AUTOMATION WORKFORCE PRODUCTIVITY.

How Illinois Manufacturers are Adopting Advanced Technologies:

An Insight Report on Automation, Workforce, and Productivity

August 2021

Produced in Partnership with:

IMEC Plan. Implement. Excel.

tma

VIA Valley Industrial Association

IMA Illinois Manufacturers' Association

W.E. Upjohn Institute for Employment Research

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Table of Contents

PRIMARY SURVEY FINDINGS.

Ten Important Things to Know About Advanced Manufacturing Technologies in Illinois

1. Advanced manufacturing technologies helped with pandemic resilience.
2. Two-thirds of manufacturers have made modest to minimal progress in adopting advanced manufacturing technologies.
3. Smaller manufacturers lag behind larger manufacturers in the adoption of advanced manufacturing technologies.
4. It's automation AND workforce: Drivers and barriers to adoption.
5. Strategy matters: Manufacturers using an innovation strategy invest heavily in advanced manufacturing technologies.
6. Technology to meet mix and volume.
7. Process first, technology second.
8. Digital technologies - the "great equalizer" for small manufacturers.
9. Short term financial uncertainty prevents manufacturers from realizing long-term productivity gains.
10. There is still so much to learn about advanced manufacturing technologies, and so many ways to do it.

Executive Summary

This new era of industrial adjustment, also known as advanced manufacturing technologies, Industry 4.0, or "smart" manufacturing, describes the next wave of important technological change affecting the manufacturing sector. In the spring of 2021, the Illinois Manufacturing Excellence Center (IMEC) partnered with the Illinois Manufacturers' Association (IMA), the Technology and Manufacturing Association (TMA), the Valley Industrial Association of Illinois (VIA) and the W.E. Upjohn Institute for Employment Research to better understand where manufacturers are in their journey to adopting advanced manufacturing technologies and processes. To understand what was driving technology adoption, a sample of business leaders were asked to share their opinions on advanced manufacturing through an online survey. The respondents represent small and mid-sized manufacturers providing a unique insight from their perspective. This study shows a picture of how manufacturers are implementing advanced manufacturing technologies, the benefits and opportunities available in adopting advanced manufacturing technologies, and the obstacles faced.

This survey of select manufacturers found ten important things to know about advanced manufacturing technologies:

1. Advanced manufacturing technologies helped with pandemic resilience.
2. Two-thirds of manufacturers have made modest to minimal progress in adopting advanced manufacturing technologies.
3. Smaller manufacturers lag behind larger manufacturers in the adoption of advanced manufacturing technologies.
4. It's automation AND workforce: Drivers and barriers to adoption.
5. Strategy matters: Manufacturers using an innovation strategy invest heavily in advanced manufacturing technologies.
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9. Short term financial uncertainty prevents manufacturers from realizing long-term productivity gains.
10. There is still so much to learn about advanced manufacturing technologies, and so many ways to do it.

Overall, this study finds the adoption of advanced manufacturing technologies is not a "one size fits all" proposition. Firm characteristics, such as size, production process, and business strategy, are important for understanding what technologies and processes are adopted. Also important are resource limitations, such as the ability to make financial investments and the quality and supply of workers. Costs, both direct, indirect, and hidden can also influence the adoption of advanced manufacturing technologies.

About the Survey

From mass production and the assembly line to automation and the adoption of computers, technology has revolutionized manufacturing practices since the Industrial Revolution. This new era of industrial adjustment, also known as advanced manufacturing, Industry 4.0, or "smart" manufacturing, describes the next wave of important technological change affecting the manufacturing sector. Today, manufacturers stand at a crossroads. The COVID-19 pandemic has forced manufacturers to rethink their competitive position and resiliency to disruption. On top of that, U.S. manufacturing has been experiencing declining productivity growth. The competitive and economic risk of such changes can only be resolved with investments in new skills and new technologies.

In the spring of 2021, the Illinois Manufacturing Excellence Center (IMEC) partnered with the W.E. Upjohn Institute for Employment Research to better understand where manufacturers stand in their adoption of advanced manufacturing technologies and processes. To understand what was driving technology adoption, manufacturers were asked to share their experiences with advanced manufacturing technologies through an online survey.

The online survey consisted of 25 questions designed to capture manufacturing leaders' views on the current state of advanced manufacturing technology adoption within their companies. The survey was developed based on previous surveys conducted in Georgia, Iowa, and Ohio. It also built on questions used by the U.S. Census Bureau to obtain information about the effects of COVID-19 on businesses. Participation in the survey was completely voluntary. A copy of the survey questions can be found in APPENDIX A.

The target population for the survey consisted of manufacturers in the state of Illinois. For the purpose of this survey, "manufacturers" included any employer with a NAICS code between 310000 and 330000. A sampling frame was

The survey had three primary objectives:

1. To understand the degree to which manufacturers are using and implementing advanced manufacturing technologies.
2. To examine what manufacturers see as the opportunities and challenges to deploying advanced manufacturing technologies in their companies.
3. To explore how workforce development needs are changing as a result of advanced manufacturing technology adoption.

constructed by staff at IMEC, as well as through partner organizations, including the Illinois Manufacturers' Association (IMA), the Technology and Manufacturing Association (TMA), and the Valley Industrial Association of Illinois (VIA). As a result, not all manufacturers in the state of Illinois were included as part of the sampling frame. Rather, this survey employed a convenience sample of manufacturers affiliated with IMEC and its partner organizations. As these are the leading manufacturing organizations in the state of Illinois, it is likely that a majority of manufacturers in the state were invited to participate in the survey. However, because we cannot ensure full coverage of manufacturers in the sampling frame, the results of this survey should not be generalized to all manufacturers in the state.

Invitations were sent out on May 10, 2021, by email using a Survey Monkey link. The survey closed on June 15, 2021. Out of the invitations sent out, 247 manufacturers responded. From those responses, there were 215 usable responses. Duplicates—i.e., surveys taken by the same person more than once-were removed from the sample. In removing those duplicate surveys, the first survey taken by the individual was kept for inclusion in the estimates.

Out of the usable surveys, 171 provided firmographic details. The median total employment for manufacturers answering the survey was between 50 and 99 employees, and the median age of the manufacturing firm was 43. About one-quarter (28.1%) of manufacturers were in the fabricated metal products sector, while machinery manufacturing (17.5%) and miscellaneous manufacturing (15.2%) represented the other top sectors responding to the survey. Manufacturers in urban areas made up the majority (90.6%) of the respondents, as did single locations (61.4%). The median capital expenditure budget was $400,000, and, on average, respondents spent 31.0% of their capital expenditure budget on advanced manufacturing technologies and processes.

