular technology area. Each Institute is designed to serve as an industrial commons for a technology domain (e.g. additive manufacturing, photonics), bringing together research institutions and private firms. In FY 2019, federal funding for the Manufacturing USA Institutes was $133 million.[xi]

Manufacturing USA Institutes aim to advance the technological frontier of U.S. manufacturing. Institutes convene and fund collaborations between firms and universities on research projects to pursue promising technological advances. Some institutes have also developed programs for the manufacturing workforce, developing curricula and training workers in the technologies and techniques relevant to an Institute's disciplinary focus. AIM Photonics, for example, has developed online courses and an in-person bootcamp focused on improving incumbent workers' skills in integrated photonics.

The United States is not alone in pursuing efforts like these. Indeed, China and Germany, among other nations, have invested in similar industrial policy efforts – in some cases with broader scope and more ambitious funding than the United States. Germany is home to the Fraunhofer-Gesellschaft network that conducts applied research – largely in manufacturing-related fields –with an *annual* budget of approximately $2.8 Billion derived from private sector and government sources.[xii] The Made in China 2025 industrial policy initiative has a much broader scope than Manufacturing USA, setting ambitious targets for R&D and production across a variety of technologies. Made in China 2025 invests in innovation centers as well as investment funds to subsidize manufacturing businesses. Data on Chinese government expenditures vary, but some estimates of Chinese industrial policy expenditures are in the hundreds of billions of dollars – far outpacing U.S. public investment.[xiii]

The MIT IKIM study seeks to expand the size and scope of the workforce programs of the Manufacturing USA Institutes, as well as federal programs like MEP and SBIR. It identifies ways to meet the workforce needs of large firms that are pushing the technological frontier, some of which are involved in Manufacturing USA Institute programs. The study also emphasizes the importance of tackling the workforce and technological challenges facing smaller, less technologically-advanced manufacturers. When these firms struggle, they constrain the capabilities of entire supply chains. Improving U.S. manufacturing productivity will require federal interventions that both push the frontier and build up the lower tiers.

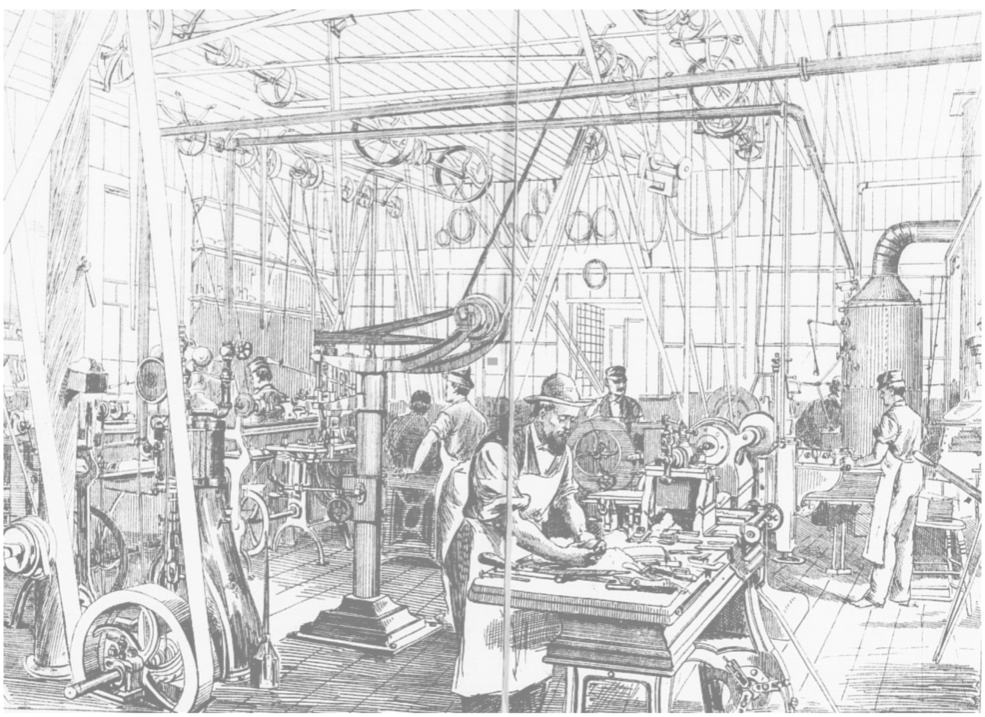


Image credit: Rutgers University Thomas A. Edison Papers, Edison Innovation Series – The Invention Factory. http://edison.rutgers.edu/inventionfactory.htm.

# II. Challenges: Escaping a Low-technology, Low-wage Equilibrium

One of the clearest symptoms of America's manufacturing challenges is stalled productivity. Between 2010 and 2020, the productivity of American manufacturers declined in absolute terms as well as relative to foreign competitors. Recent studies of American manufacturing productivity suggest that past measures of American productivity overstated the growth of American manufacturing productivity for decades as American factories shuttered and millions of workers lost their jobs.[xiv] For American manufacturers to continue producing goods reliably and at the technological frontier, plants must continue to improve productivity. But stagnating productivity is a symptom – not an underlying cause – of lost manufacturing competitiveness.

What explains the productivity challenges facing U.S. manufacturers? According to industry-wide data on U.S. manufacturing, as well as our firm-level interviews with manufacturing leaders, insufficient investments in new technologies and inadequate workforce development stand in the way of productivity growth.

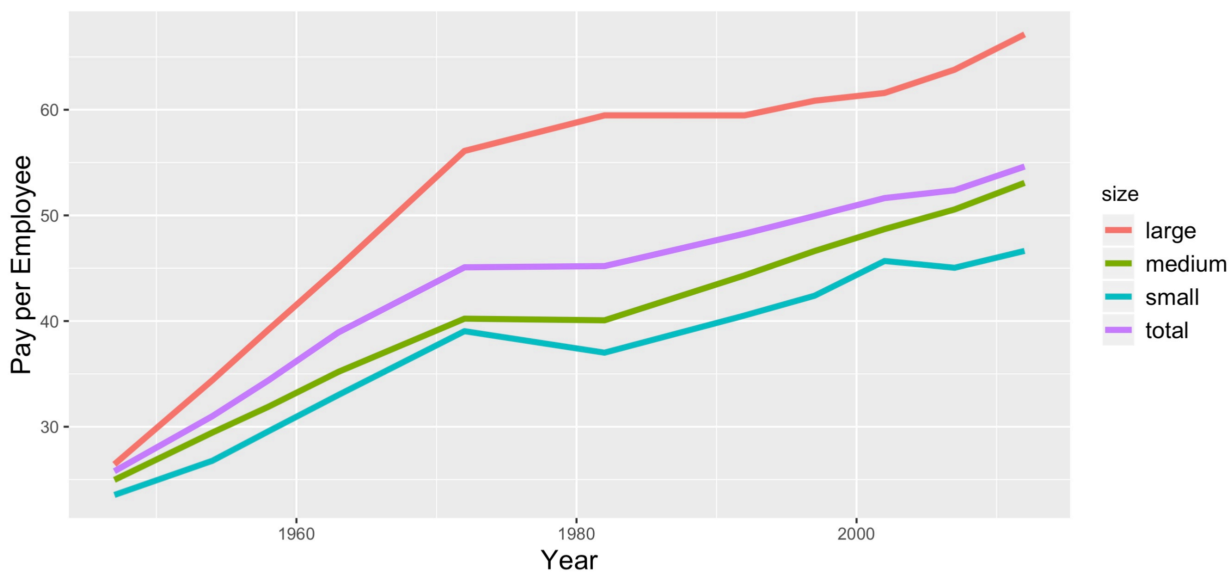
Although this study focuses on ways to improve the capabilities of the manufacturing workforce, manufacturing workers and manufacturing technologies are interdependent. Workers in a low-technology factory will require different training – and have different opportunities – than workers in a factory equipped with advanced technologies. Factories with more advanced technological environments are more likely to adopt strong workforce training practices for their workers.[xv]

Current research indicates that many U.S. manufacturing firms operate in a comparatively low-wage, low-technology equilibrium. These problems are particularly prevalent at Small and Medium Enterprise (SME) manufacturers (firms or plants with fewer than 500 employees), which make up a large portion of U.S. factories and the Defense Industrial Base.[xvi]

A large share of SME manufacturers contributes to the defense industrial base in some way. More than 40% of one sample of SME manufacturers in Ohio had a contract or sub-contract with the

Department of Defense since 2008.[xvii] A similar proportion of manufacturing SMEs in New England have some relationship with the DoD. Approximately half of all facilities supplying the Department of Defense have annual revenues of $25 million or less.[xviii]

## FIGURE 2. THE PAY GAP BETWEEN LARGE AND SMALL MANUFACTURERS[xix]




Note: The pay per worker at large manufacturing plants has been consistently higher than pay per worker at small and medium plants. The pay gap between large and small plants has grown since 2000.