This study used a variety of statistical techniques to analyze the results of the survey. The goal was to identify those characteristics of the manufacturers that had significant effects on various elements, such as the likelihood of adopting new technologies. Summary statistics are provided for the relevant characteristics.

The potential for advanced manufacturing to radically transform manufacturers' operational performance and business practices is enormous. The benefits include increased output, higher quality, and improved business performance. The ability of manufacturers to deploy advanced manufacturing technologies and lead automated organizations will become an important competitive advantage in the future.

Ultimately, this study provides a picture of how manufacturers are implementing advanced manufacturing technologies, the benefits and opportunities available to them in adopting the advanced technologies, and the obstacles they face.

1 Advanced manufacturing technologies helped with pandemic resilience.

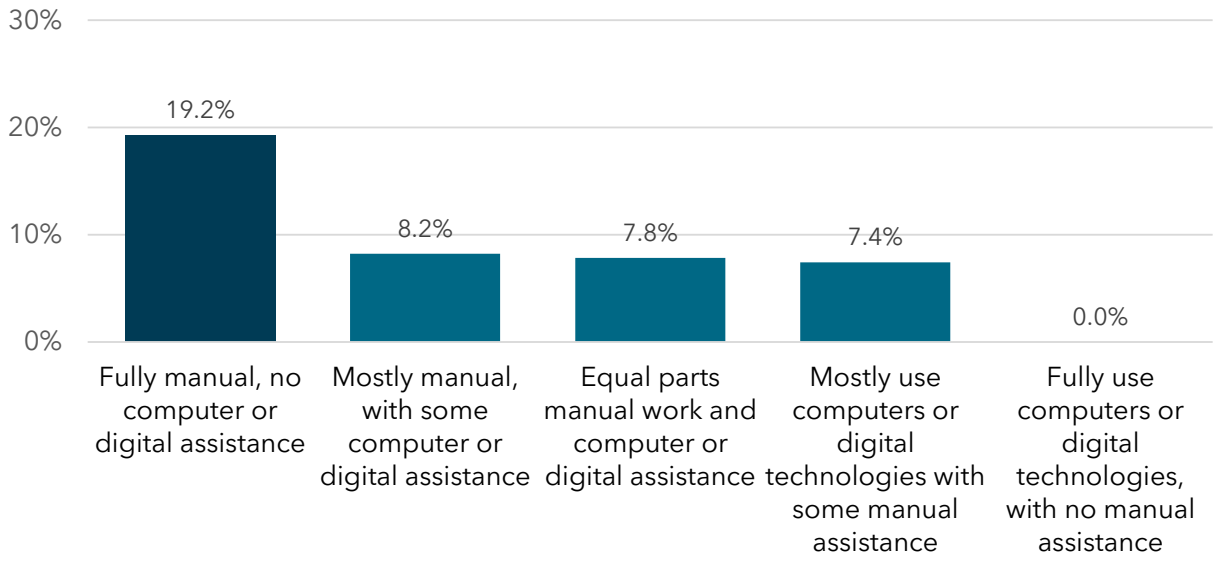
Key Points:

- Manufacturers that reported higher levels of technology adoption and digitalization were less likely to report adverse workforce impacts as a result of the pandemic.
- The COVID-19 pandemic was not a driving force for advanced manufacturing technology or process adoption.
- Almost all of the manufacturers (91.5%) who said they had fully integrated advanced manufacturing technologies or processes, or had made substantial progress on doing so, also responded that they were optimistic or very optimistic about their business outlook for 2021.

Less than one percent of manufacturers (0.8%) indicated the COVID-19 pandemic was a driver for implementing advanced manufacturing technologies. In actuality, manufacturers that reported higher levels of technology adoption were less likely to have been impacted by the disruptions of the COVID-19 pandemic. The decision to implement more advanced manufacturing technologies was associated with being less likely to report that COVID-19 impacted the company's ability to rehire furloughed or laid off employees. Some 13.3% of manufacturers who had adopted no advanced manufacturing technologies reported that this was an issue, compared to only 7.9% of manufacturers who had adopted three to four technologies.

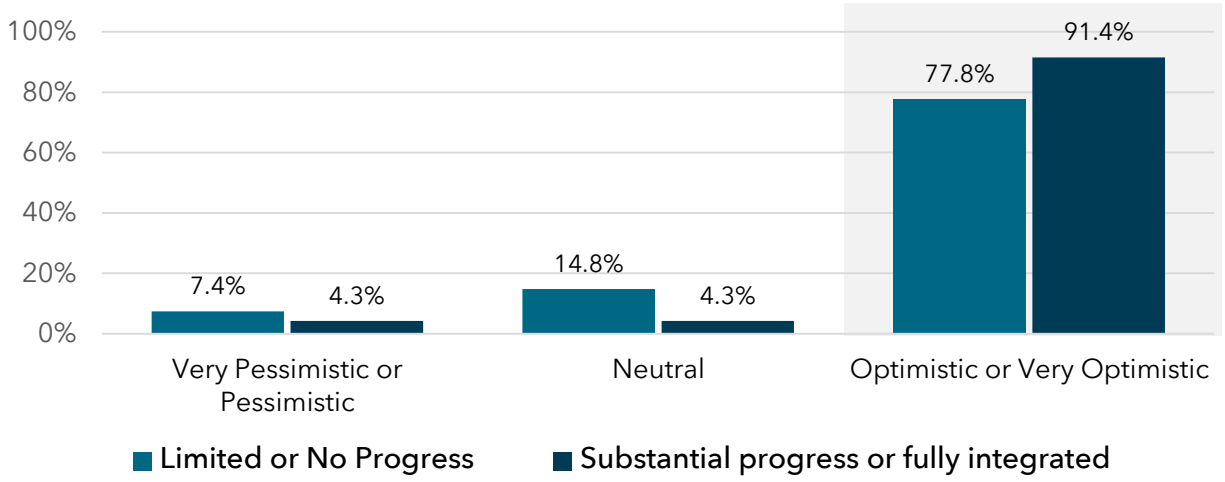
Manufacturers reporting higher levels of digitalization (using computers or digital technologies to automate cognitive processes) were also less likely to say that current employees being unable to work was an impact of COVID-19. About two in ten manufacturers (19.2%) reporting their cognitive operations were performed fully manually, with no computer or digital assistance, also reported current employees were unable to work. Comparatively, only 7.4% of manufacturers who reported they mostly used computers or digital technologies, along with some manual

Manufacturers reporting higher levels of digitalization were less likely to indicate current employees being unable to work was an impact of COVID-19.



assistance reported the same. While this study does not find strong evidence that the COVID-19 pandemic encouraged the adoption of advanced manufacturing, there is some evidence to suggest manufacturers who had adopted a higher degree of advanced manufacturing technologies were able to insulate themselves from some of the more negative workforce challenges caused by the pandemic.

Manufacturers who had made substantial progress or fully integrated advanced manufacturing technologies were more likely to report being optimistic or very optimistic about the business outlook for 2021.



Manufacturers who had adopted a higher degree of advanced manufacturing technologies were able to insulate themselves from some of the more negative workforce challenges caused by the pandemic.

This might help to explain why manufacturers that have made more progress in the implementation of advanced manufacturing technologies are more optimistic about the future. When asked about the business outlook for 2021, almost all of the manufacturers (91.4%) who said they had made substantial progress or had fully integrated advanced manufacturing technologies or processes in the last year also said they were optimistic or very optimistic about their business outlook for 2021. In comparison, only a little over three in four manufacturers (77.8%) who reported they had not fully integrated nor made substantial progress on fully integrating advanced manufacturing technologies in the last year indicated they were optimistic or very optimistic about their business outlook for 2021.

Why this matters:

Investments in advanced manufacturing technologies and processes provided firms with the needed capabilities to respond to a quickly changing and tempestuous business environment.

During the pandemic, manufacturers with high levels of digitization in production demonstrated greater resilience and adaptability than manufacturers with less digitized production environments (Okorie, et al., 2020). A 2021 McKinsey & Company report found that 94.0% of surveyed executives believe advanced manufacturing helped keep their facility functioning during the pandemic, with 56.0% identifying the technologies as "critical" to their response (Agrawal, Dutta, Kelly, & Millán, 2021). Two-thirds of respondents found advanced manufacturing more valuable than they had one year before. Manufacturing with digital "twins" of supply chain data proved particularly successful at weathering the pandemic (Ivanov & Dolgui, 2021). By digitally replicating the entire network of suppliers and clients, manufacturers could model decisions to minimize disruptions. Manufacturers with extensive analytics capabilities could anticipate bottlenecks and promptly devise alternative supply chains. Overall, investments in advanced manufacturing technologies and processes provided firms with the needed capabilities to respond to a quickly changing and tempestuous business environment.

Bottom line for businesses:

Firms with an advanced manufacturing technology infrastructure already in place had a competitive edge enabling them to weather the economic uncertainty created by the COVID-19 crisis.

Potential policy opportunities:

Improving the overall innovative capacity of companies is important for economic resilience.

2 Two-thirds of manufacturers have made modest to minimal progress in adopting advanced manufacturing technologies.

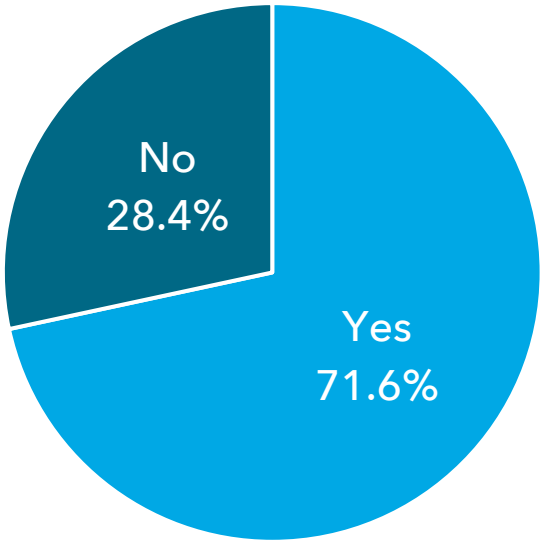
Key Points:

- Among manufacturers intending to implement advanced manufacturing technologies, three in four (77.0%) described them as "very important" or "essential" to the long-term business strategy.
- Just over one-third of manufacturers (36.9%) indicated substantial progress or full integration of advanced manufacturing technologies had been made over the past year.

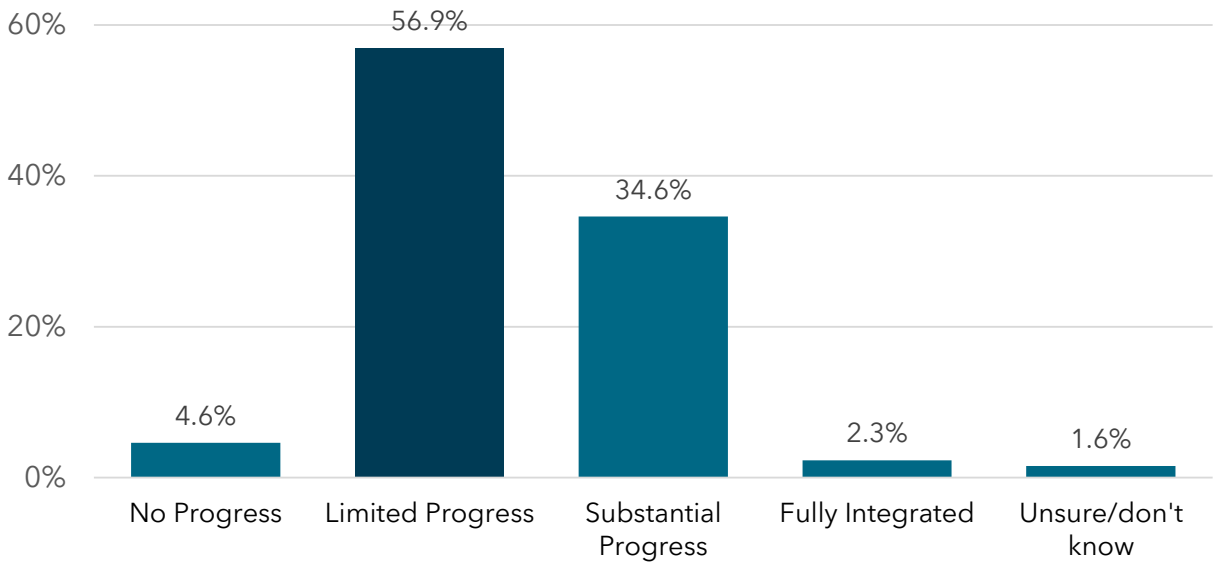
Deciding if and when to adopt advanced manufacturing technologies is an important decision for manufacturers. This survey finds, there are many factors influencing this decision. While manufacturers see the value of advanced manufacturing, they have been slow to implement it.