The challenge for these firms is that low wages and low technology investment are mutually reinforcing. New technology acquisitions will require firms to invest in training their current workers, or recruiting workers with new skills. In either case, the more skilled workers are likely to demand higher wages. Low-wage, low-technology SMEs are not necessarily low-skill firms. These firms frequently require workers to possess high levels of skills to perform difficult tasks with equipment that may be generations old. However, workers at these firms receive lower wages on average (Figure 2). Manufacturing Innovation Institutes have strong connections to large firms, but in many cases SMEs are less represented among Institute members and active participants. A central aim of this study is to identify ways to improve the skills and technological capabilities of American manufacturers with a particular focus on improving the capabilities of SMEs.

For the past decade, the federal government has invested in revitalizing the U.S. manufacturing economy through the Manufacturing USA program. The network of Manufacturing Innovation Institutes represents one approach to the workforce and technology challenges facing U.S. manufacturers, but they do not address many other manufacturing weaknesses. Manufacturing Innovation Institutes have sought to push the technological frontier in specific domains, all while creating training opportunities to bridge the "skills gap" between workers' current capabilities and the capabilities required to operate the newest manufacturing technologies. The implicit assumption behind the skills gap approach is that manufacturing firms have adopted and developed new technologies faster than manufacturing workers have learned how to operate them.

One limitation of the skills gap approach is that training focused on advanced technologies is most relevant to firms that are more technologically advanced, more productive, and pay higher wages. Moreover, addressing the skills gap in one technology area – such as robotics – does little to improve the capabilities of firms in adjacent fields.

Addressing the skills gap alone would not provide any remedy for the struggles of lower-technology suppliers. The wider the divide between the capabilities of large, high-tech firms and weaker suppliers, the more large firms will be forced to make advanced technology components in-house or purchase them from abroad rather than buy them from U.S. suppliers. Lagging capabilities of small US suppliers risks limiting the technological complexity of the goods that the United States can produce domestically, especially for the DoD.

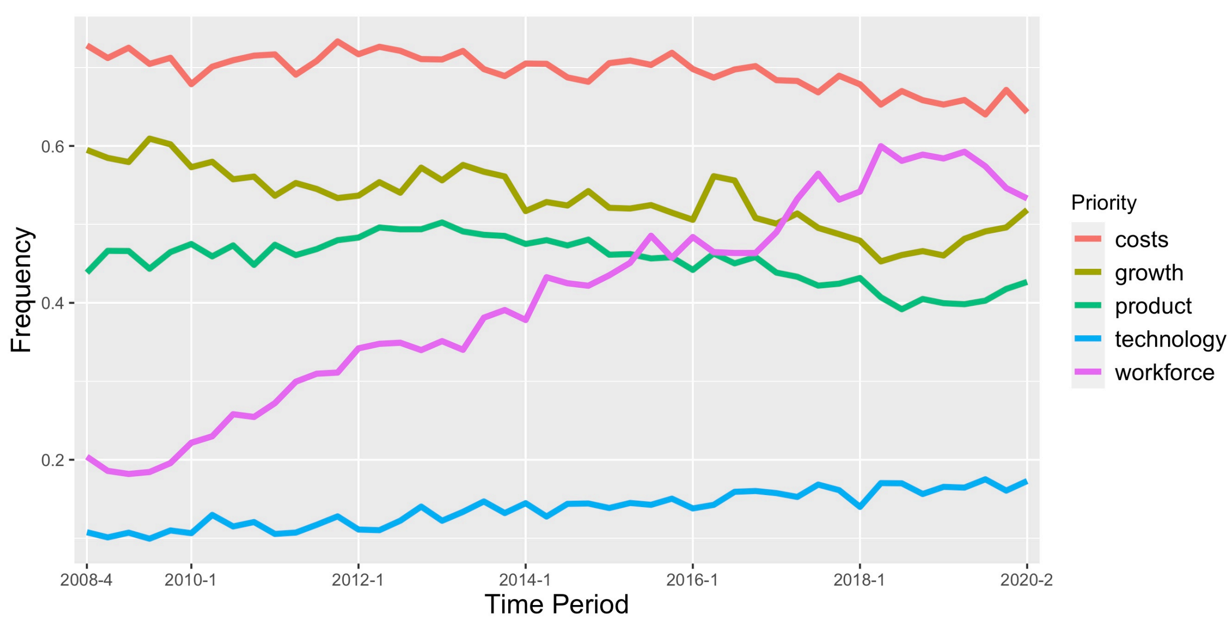
## i. Workforce Challenges

Leaders of manufacturing firms as well as industry analysts report that their firms have difficulty finding workers with the skills and experience to fill their open positions. After more than three decades of job losses and factory closures, U.S. manufacturers added more than one million jobs between 2010 and 2020, growing the manufacturing workforce by 12%.[xx] As manufacturing employment began to grow (albeit gradually), job openings in manufacturing climbed from around 150,000 in 2010 to more than 500,000 in 2018.[xxi]

Industry reports indicate that the impending retirement of more than 2.5 million workers over the next decade could exacerbate manufacturers' workforce challenges.[xxii]

Surveys of manufacturing firms that have worked with the federal government's Manufacturing Extension Program document how the priorities of U.S. manufacturing firms have evolved over time. In 2010, as some firms were emerging from the recession, their most common priorities were cutting costs, finding ways to grow, developing new products, and environmental sustainability. Workforce recruitment and retention was fifth out of nine potential priorities. By 2018, workforce issues were second only to cost-cutting (Figure 3).

## Figure 3. Workforce Issues a Growing Priority for SMEs



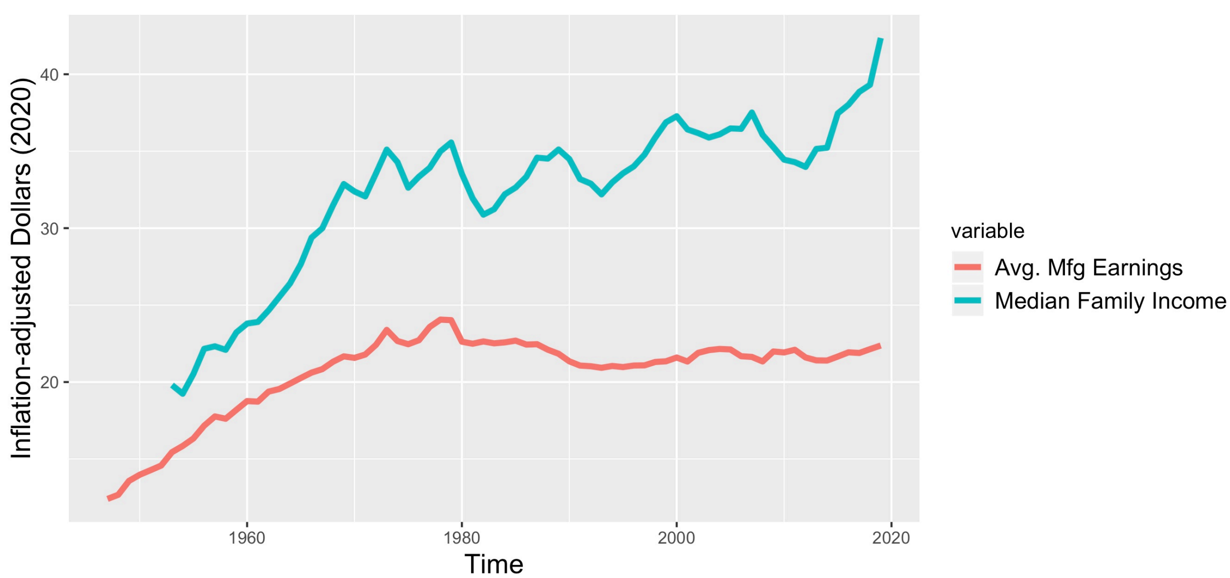

Note: SMEs' interest in addressing workforce development and retention challenges have grown substantially as other priority areas have been stable.

All the while, wages for the average production worker stagnated. After World War II, as U.S. manufacturers continued to innovate and add production jobs, the average wage adjusted for inflation nearly doubled in three decades – from $12.40 per hour (2020 dollars) in 1947 to $24 per hour in 1978. In the four following decades, average production wages in manufacturing stagnated and even declined, settling between $21 and $23 per hour between 2000 and 2020. All the while, the median family income has grown by comparison (Figure 4). When employers report a shortage of skilled workers, one might expect that wages would rise. What can explain the high demand and stagnant wages for U.S. manufacturing workers?

## a. On-the-job training

One explanation is that U.S. manufacturers – particularly SMEs – have adapted to a skill shortage by hiring inexperienced workers and providing them with extensive on-the-job training. In our interviews, manufacturing executives at SMEs in the defense supply chain explain that they hire workers for "will" more than "skill." Several manufacturing executives say that they would hire workers with experience if they could recruit them. Absent a pool of skilled workers, they hire workers who show up on time and ready to learn.

FIGURE 4. WAGE STAGNATION FOR PRODUCTION WORKERS[xxiii]




Note: Inflation-adjusted hourly wages for production workers in manufacturing have been flat for decades. Even the slow growth of median family income (hourly estimate) has outpaced manufacturing wages.

It may take years for these workers to learn all the skills required for precise, high-quality production. Manufacturing executives report that it can be 2-5 years before an entry-level worker can be fully self-sufficient on the job. This extended length of time to provide workers on-the-job training is burdensome for individual firms as well as the industry as whole. For firms, training can be extraordinarily costly given that time workers are paid to learn is not typically time that workers are producing. Moreover, on-the-job training is designed to give workers skills to excel at a particular firm – not necessarily the flexibility to move between firms with related specialties. Even if on-the-job training is growing the number of skilled manufacturing workers, it is not necessarily growing the common pool of skilled workers from which many manufacturers can recruit.

Firms have always performed some degree of on-the-job training for new hires, but the length and extent of on-the-job training at SME manufacturers in the U.S. is remarkable. Several factors contribute to the challenges associated with the "hire for will, train for skill" model:

1. **Training jacks-of-all-trades.** Firms explain that on-the-job training frequently takes so long due to the variety of tasks that today's manufacturing workers perform. An executive at a manufacturer of low-volume, high-margin goods for the Department of Defense said that each of its trainees might only see one task a few times per year. When a manufacturing firm builds many different products, each in small batches, the technician must learn how to respond in a variety of environments rather than master a particular place in the production line. If repetition helps build expertise, then it might seem inevitable that on-the-job training at manufacturers takes a long time.

2. **Companies, not classrooms.** The first goal of the manufacturing firm is to build products and ship them to customers. The shop floor is designed to produce goods efficiently – not to help trainees learn. Senior production workers on the shop floor are simultaneously responsible for helping junior colleagues *and* keeping the production process moving. Training typically pulls workers away from their production work. And when trainees excel, firms risk poaching by their competitors.

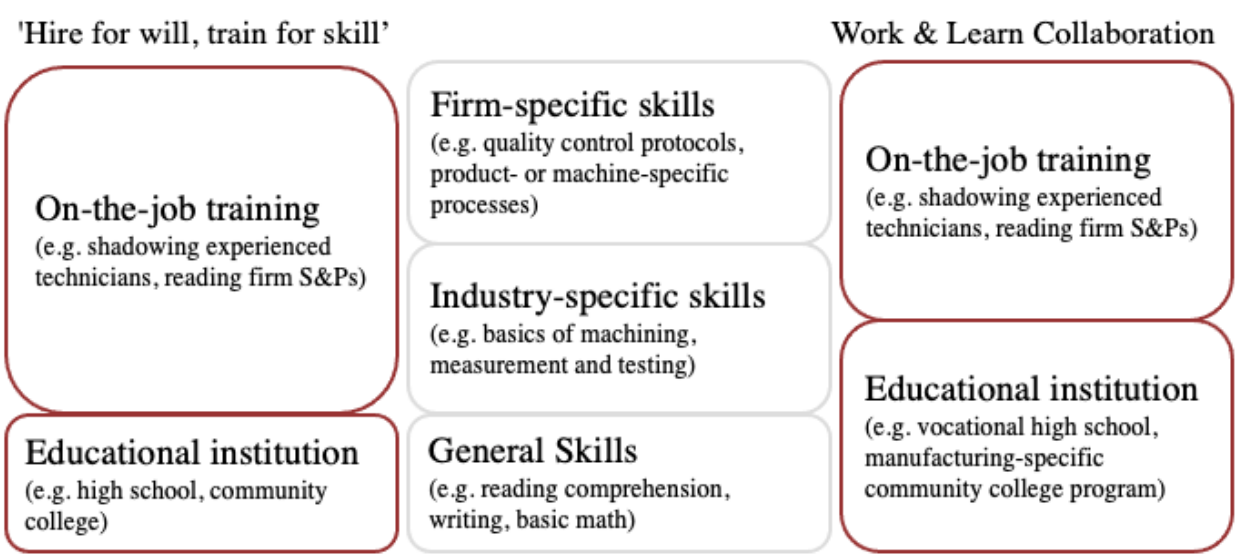
3. **Low-flow talent pipeline**. Manufacturing executives claim that young people are not tempted by manufacturing careers. They attribute the problem to the decline in vocational opportunities (e.g. disinvestments from 'shop class') as well as a broader image problem that deters young people from manufacturing careers. Manufacturing leaders say the jobs that their firms currently offer are different from the dirty and dangerous jobs of the past. Another interpretation of the pipeline problems based on industry data is that manufacturing employment declined substantially over multiple

generations, and too many remaining manufacturing jobs pay low or stagnant wages. These factors – in addition to those that manufacturing executives cite – could also contribute to the lack of interest in manufacturing careers. The absence of young workers ready to enter manufacturing careers could also be due to decades of job losses in manufacturing, coupled with low wages.

## b. Collaborative Training Models

The most prominent alternative to on-the-job training is formal education in manufacturing disciplines at vocational high schools and/or community colleges. Historically, U.S. firms could recruit a pool of workers with industry experience, as well as entry-level graduates with skills developed through educational programs. Vocational education that provides "industry-specific skills" still thrives in European countries like Germany and Switzerland.[xxiv] In these models, where students develop manufacturing skills that they bring to employers, some on-the-job training is still required. Formal education provides industry-specific skills (e.g. basics of machining, measurement, and testing), whereas on-the-job training provides complementary, firm-specific skills (e.g. processes and techniques tailored to products and machines).

FIGURE 5. SKILL DEVELOPMENT IN COLLABORATIVE TRAINING MODELS



A study of two New Hampshire manufacturing firms, one small and one large, highlights the potential advantages for U.S. manufacturers that partner with educational institutions.[xxv] The small firm relied heavily on on-the-job training. The larger firm partnered with a community college, designed a curriculum that met its production needs, and hired graduates of the program. The partnership offered a far more efficient approach to workforce training.

See the appendix for case studies of promising community college programs that provide work-and-learn opportunities for prospective manufacturing workers.