Only two in three manufacturers (71.6%) reported they intended to or already have implemented advanced manufacturing technologies and processes, while less than one-third of manufacturers (28.4%) reported that they did not intend to implement advanced manufacturing technologies and processes. As a group, these non-adopters had much lower levels of current automation in their production facilities compared to the group moving toward advanced manufacturing technology adoption.

Over two-thirds of manufacturers intend to or are currently implementing advanced manufacturing technologies.



The majority of manufacturers intending to implement advanced manufacturing technologies have made limited progress in the adoption of advanced manufacturing.



When manufacturers intending to implement or currently implementing advanced manufacturing were asked how important advanced manufacturing technologies and processes were to the long-term strategy of their business, more than three-fourths (77.0%) described advanced manufacturing as an "essential" or "very important" component of their long-term strategy. At the same time, less than one-quarter of these manufacturers (22.3%) described advanced manufacturing as "somewhat important" to future strategy.

While many manufacturers recognize the importance of advanced manufacturing to their long-term success, only about one-third of manufacturers (34.6%) indicated substantial progress, and under 1 in 40 (2.3%) indicated full integration of advanced manufacturing technologies and processes. Six in ten manufacturers (56.9%) reported limited progress in implementing advanced manufacturing, while less than 1 in 20 (4.6%) indicated no progress. Manufacturers who said implementing advanced manufacturing technologies and processes was critical to their long-term (over the next three years) business strategy were the most likely to have made progress in implementing advanced manufacturing technologies and processes this year.

The limited progress of manufacturers in implementing advanced manufacturing technologies and processes may reflect the complexity of the challenge.

Why this matters:

Integrating operational and information technologies is essential to the implementation of advanced manufacturing technologies.

Realizing the benefits of advanced manufacturing technologies requires more than one-time capital expenditures. Advanced manufacturing can revolutionize industrial operations and improve operational excellence by identifying and eliminating process inefficiencies. Manufacturers might cut labor costs in half, boost productivity by a third, and reduce quality-control costs by 20 percent (McKinsey Digital, 2015; Mahoney & Kota, 2020).

The limited progress of manufacturers in implementing advanced manufacturing technologies and processes may reflect the complexity of the challenge. Even with more aggressive investment patterns, few manufacturers can immediately establish advanced manufacturing practices (Mahoney & Kota, 2020). Advanced manufacturing is about integrating operational and information technologies. Complete implementation of advanced manufacturing technologies requires an integrated, controllable flow of products analyzed in real time by a network of sensors (Waldman-Brown, 2020). Many manufacturers lack the time or resources to integrate sensors into all aspects of the manufacturing process, develop the IT infrastructure necessary to analyze the monitoring data, or pause production for the installation of new technologies (McKinsey Digital, 2015). Integrating operational and information technologies is essential to the implementation of advanced manufacturing technologies.

Bottom line for business leaders:

Developing a strategy for implementing advanced manufacturing technologies and processes is critical to making the initial investment.

Potential policy opportunities:

Encouraging manufacturers to invest in advanced manufacturing technologies requires providing opportunities to test and access cutting edge technologies and processes.

3 Smaller manufacturers lag behind larger manufacturers in the adoption of advanced manufacturing technologies.

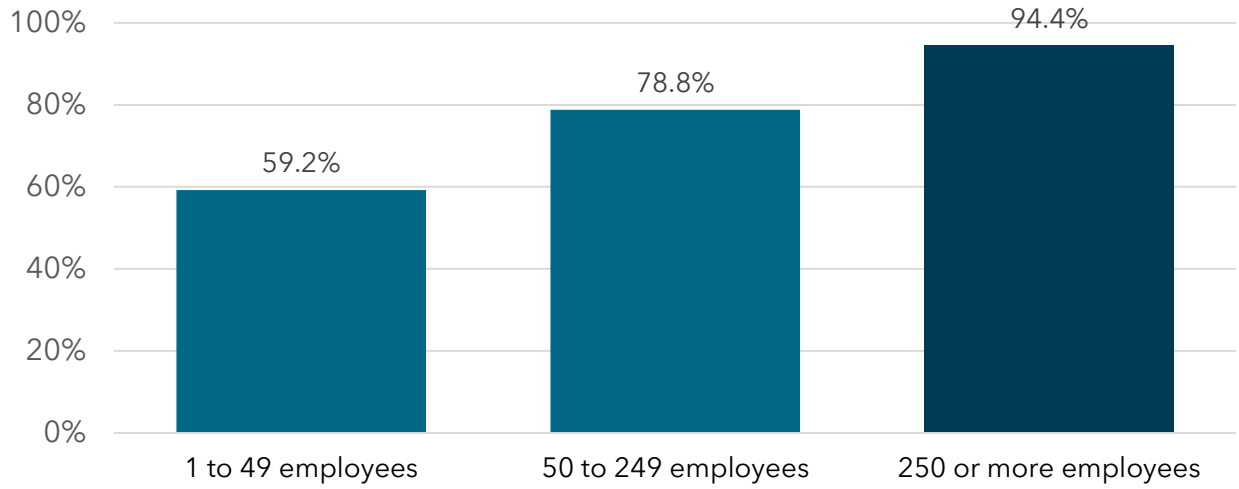
Key Points:

- Almost all (94.4%) of the largest manufacturers (250 or more employees) intend to implement or have already implemented advanced manufacturing technologies and processes.
- In comparison, only 6 in 10 (59.2%) of small manufacturers (1 to 49 employees) intend to implement or have already implemented advanced manufacturing technologies and processes.
- The largest manufacturers (250 or more employees) are the most likely to invest in technologies such as robots/cobots, additive manufacturing (3D printing), and augmented reality.

Overall, the largest manufacturers reported a higher rate of adoption of advanced manufacturing technologies. When asked whether they intend to or already have implemented advanced manufacturing technologies and processes, more than 9 in 10 (94.4%) of the largest manufacturers (250 or more employees) intended to or already had done so. In comparison, 8 in 10 (78.8%) of medium-sized manufacturers (50 to 249 employees) and 6 in 10 (59.2%) of small manufacturers (1 to 49 employees) said they intended to or had already adopted advanced manufacturing technologies and processes.