However, leaders of SME manufacturers report in interviews that many graduates from these programs still require years of on-the-job training. SME manufacturing executives consistently lamented that local educational institutions were not focused on developing skills that were relevant to their business. These criticisms are consistent with research that suggests that much of vocational training in the United States has insufficient employer engagement.[xxvi]

The skill challenges that U.S. manufacturers face vary in part due to the technological capabilities of the firms. How a manufacturer decides which workers to recruit, how to provide on-the-job training, and whether to partner with a community college will depend in part on the technological capabilities they have and the technological requirements of their products. These technologies are not fixed – as firms adopt new technologies, their workforce needs and approaches can change as well.

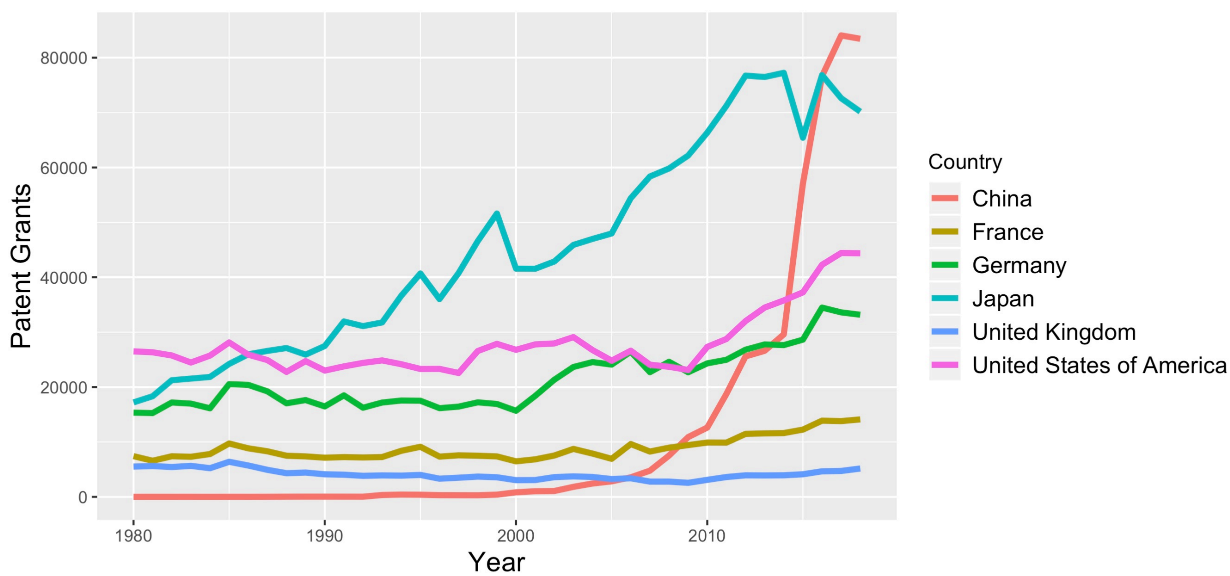
## ii. Technology challenges

The technological capabilities of U.S. manufacturing firms lag in two ways. The first is slow innovation. Over the past four decades, as U.S. manufacturing employment has declined, the United States has lost ground in manufacturing-related patents compared to Japan and China (Figure 6). Research on innovation in manufacturing suggests that the process of invention benefits from the design process being co-located with the early stages of production.[xxvii]

One explanation for slow innovation is that many U.S. manufacturing firms are "home alone," or without an ecosystem of supporting institutions to help transfer knowledge, provide training, and lend technical expertise.[xxviii] Research on U.S. manufacturers suggest that manufacturers without such an ecosystem can struggle to innovate and scale up new technologies. Building connections to a broader manufacturing ecosystem could also improve the efficiency with which manufacturing workers develop new skills.

The second source of technology lag is that small and medium firms have been slow to adopt advanced machines and digital technologies. In interviews with SME manufacturers in the defense supply chain, firms report that they are using machines that are several generations old to produce precision parts for defense applications. For example, one firm relies on 50-year-old machines to fabricate specialty metal parts; another firm reports that only 20% of its machines are numerically controlled. The rest remain manual machines. These observations are consistent with other research on manufacturing SMEs noting the absence of new technologies on the factory floor.[xxix]

## Figure 6. Slow Innovation in Manufacturing-Related Technologies[xxx]



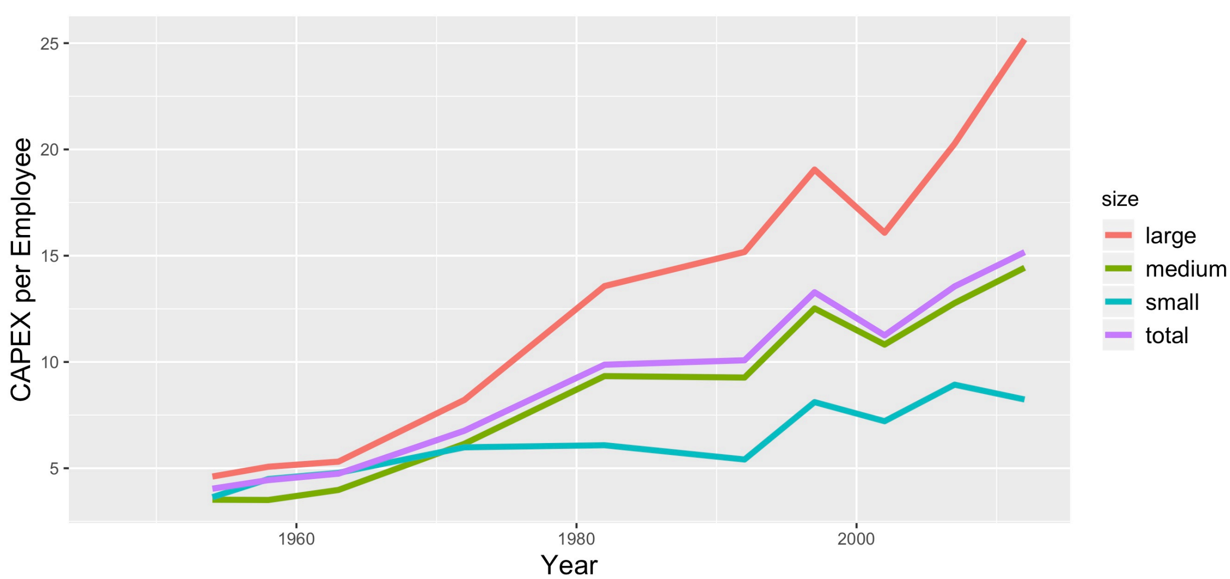

Note: Manufacturing-related patenting in the United States has been stable as Chinese and Japanese patenting has grown dramatically.

In interviews, firms explain their slow adoption of advanced technology in two ways. The first is that since many of these businesses specialize in producing low-volume, high-variety goods, new technologies focused on automation would not be worth their high cost. These technologies, they claim, are most helpful for firms that require a specific task to be performed hundreds of times per shift. By contrast, these firms add value in the variety of precise tasks that they perform to produce a component, assembly, or finished good.

A second explanation is that firms are interested in acquiring more advanced technologies, but they cannot afford to purchase them. Firms often want orders in hand before they decide to finance the purchase of expensive new equipment to avoid undue risk. One CEO of a small manufacturer, for example, reported that he would like to try integrating co-bots (robots that work in tandem with an operator on the shop floor), but he does not currently have the resources to make the purchase.

The underlying challenge is that SME manufacturers typically make technology purchases incrementally. However, getting the most value from new machines may require a more systematic approach that involves purchasing multiple machines at once or even overhauling the production process. The incremental approach of SMEs has been described as "layering" new technologies on old as part of the same overall production process.[xxxi]

## Figure 7. Capital Expenditures per Employee by Manufacturing Firm Size[xxxii]




Note: Capital expenditures per worker have grown much faster at large plants than at small plants, where technology adoption has been slow.

Interview responses are consistent with industry-wide data on capital expenditures by manufacturing plant size (Figure 7), which indicate that capital expenditures per employee at small plants have stagnated for decades. However, larger plants – which have more resources to capitalize on more systematic investments in technology – have increased their capital expenditures per capita dramatically in the past two decades.

The divide in technological capabilities between small and large plants is a problem for the productivity of SMEs, as well as for their supply chains. When small suppliers do not invest in new technologies, then the complexity and the quality of the supply chain can suffer. An OEM developing an electronic device for defense purposes said that the technological shortcomings of their suppliers compared to firms in East Asia limited the complexity of the finished goods they could produce. In another case, a supplier lacked the advanced measurement equipment of their OEM customer, creating problems when the OEM discovered flaws in the component that the supplier could not detect. The technological limitations of U.S. manufacturers ripple through the domestic manufacturing economy.

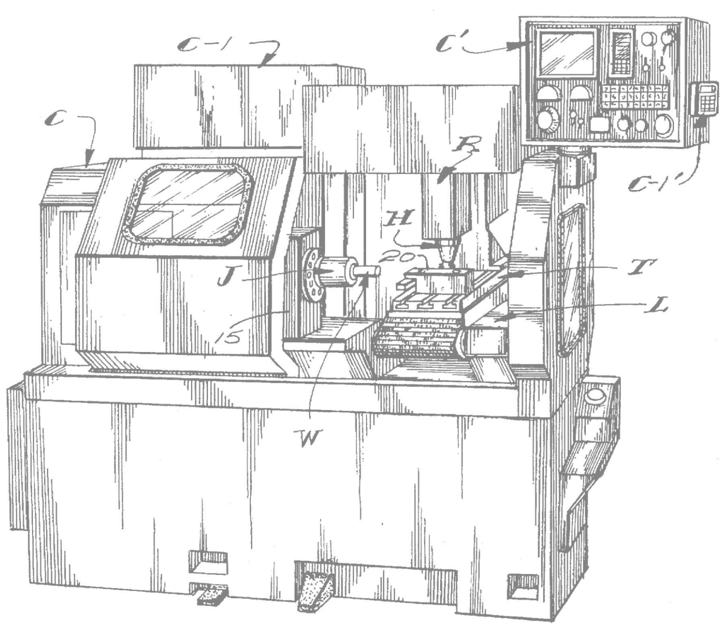



Image credit: United States Patent 5,751,586. "CNC Machine Tool."

# III. Paths Forward: Bridging Gaps in the U.S. Manufacturing Ecosystem

Workforce challenges and technology challenges are linked. When firms lag behind technologically, they do not have reasons to hire workers with advanced manufacturing skills who typically make higher wages. When firms adopt new tools, however, they often invest in new training to manage those tools – and begin hiring workers with technology-relevant skills. The path forward for U.S. manufacturing should aim toward increasing the technological capabilities of firms and increasing the skills of the workforce as well.

This study proposes a three-pronged approach to this challenge. First, it introduces models to stimulate **technology** adoption at manufacturing firms, reducing the technology gap between firms that are more advanced and firms that lag behind. Second, widespread technological progress in manufacturing will require new **training content**. There are promising examples of how firms, governments, and Manufacturing Innovation Institutions can generate new courses and curricula that help workers manage advanced technologies. Third, there are examples of collaborative efforts to provide training in ways that are more cost-effective for firms and more flexible for workers. These collaborative efforts – whether led by firms or educational institutions – have the potential to usher in more streamlined systems of **training delivery**.

## i. Technology adoption

Addressing the technology gap between large and small manufacturers would require efforts to improve technology adoption and development at SME manufacturers. The benefits of improving the technological capabilities of lagging firms are both to improve the productivity and competitiveness of U.S. firms, as well as to expand the capabilities of domestic supply chains. More productive firms with more technological capabilities may also provide better job opportunities for manufacturing workers. There are four models for improving technology adoption at SMEs.

1. **Government support**. Government buyers of manufactured goods – primarily the U.S. military – have long become early customers of new manufacturing technologies to incentivize the production of advanced goods, such as drones and microchips. One relevant example for manufacturing technology is the military's involvement in the early development and adoption of Numerically-Controlled (NC) machining technology. As NC machines were first developed in the late 1940s, military customers paid $200,000 for an early, small-unit order. The inventor collaborated with a lab at MIT to fill the order. After the technology had been developed, but was not being adopted widely, the military stepped in again. To stimulate adoption, the U.S. Army built 120 NC machines and leased them to suppliers.[xxxiii]

   Another model for government intervention is the Massachusetts Manufacturing Innovation Initiative (M2I2), which provides grants to firms and research institutions for new capital equipment to improve their technological capabilities. The grant program, which has awarded more than $50 million thus far, is designed to defray the costs and the risks of acquiring new technologies for the state's research universities and manufacturing firms.

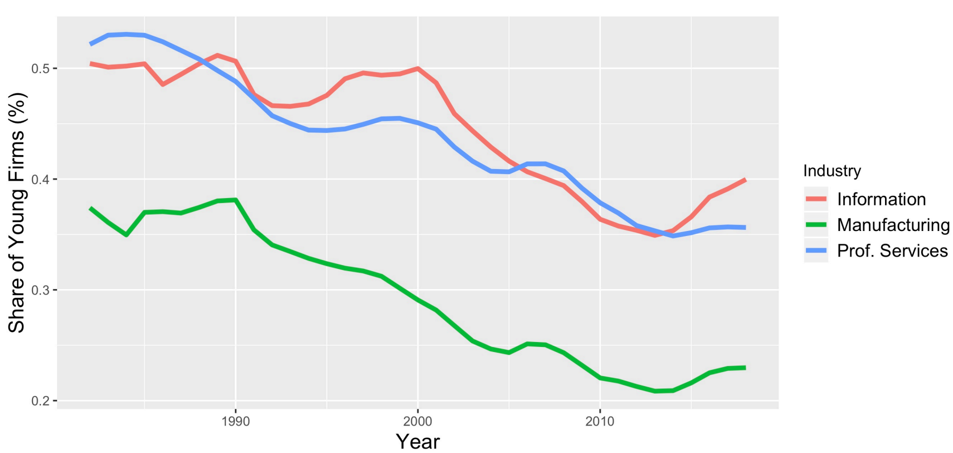
2. **Supply chain leadership**. OEMs with an interest in improving the capabilities of their suppliers might invest in their suppliers' adoption of new technologies. When OEMs develop and produce a product that requires advanced technological capabilities, they might support or require suppliers to upgrade their capital equipment to make the necessary components. When a prime defense contractor needed a complex assembly to go into the end product, they had the choice to build it themselves or buy it from a supplier. The OEM could not find any suppliers in the United States capable of building the component they needed, so the prime contractor effectively paid a supplier to learn to build the assembly they needed, an OEM leader reported. This involved paying a high price for the first units of the assembly to compensate the supplier for learning and technology adoption, after which the OEM had a reliable supply of the component.

   Another model of diffusing new knowledge across manufacturers comes from a partnership between MSC Industrial – a leading metalworking equipment supplier – and the Manufacturing Demonstration Facility at Oak Ridge National Laboratory in Tennessee (see Appendix).

3. **Training manufacturing executives and shop floor leaders**. Sharing the best practices of technology adoption can help SME manufacturers capture and disseminate the benefits of technological innovation. In interviews, SME manufacturing executives report investing in robotic automation, for example, only for the robots they purchased to end up gathering dust in a corner of the factory.[xxxiv] The layering of new manufacturing technologies atop old suggests that firm leadership does not recognize the benefits of re-organizing their production process around new technological capabilities to improve productivity. Training has the potential to improve SME manufacturers' awareness of new technologies and their benefits, but it does not remedy the challenge of SME manufacturers that wish to invest in new technologies, but do not have the resources and/or are not willing to take the risk.

4. **Educating entrepreneurs**. Introducing advanced manufacturing technologies to experienced entrepreneurs could help generate new, technologically advanced domestic manufacturers. The share of young manufacturing firms (less than 5 years old) in the United States has steadily declined over the past three decades (Figure 8). Interviews with manufacturing SMEs offer suggestive evidence that manufacturing startups are more likely to adopt advanced manufacturing technologies and in some cases develop new technologies themselves. The simplest explanation for the younger firms having more advanced technologies is that these firms do not have to build on top of legacy equipment that clutters the shop floor. They can build their production processes around a new generation of machines.