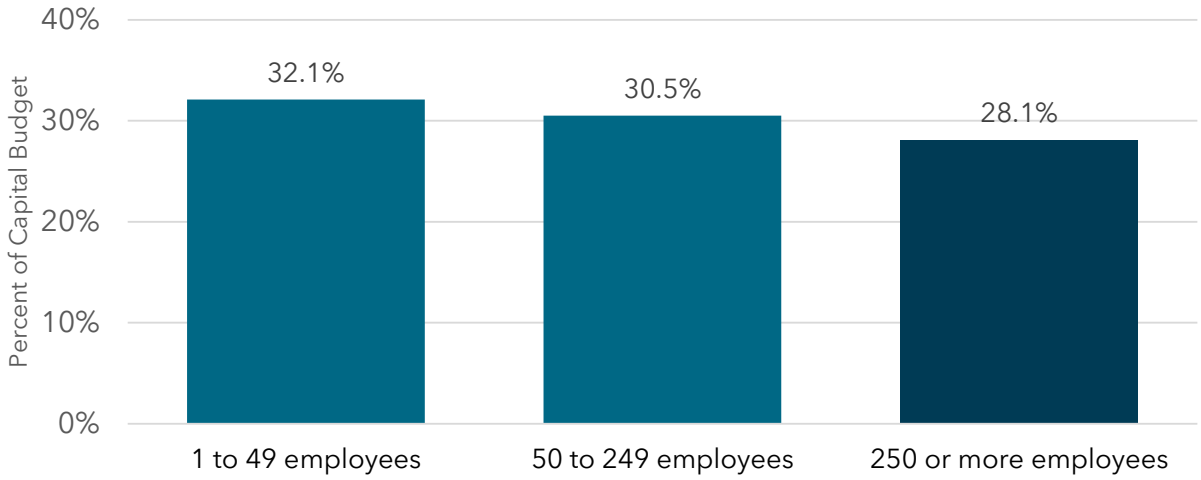
One factor that may be enabling the largest manufacturers to invest in such technologies much more than the smallest manufacturers is their cost.

Almost all the largest manufacturers intend to or have already implemented advanced manufacturing technologies and processes.



Fewer than 1 in 10 (6.3%) of the smallest manufacturers (1 to 19 employees) had implemented or intended to implement robots/cobots, compared to almost 6 in 10 (58.8%) of the largest manufacturers (250 employees or more). Additionally, the smallest manufacturers (1 to 19 employees) were the least likely to implement or to intend to implement additive manufacturing (3D printing): only 6.3% indicated they would do so, compared to 58.8% of the largest manufacturers (250 or more employees). The largest manufacturers were more likely to implement or to intend to implement augmented reality: 29.4% of manufacturers responded affirmatively, compared to only 6.3% of the smallest (1 to 19 employees) manufacturers.

The largest manufacturers (250 or more employees) report spending proportionately less of their capital expenditure budget on advanced manufacturing technologies.



One factor that may be enabling the largest manufacturers to invest in such technologies much more than the smallest manufacturers is their cost. Robots/cobots, additive manufacturing (3D printing), and augmented reality can cost upwards of hundreds of thousands of dollars for customized systems (Linke, 2017; Fade, 2019; McKinsey, 2019). The largest manufacturers (250 or more employees) were the least likely to indicate an uncertain economic benefit or return on investment presented an obstacle, as only one in nine manufacturers (11.1%) of this size chose this answer.

The largest manufacturers (250 or more employees) had a capital expenditure budget that was, on average, 3.2 times larger than the smallest manufacturers (1 to 19 employees). However, the largest manufacturers report spending proportionately less of their capital expenditure budget on advanced manufacturing technologies. They report spending 28.1% of their budget on advanced manufacturing technologies, while medium-sized manufacturers (50 to 249 employees) report spending 30.5% of their budget on advanced manufacturing technologies, and small manufacturers (1 to 49 employees) report spending 32.1%.

Why this matters:

Having the ability to devote time and knowledge in addition to capital to the implementation of advanced manufacturing technologies is beneficial in following through on the adoption of such technologies.

Large manufacturers are better able to capitalize on innovation because the risk of an unsuccessful investment can be spread more widely and there is a lower relative cost for adopting the technology (Harris & Trainor, 1995). They have, on average, larger capital expenditure budgets and thus a greater ability to invest in advanced manufacturing technologies. However, large firms do not necessarily spend proportionately more of their capital expenditure budget on advanced manufacturing technologies and processes than small or medium-sized enterprises.

Larger firms also tend to be more specialized, this enables them to have departments dedicated to researching and investing in advanced manufacturing technologies and processes. The ability to devote more time for research and hire the specialized talent needed to invest in advanced manufacturing is a sizable benefit for large firms. Overall, having the ability to devote time and knowledge in addition to capital to the implementation of advanced manufacturing technologies is beneficial in following through on the adoption of such technologies.

Bottom line for businesses:

Investing in advanced manufacturing technologies, regardless of firm size, creates a competitive advantage for manufacturers.

Potential policy opportunities:

Using policies, such as tax incentives, grants, loans, and vouchers to support investments in training and equipment can help manufacturers as they integrate advanced manufacturing technologies into their operations.