FIGURE 8. THE LONG-TERM DECLINE OF MANUFACTURING STARTUPS[xxxv]



Note: Entrepreneurship in manufacturing has historically been lower than other industries, and it has declined dramatically as U.S. manufacturing employment has shrunk.

Hardware accelerators, such as AlphaLab Gear in Pittsburgh, have emerged as fledgling models of training manufacturing entrepreneurs since 2010 (the first period in decades when the share of young manufacturing firms has grown). AlphaLab Gear has provided small investments and mentorship to hardware startups, helping seed a growing regional ecosystem of young manufacturing companies that venture capitalists have largely ignored. Another potential model is the Defense Innovation Unit (DIU), which supports firms building new defense-related technologies. DIU solicits proposals for "solutions" to defense technology problems, offering "prototype contracts" that serve as funding for new product development. Although the DIU model is relatively young (the Unit was founded in 2015) there is evidence from manufacturer interviews of such contracts supporting the growth of young firms.

These channels for bridging the technology gap are not typically associated with workforce development, or a plan to rebuild the American manufacturing workforce. However, higher-quality, higher-wage manufacturing jobs depend on higher-productivity manufacturing employers – and manufacturing employers that acquire new technologies will require new training for their workers so that they can thrive in a new production environment. Therefore, technology adoption that augments firms' demand for skilled workers must go hand in hand with training that delivers new and relevant skills.

## ii. Training Content

When US manufacturers adopt new technologies, their workers need training. Many technologies have established training content (classes, curricula, credentials) associated with them, but some of the most advanced manufacturing technologies do not yet have standard classes and curricula for training workers. A standardized process for developing training content for new manufacturing technologies will be necessary for firms and workers to get the most value from manufacturing innovations.

Establishing credentials that recognize the skills of workers who complete these training programs is important both as a signal to firms and as an asset for workers. Establishing credentials along with training content is important, but the model credentialing process will inevitably vary by technology, as the different approaches to credentialing at MIIs has shown.

There are multiple potential models of how to generate new training content that meets firm and worker needs.

1. **Firm-led curriculum development**. The robotics firm FANUC collaborated with the credentialing organization NOCTI to develop curriculum for training robotics operators and technicians. The training program works for incumbent workers in manufacturing, as well as for students at vocational high schools and community colleges. Firms developing advanced manufacturing technologies can be a source of training content for machines and techniques that have found their way to the shop floor.

2. **MII-led content development.** Each of the Manufacturing Innovation Institutes (MIIs) have Education and Workforce Development leads charged with supporting training efforts. In emerging advanced manufacturing fields, MIIs can work with firms to develop training content. AIM Academy is one example of a MII developing original photonics courses including short online courses of 4-6 weeks as well as more extensive curricula for community colleges.[xxxvi] ManTech has encouraged Institutes to develop a regional focus, and to partner with one another. The Institutes have an opportunity to create training content for regional partners across technology domains.

3. **State-led training program.** The Massachusetts pilot project MassBridge has convened state education, labor and economic development officials to train advanced manufacturing workers. The program will develop a "roadmap" of the skills that technologically-advanced manufacturing firms will need, along with curricula to educate workers to fill open production jobs in the coming decades.[xxxvii] This program stands as a potential model for other states.

These three models share an emphasis on collaboration among firms, educational institutions, and third-party organizations. In addition to generating training content, such cooperation can improve content delivery.

## iii. Training Delivery

Better content training delivery systems will save firms time and money currently spent on years of on-the-job training, and provide workers capabilities that are portable from firm to firm. To be successful, firms and educational institutions need to forge partnerships to share the cost of training and coordinate on curriculum to ensure it is mutually beneficial.

Regional experiments with manufacturing training partnerships offer three different models of how collaborative training systems might work. The first is for firms with related training needs to pool resources and jointly train their workers. A second model is for an educational institution to develop curricula that can serve multiple firms' needs. And a third model is for online educational platforms to allow firms and schools to share and deliver training material more efficiently.

1. **Firm-led regional collaborations**. Manufacturing firms have historically located near one another in part to draw on shared infrastructure, a common pool of talent, and knowledge from nearby collaborators and competitors, where supplier firms have links to the primes they support. For firms that struggle with being "home alone," partnerships with nearby firms facing similar workforce challenges present an opportunity to share the cost of training and benefit from the knowledge of peer organizations. However, regional cooperation between firms on training or technology development is rare.

   Such cooperation among firms around training is challenging for at least two related reasons. For one, manufacturers frequently emphasize that the work that they do is unique. They aim to train their workers with firm-specific skills. As a result, it would be challenging to decide on a joint training curriculum with nearby employers. And second, companies could balk at joint training initiatives for fear that their competitors will poach their trained workers.[xxxviii] Economic models of firm investments in workforce development highlight this problem. They suggest that firms will underinvest in workforce education since there is a risk that other firms will hire away trained workers, effectively free riding on the training firm's education investment. Despite these barriers to collective action, models of firm-led regional networks begin to demonstrate the benefits of cooperation in training.

An example of this firm-led collaboration is provided by the Alliance for Working Together (AWT) in Ohio. In 2019, five local firms selected incumbent workers to participate in classes that the firms ran to build CNC machining skills, forming an apprenticeship program. An AWT case study included in the Appendix provides more detail, but it stands as an example of what groups of regional employers can achieve when they collaborate.

2. **Education institution-led collaborations.** Community colleges and vocational schools can also lead training partnerships. Educational institutions have the infrastructure to train students at scale, taking the burden off of employers. In interviews, however, some firms were critical of community college training programs for providing training that was too far removed from what employers – particularly SMEs – seek.

   Some education institution-led training partnerships have overcome this challenge. In these cases, a community college convenes regional companies to determine their skills needs, developing training content that matches regional demand. A college might build its curricula on training regimens that industry leaders have already developed. Lorain Community College in Northeast Ohio, for example, adopted FANUC's robotics curriculum, Rockwell Automation's process control curriculum, and Lincoln Electric's welding curriculum. Successful partnerships have also incorporated "work-and-learn" options where students mix training at an educational institution with training at a firm, accelerating their job readiness.

   The Appendix includes noteworthy education institution-led collaborations, as well as two case studies of school-employer collaborations.

3. **Platforms for training content development**. In the past decade, there has been a proliferation of online learning platforms targeted at providing training in manufacturing. These online courses and videos can teach prospective workers or incumbent workers how to operate particular machines or understand certain principles of manufacturing. While the prominent model for online platforms is to offer standardized courses to provide students with general or industry-wide skills, some online education tools allow firms to

make their own firm-specific content. Newer training models incorporate virtual and augmented reality technologies that promise to extend the capabilities of online training.

Although training via technology platforms is unlikely to provide comprehensive knowledge of a machine or technique – even proponents of online education promote combining online material with in-person practice – there are clear benefits. Rather than having a trainee turn to their more experienced colleague repeatedly for assistance, they can rely on recorded material that answers frequent questions. The presence of online material also lowers the cost of collaboration. For instance, if an OEM wished to share best practices with suppliers, it would be cost-intensive for experts from the OEM to visit all suppliers and conduct trainings. It is more practical for the OEM to record trainings that could be used with its workforce – as well as the workforces of its suppliers.

Online learning platforms can help both firms and educational institutions. DoD ManTech funded the launch of an Open edX platform for the DoD Manufacturing Innovation Institutes and their partner firms and educational institutions, which will allow the Institutes to share their expertise and training materials more efficiently.