4 It's automation AND workforce: Drivers and barriers to adoption.

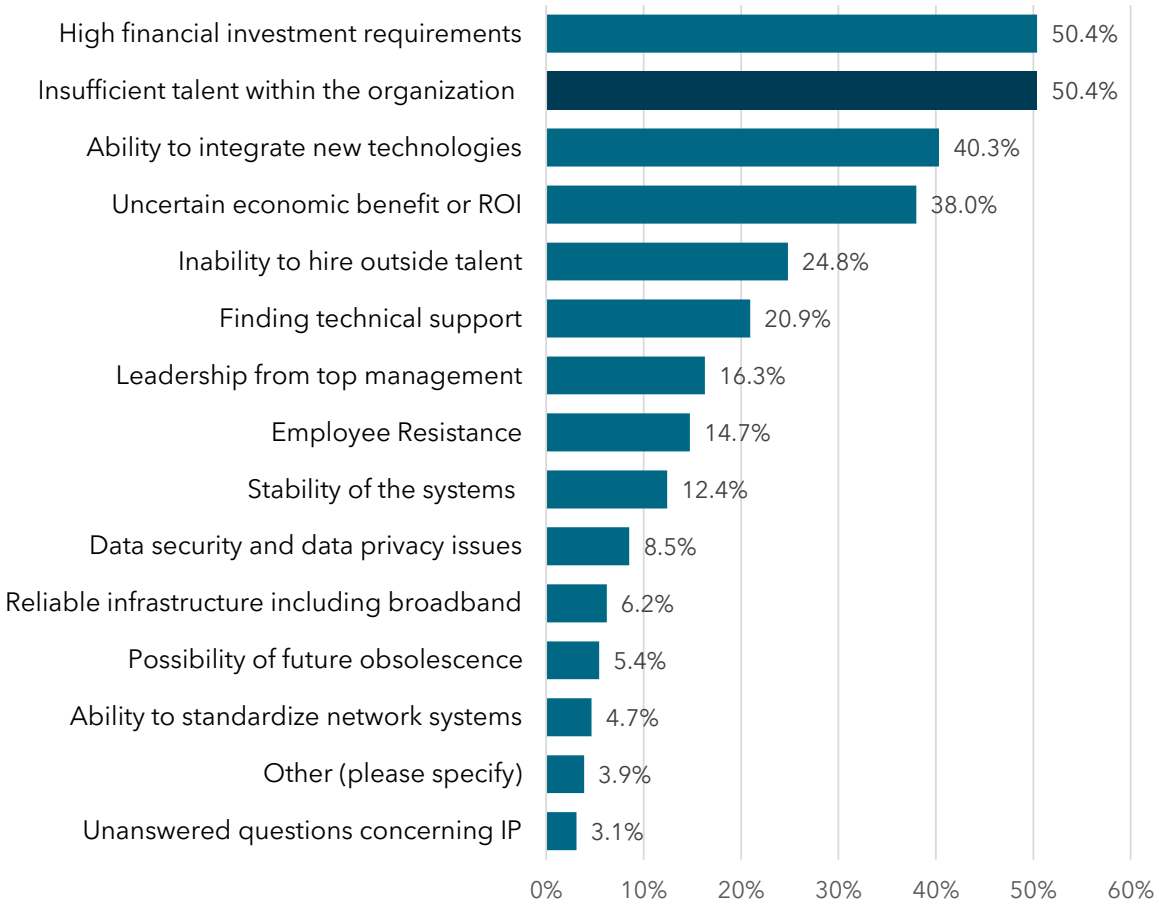
Key Points:

- Just under half of manufacturers cited some sort of workforce issue as a primary driver for implementing advanced manufacturing technologies and processes.
- The more advanced the manufacturing technologies and processes adopted by the manufacturer, the less likely they were to report that the applicants for their positions were qualified.

Highly skilled workers are needed to work for more technologically advanced manufacturers. Finding those employees is not always easy, and many manufacturers report having a hard time finding people to fill these roles. Just under half of manufacturers cited some workforce issue as a primary driver for implementing advanced manufacturing technologies and processes. This can create a reinforcing cycle, as manufacturers are automating to compensate for being unable to find workers, and then needing more skilled workers to work in more a technology advanced workplace.

When asked to identify the biggest obstacles in implementing advanced manufacturing technologies, just over half of manufacturers (50.4%) cited insufficient talent within the organization. This was the top answer, along with high financial investment requirements. Manufacturers implementing or intending to implement advanced manufacturing technologies and processes were more likely to respond that current applicants for production-worker positions were unqualified---22.8% of manufacturers responded affirmatively, compared to 6.1% of manufacturers who were not intending to implement advanced manufacturing technologies and processes. The more advanced manufacturing technologies and processes adopted by the manufacturer, the less likely they were to report that the applicants for their positions were qualified. This would suggest that either a higher skill level is needed by these applicants or the manufacturer has automated to overcome workforce issues.

Insufficient talent with the organization was tied for the top biggest obstacle to implementing advanced manufacturing technologies.

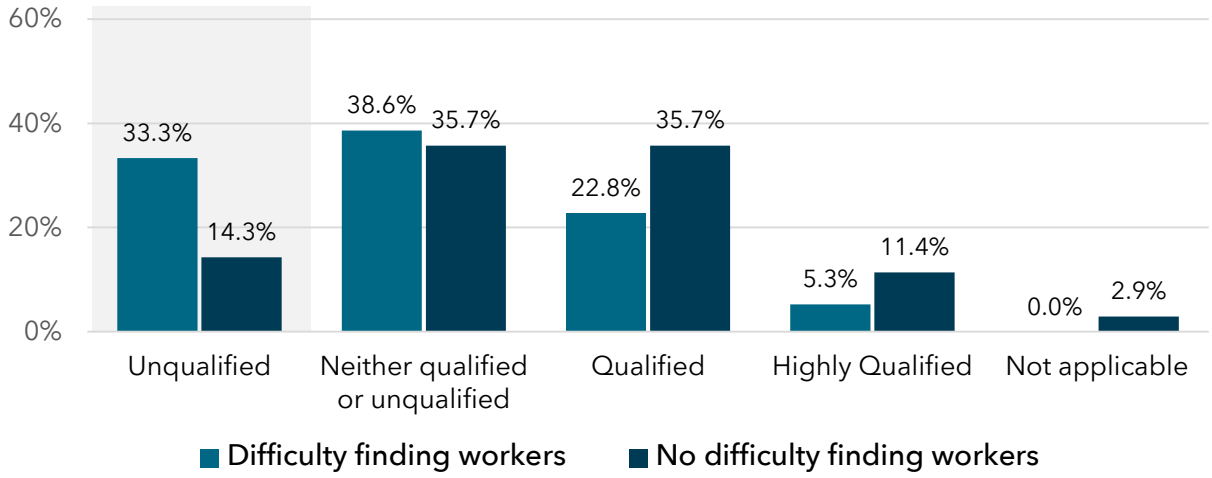


Manufacturers implementing or intending to implement advanced manufacturing technologies were more likely to view training provided by the company as the best way for potential production employees to acquire the specific skills required for future employment at their businesses: 82.2% cited this type of training as beneficial, compared to 70.0% of manufacturers not intending to implement advanced manufacturing technologies.

It is interesting that some manufacturers view increased levels of automation as a

The more advanced manufacturing technologies and processes adopted by the manufacturer, the less likely they were to report that the applicants for their positions were qualified.

Manufacturers reporting difficulty finding workers was a primary driver for implementing advanced manufacturing technologies were twice as likely to indicate applicants for production jobs were unqualified.



solution to this issue. Perhaps that is because fewer workers would then be needed to perform the tasks at hand, meaning fewer qualified applicants would be needed to fill positions. When asked what drove businesses to implement advanced manufacturing technologies and processes, more than four in ten manufacturers (44.6%) cited difficulty finding workers. And one-third (33.3%) of those who cited difficulty finding workers as a primary reason they were implementing advanced manufacturing also said current applicants for production-worker positions were unqualified, compared to 14.3% of manufacturers that did not cite difficulty finding workers as a primary reason for implementing advanced manufacturing technologies and processes. More than one in three of manufacturers (36.2%) who said a benefit of implementing advanced manufacturing technologies was the ability to overcome workforce/staffing challenges also responded current applicants for production-worker positions were unqualified.