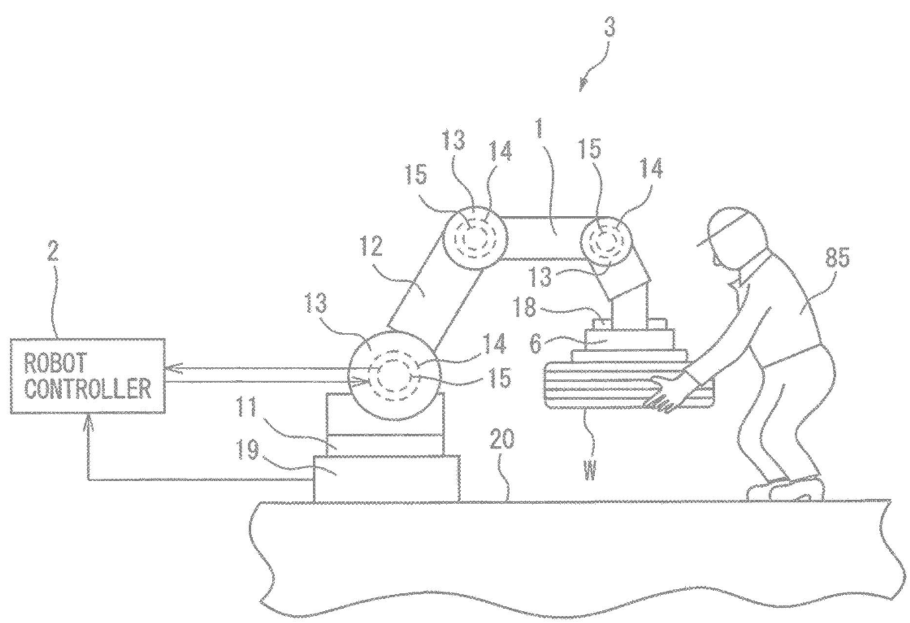



Image credit: United States Patent 10,807,235 B2. "Machine Learning Device, Robot Controller, Robot System, and Machine Learning Method for Learning Action Pattern of Human."

# IV. A Policy Framework

Government programs and policies to address challenges facing U.S. manufacturers should build on the promising models identified above. They should also reflect the roles in which government has most effectively supported the manufacturing economy in the past: as an investor, a convenor, and a standard-setter. We recommend that the federal government adopt three ambitious initiatives to address the problems facing the manufacturing economy.

### Table 1. Policy Recommendations

| Category | Objective | Components |
|---|---|---|
| Advanced Technology → Advanced Training | Improve technology adoption to increase productivity and demand for advanced manufacturing skills | • Prototyping and testing new technologies<br>• Support technology acquisition at SMEs<br>• Incentivizing 'model suppliers' |
| A Network of Training Collaboratives | Facilitate cooperation among firms and with educational institutions to improve training delivery | • Supporting state-led advanced manufacturing plans<br>• Convening regional training networks<br>• Providing incentives for Primes to become training leaders |
| U.S. Manufacturing Academy | Create a platform for the generation and sharing of training content for advanced and legacy manufacturing technologies | • Training manufacturing leaders in new technologies<br>• On-line manufacturing education library<br>• Research center evaluating industrial policy and practice |

## 1. Advanced Technology → Advanced Training

The federal government should provide incentives for firms to both acquire new technologies and train workers in them. We propose four components to this approach:

a. **Prototype and test**. The DoD, in partnership with MIIs and national labs, should enlist defense suppliers to test new tools at a subsidized cost, building awareness of emerging technologies in the industrial base. This model builds on the MSC Industrial – Oak

Ridge National Laboratory partnership, which focused on introducing Millmax technology.

b. **Support technology adoption**. Building on the federal government's history of promoting new technologies among domestic manufacturers, the DoD has an opportunity to incentivize its contractors and subcontractors to upgrade their technological capabilities. Several models could push domestic manufacturers – particularly SMEs – to become more technologically advanced. The Defense Production Act enables the DoD to purchase and lease advanced manufacturing equipment to defense suppliers, including SMEs. The DoD has also served as an early customer for early-stage technology and equipment in the past, ranging from CNC machines to heavy presses. The federal government could also replicate the Massachusetts M2I2 program, soliciting proposals from defense suppliers – particularly SMEs – for assistance in financing capital equipment purchases.

c. **Incentivize manufacturers to become 'Model Suppliers.'** Federal agencies with authority to support domestic manufacturing should convene "model suppliers" adopting advanced manufacturing to share workforce best practices, highlighting exceptional small firms operating in a higher-wage, high-technology equilibrium. The program is based on the *Modern Machine Shop* Top Shop awards highlighting excellence in the field.

## 2. A Network of Training Collaboratives

There are multiple models for building fruitful training partnerships, and the federal government should play a role in convening and funding such partnerships. We recommend focusing on three variants of training partnership initiatives.

a. **Prime-led training partnerships.** The DoD, through grant-making and contracting, should offer Prime contractors incentives to develop training standards and content for their supply chains. MIIs – which count Prime contractors and other OEMs as their members – along with regional partners such as MEPs should facilitate training partnerships between Primes and suppliers by providing training content and coordinating training delivery.

b. **Regional firm collaboratives**. Manufacturing Innovation Institute EWD programs, including cross-institute efforts, should convene and provide incentives for regional networks of firms to share training resources and implement shared work-learn programs. The AWT initiative in Ohio offers a promising model.

c. **State advanced manufacturing plans** – Federal agencies should support states in developing comprehensive workforce education plans, which build partnerships between educational institutions, industry, and government to identify and anticipate the technological and training needs facing industry. Building on experiments like the DoD-supported MassBridge program in Massachusetts, federal agencies have a role to play in supporting the scale-up of state-level initiatives that demonstrate success.

## 3. U.S. Manufacturing Academy

We propose that the federal government create a Manufacturing Academy to serve as a hub for generating and sharing new knowledge related to the manufacturing economy. The Academy would be a public-private partnership between the federal government, U.S. research universities and community colleges, and industry partners.

One of the core challenges of implementing an advanced technology, advanced training agenda is the fragmentation of federal policy related to manufacturing. Federal agencies currently invest in a variety of industrial policy and training efforts (e.g. MIIs, MEPs, NIST labs) focused on supporting the manufacturing economy.

The Manufacturing Academy would build on the DoD's ongoing investments in education and workforce development to become a source of in-person and online training content for manufacturing workers and leaders – as well as a vehicle for research on the effectiveness of manufacturing initiatives and new evidence-based policy directions.

a. **Technology leadership training for manufacturing executives and shop-floor managers.** The Academy should create and host in-person and on-line programs to introduce manufacturing leaders – particularly executives and shop-floor managers from SMEs – to the latest manufacturing technologies. Experts from firms, universities, MIIs and other institutions would lead the training programs with the goal of stimulating demand for new technologies at SMEs by highlighting the use cases and business cases of advanced manufacturing technologies.

b. **National library for on-line manufacturing education.** The Academy should build a library of content and curricula for advanced manufacturing education. The library should include existing curricula that MIIs have curated, which ARM and America Makes have already begun to do. It should also build on the Open EdX platform that DoD ManTech has already supported. In addition to serving as a platform for individual learners and community colleges, the library would also work with MEPs to help firms identify content that can suit their training needs.

c. **Research hub for measuring effectiveness of federal manufacturing initiatives and practices.** This study calls for an expansion of the scale and scope of U.S. manufacturing initiatives. As programmatic investments grow and change, it will be important to continuously measure the effects of these policies on the firms and workers that they intend to support. The Manufacturing Academy should support independent, collaborative research and data collection on the manufacturing economy to evaluate current manufacturing policy efforts critically and identify new policy directions.

# APPENDIX - CASE EXAMPLES

## A. MILLMAX TECHNOLOGY

MSC Industrial and Oak Ridge National Lab entered into a cooperative R&D agreement to identify more efficient ways to operate CNC machines. Less than a year after the initial agreement, the partners announced that they would distribute "Millmax" technology, which helps machine shops run their CNCs at the right speed for the most efficient cuts.[xxxix] As a supplier with a network of technical experts that interact with manufacturers across the United States, MSC was well-positioned to distribute the Millmax technology. Just as MSC has the network to diffuse knowledge as a supplier to many customers, OEMs can pass knowledge down to their suppliers.