Manufacturers citing difficulty finding workers as a primary reason they were implementing advanced manufacturing technologies and processes were less likely to indicate more than 75% of workers were proficient at their jobs: only 20.7% of manufacturers said this was true, compared to 42.3% of manufacturers who did not cite difficulty finding workers as a primary reason for implementing advanced manufacturing technologies and processes. Manufacturers located in metro areas were less likely than manufacturers in non-metro areas to say difficulty finding workers was a primary driver in implementing advanced manufacturing technologies. Additionally, those firms indicating that difficulty finding workers was a primary driver for implementing advanced manufacturing technologies were the ones most likely to report their inability to hire outside talent to perform certain jobs was an obstacle to implementing advanced manufacturing technologies, and their ability to overcome workforce/staffing challenges was a benefit to implementing advanced manufacturing.

Why this matters:

As the nature of jobs changes, the skills needed to perform tasks in the new economy will also evolve.

There are many interactions between advanced manufacturing technologies and the workforce. First, the savings associated with advanced manufacturing technologies assumes that technology substitutes for labor (Baur & Wee, 2015; McKinsey Digital, 2015). When technology replaces the tasks done by workers, fewer workers are needed to complete the same number of tasks. However, many manufacturers view technology as a complement to labor and purchase new equipment to augment their capabilities and accept new clients, not to displace workers (Acemolgu & Restrepo, 2018; Waldman-Brown, 2020). The issue with this strategy is finding qualified workers to complement technology, since manufacturers implementing automation reported that a higher percentage of workers at their firms were unqualified.

As the nature of jobs changes, the skills needed to perform tasks in the new economy will also evolve. In order to keep up with technological advancements, investments in complementary human skills are needed, as soft skills such as leadership, team building, and creativity will become increasingly important (Brynjolfsson & McAfee, 2012). While computers have proven to be good at pattern recognition, they do not yet fully possess the capacity for problem-solving, as they lack creative ability. This changes the role of operators on the shop floor into that of workers who need to be skilled in decision making and problem solving.

Bottom line for businesses:

Upskilling the workforce is an essential part of investing in advanced manufacturing technologies and processes.

Potential policy opportunities:

Building the pipeline of skilled workers requires developing educational and training programs that enable workers to gain the skills needed for jobs utilizing advanced manufacturing technologies.

5 Strategy matters: Manufacturers using an innovation strategy invest heavily in advanced manufacturing technologies.

Key Points:

- Manufacturers using an innovation strategy implemented more advanced manufacturing technologies than their peers.
- Manufacturers using an innovation strategy devoted more of their capital expenditure budget to advanced manufacturing technologies.
- Manufacturers using an innovation strategy were the most likely of any of the business strategies to have made substantial progress or to have fully implemented advanced manufacturing technologies and processes in the past year.

Manufacturers indicating innovation was their dominant business strategy differentiated themselves from their peers in the adoption of advanced manufacturing technologies. Other strategies listed as the top way facilities compete in the marketplace for business included through high quality products, superior customer service, quick and timely delivery, customized and specialized manufacturing, and low cost.

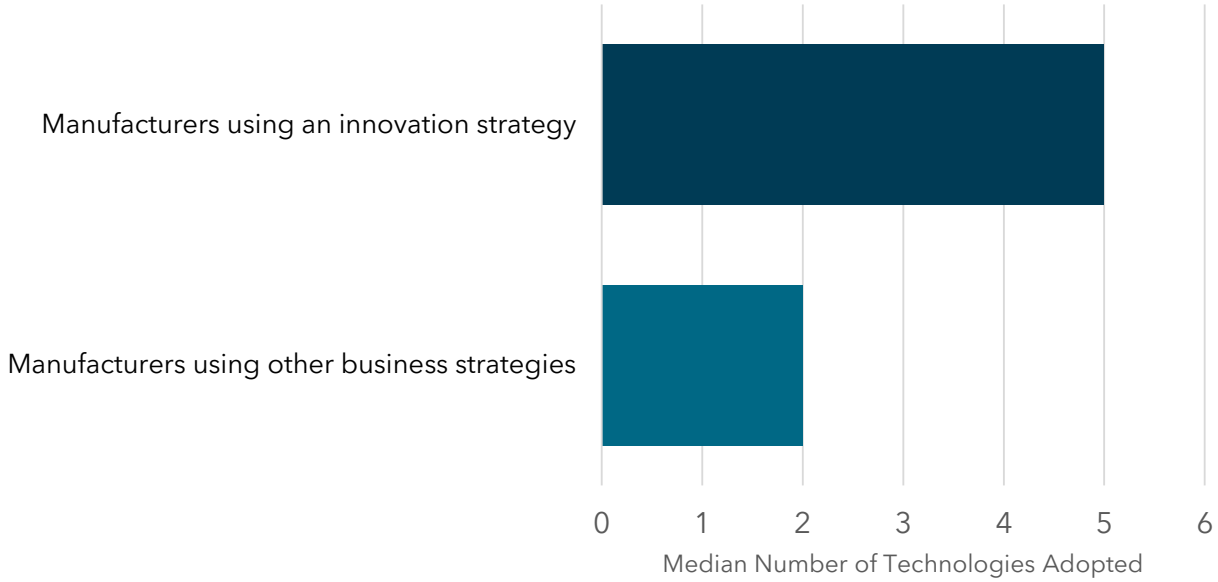
Manufacturers using an innovation strategy were two-and-a-half times more likely to adopt technologies than their peers, with a median adoption rate of five technologies compared to two for all other business strategies.