## B. ALLIANCE FOR WORKING TOGETHER (AWT)

The Alliance for Working Together (AWT) was founded in Ohio in 2002 by a group of manufacturing executives – led by Roger Sustar, founder of Fredon – who struggled to find skilled workers to fill open positions. They began by sponsoring a robotics competition at local public high schools to build a talent pipeline.

In 2019, AWT launched a joint apprenticeship program. Five local firms selected junior workers to attend weekly CMC machining classes. The CEO of one of AWT's member companies teaches the class, and a local community college offers credits. The instructor stimulates students' interest in manufacturing technology. He even asks students to follow the Twitter and Facebook feeds of leading machine tool manufacturers, to get them excited about upcoming advances.

## C. COLLABORATIVE TRAINING PARTNER: LORAIN COMMUNITY COLLEGE

Lorain County Community College in northeast Ohio is an example of a community college that embraces many of these approaches.[1] In keeping with the need for *short programs* and *stackable credentials*, Lorain offers numerous roughly 16-week manufacturing certificates, from welding to automation. The credentials are stackable and lead to 1-year certificates and 2-year degrees. Lorain adopted "acceleration strategies" to move students quickly through programs focused on *specific skill competencies*. Lorain *builds industry certifications into its academic programs*. Working with the state of Ohio, it participated in a program that evaluated 3,500 industry credentials and chose 309 for the state's and its own programs. It is also working with five MIIs to develop advanced manufacturing credentials. Students can work toward a new applied baccalaureate degree.

Through its "*learn-and-earn*" program, Lorain has students work with employers toward credentials. It also has wrap-around student services, to help students with financial aid, remedial studies and job placement support. It has a new one-year, advanced manufacturing program for *incumbent workers*, to give them industry 4.0 skills. It also has ties to *high school programs*, partnering with them in a "college credit plus" program that helps high school students continue on to Lorain. Behind these efforts is deep relationship with the Ohio Manufacturers Association, which connects Lorain to *industry*. Lorain secured a Labor Department grant with others to form the Ohio Tech Net, which includes a new apprenticeship program with OMA members.

### D. Tennessee Colleges for Applied Technology (TCATs)

A continuing problem at community colleges is *completion rates* around 30%. Many students arrive underprepared and get bogged down in remedial courses. A network of 27 Tennessee Colleges for Applied Technology (TCATs) offer 70 career programs, including in manufacturing. These lead to certificates and associate degrees, and include courses that prepare students for college-level work so no one gets singled out as needing remedial help.

Students move quickly into their chosen career courses, as they see their classmates moving into exciting jobs. Struggling students can take advantage of individualized remedial learning plans that includes a mix of classes, online exercises, and access to mentoring at a learning lab. Students pursue this foundation program at their own pace. The great majority of students complete their foundations programs shortly after their first trimester. The completion rate across all the TCATS is 81%, with job placement rates into the student's chosen field of study at 86%.

[i] See, for example, " 'Made in China 2025' Industrial Policies: Issues for Congress." *Congressional Research Service.* 11 August 2020. https://fas.org/sgp/crs/row/IF10964.pdf. "China Manufacturing 2025: Putting Industrial Policy Ahead of Market Forces." *European Chamber of Commerce in China.* 2017. *http://docs.dpaq.de/12007-european_chamber_cm2025-en.pdf.*
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[iii] "Radio Address Delivered by President Roosevelt From Washington" (Washington, DC, December 29, 1940), https://www.mtholyoke.edu/acad/intrel/WorldWar2/arsenal.htm. "The Biden Plan" released as part of Joe Biden's presidential campaign also mentions the "Arsenal of Democracy" as a moment of historical achievement to which current policy should aspire.
[iv] Anna Slomovic, "Anteing Up: The Government's Role in the Microelectronics Industry," in *Civil and Military Technology Workshop* (Rand Corporation, 1988), https://apps.dtic.mil/dtic/tr/fulltext/u2/a228267.pdf.
[v] Russ Olexa, "The Father of the Second Industrial Revolution," *Manufacturing Engineering* 127, no. 2 (August 2001): 42–54.
[vi] Edward Kosell, "A Historical Study of Vocational Education in the Chicago Public and Technical and Vocational High Schools, 1917-1963" (Loyola University Chicago, 1965), https://ecommons.luc.edu/cgi/viewcontent.cgi?article=1770&context=luc_diss. For more on the importance of universal public high school for economic development, see Claudia Goldin and Lawrence F. Katz, *The Race between Education and Technology* (Cambridge, Mass: Belknap Press of Harvard University Press, 2008).
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[x] Organisation for Economic Co-Operation and Development, "Productivity and ULC by Main Economic Activity (ISIC Rev. 4)," The OECD Productivity Database, 2019 1995, https://stats.oecd.org/Index.aspx?DataSetCode=PDBI_I4.
[xi] "Report to Congress – Fiscal Year 2019." *Manufacturing USA.* November 2020. < https://www.manufacturingusa.com/sites/manufacturingusa.com/files/2021-01/Manufacturing%20USA%20Annual%20ReportToCongress%20FY2019%20final.pdf.>
[xii] See "Facts and Figures." *Fraunhofer-Gesellschaft.* January 2020. https://www.fraunhofer.de/en/about-fraunhofer/profile-structure/facts-and-figures.html.
[xiii] It is important to note that the design of U.S., German, and Chinese industrial policies differ – and the Manufacturing Institutes in the U.S. are only one of multiple efforts to support the U.S. manufacturing economy. See, for example, " 'Made in China 2025' Industrial Policies: Issues for Congress." *Congressional Research Service.* 11 August 2020. https://fas.org/sgp/crs/row/IF10964.pdf. "China Manufacturing 2025: Putting Industrial Policy Ahead of Market Forces." *European Chamber of Commerce in China.* 2017. *http://docs.dpaq.de/12007-european_chamber_cm2025-en.pdf.*
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[xvii] Data on SME manufacturers comes from the SBA's database of registered firms. Database of firms with prime defense contracts comes from usaspending.gov public spending data. Queries to match firms used exact matches of DUNS numbers.
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[xx] U.S. Bureau of Labor Statistics Series CES300000001. All employees, thousands, manufacturing, seasonally adjusted. In January 2020, there were approximately 11,460,000 manufacturing employees. In January 2020, there were approximately 12,792,000 manufacturing employees.
[xxi] Although job openings grew during this period across industries, the growth of manufacturing job openings is notable because it grew much faster relative to overall employment growth. Professional and business services jobs grew much faster than manufacturing jobs, but the number of job openings in professional and business services grew slower than the job openings in manufacturing.
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[xxviii] Berger and MIT Task Force on Production and the Innovation Economy.
[xxix] Although job openings grew during this period across industries, the growth of manufacturing job openings is notable because it grew much faster relative to overall employment growth. Professional and business services jobs grew much faster than manufacturing jobs, but the number of job openings in professional and business services grew slower than the job openings in manufacturing.
[xxx] “WIPO IP Statistics Data Center” (World Intellectual Property Organization, n.d.), https://www3.wipo.int/ipstats/keyindex.htm;jsessionid=A7331C46D7569F9924EFDFA80A26E875. Manufacturing-related patents in this study include WIPO Categories 25-32: “Handling,” “Machine tools,” “Engines, pumps, turbines,” “Textile and paper machines,” “Other special machines,” “Thermal processes and apparatus,” “Mechanical elements,” and “Transport.” This is not an exhaustive list, nor are all patents in these areas strictly focused on manufacturing. However, trends in these categories are an illustrative sample.
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[xxxii] See Note xvii.
[xxxiii] Olexa, “The Father of the Second Industrial Revolution.”
[xxxiv] Berger, “Manufacturing in America: A View from the Field.”
[xxxv] U.S. Census Bureau, “Business Dynamics Statistics: Firm Age by Sector,” Dataset, n.d., https://www.census.gov/ces/dataproducts/bds/data_firm.html.
[xxxvi] Disclosure: MIT IKIM is closely affiliated with AIM Academy.
[xxxvii] Disclosure: Team members of MIT IKIM are also contributing to the MassBridge initiative.