Manufacturers using an innovation strategy were the most likely to respond they intended to implement or had already implemented the following:

- Data-gathering sensors (68.8%)
- Robots/cobots (62.5%)
- Smart controllers (50.0%)
- Additive manufacturing (3D printing) (43.8%)
- Augmented reality (25.0%)

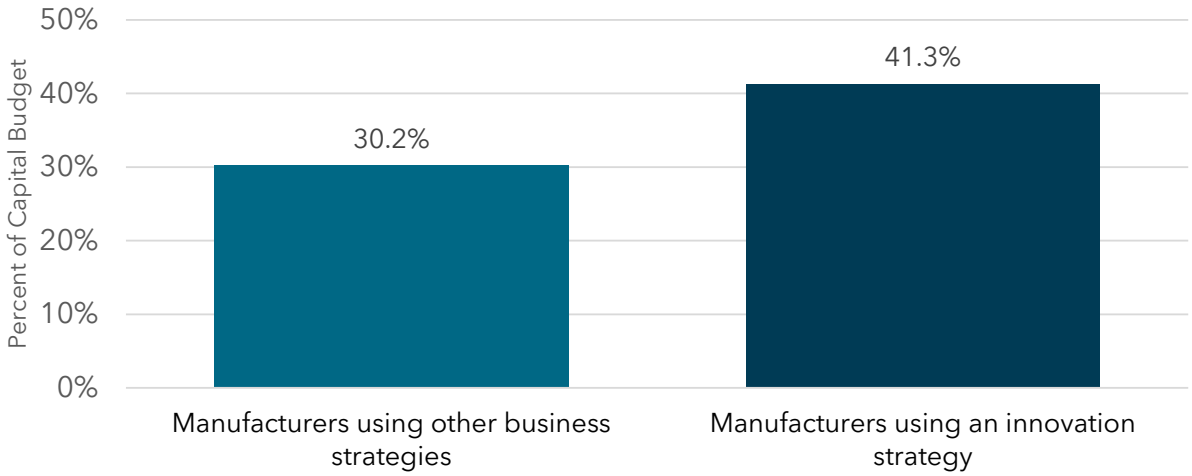
Manufacturers using an innovation strategy were two-and-a-half times more likely to adopt technologies than their peers .

Manufacturers using an innovation strategy report adopting more advanced manufacturing technologies than manufacturers using other business strategies.



The majority (53.3%) of manufacturers using an innovation strategy responded a primary driver for implementing advanced manufacturing technologies and processes was giving their business a competitive advantage. About 6 in 10 (60.5%) manufacturers using an innovation strategy indicated they had made substantial progress or had fully implemented advanced manufacturing technologies and processes,

Innovative firms report spending more of their capital expenditure budget on advanced manufacturing technologies.



compared to 34.5% of manufacturers using other business strategies. Manufacturers using an innovation strategy reported the highest average level of spending on advanced manufacturing, with 41.3% of the capital expenditure budget allocated for advanced manufacturing technologies and processes.

Why this matters:

Manufacturers prioritizing innovation are outpacing their peers in the adoption of advanced manufacturing technologies and processes.

The specialization of the manufacturer is centrally important in explaining improved productivity-enhancing investments (Cingano & Schivardi, 2004). In today's technology-driven economy, new innovations develop rapidly and there is a heightened strategic importance to adopting new technologies in a competitive marketplace. Advanced manufacturing looks to the future need to design production systems that have a high level of product individualization and flexible production processes (Schlectendal et al., 2015). Manufacturers prioritizing innovation are outpacing their peers in the adoption of advanced manufacturing technologies and processes.

Bottom line for businesses:

Creating a culture that embraces change and innovation is important in supporting a company's advanced manufacturing technology strategy.

Potential policy opportunities:

Developing innovative policies to support manufacturers as they invest in adopting advanced manufacturing technologies will be important now and in the future.

6 Technology to meet mix and volume.

Key Points:

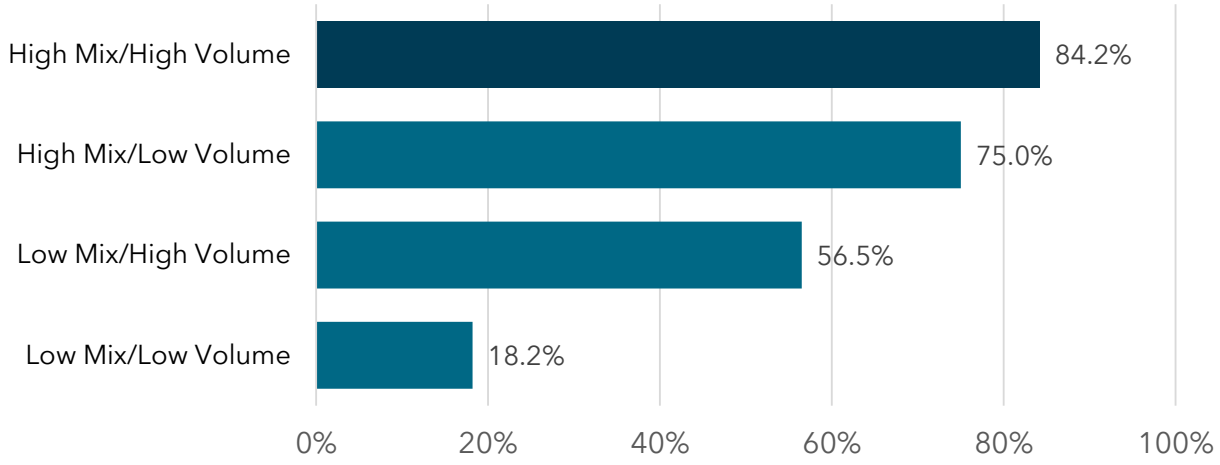
- High mix/high volume facilities were the most likely to indicate they intended to or already had implemented advanced manufacturing technologies and processes.
- High mix/low volume manufacturers were the least likely to indicate that an uncertain economic benefit or return on investment was an obstacle to implementing advanced manufacturing technologies and processes.
- Manufacturers engaging in low mix/high volume operations were the most likely to indicate that adopting advanced manufacturing technologies and processes was an "essential" component of their long-term strategy.

The potential for technology to transform business practices is immense. The benefits include increased output, higher quality, and improved reliability. The ability to staff, manage, and lead automated organizations will become an important competitive advantage for manufacturers in the future. For this competitive advantage to be realized, manufacturers must use production technologies that best fit their production process based on the idea of complementaries (Milgrom & Roberts, 1992). Advanced manufacturing is not a "one size fits all" solution; technology will have effects across the entire manufacturing facility. Overall, manufacturers are picking those technologies that best work for them and fit into their production system.

More than four in five manufacturers (84.2%) operating high mix/high volume facilities indicated that they intended to or already had implemented advanced manufacturing technologies and processes. In contrast, less than one in five manufacturers (18.2%) operating low mix/low volume facilities intended to or already had implemented such technologies and processes.

Low mix/high volume facilities were the most likely to view increased productivity as the primary benefit of advanced manufacturing technologies and processes:

High mix/high volume facilities were the most likely to indicate they intended to or already implemented advanced manufacturing technologies and processes.



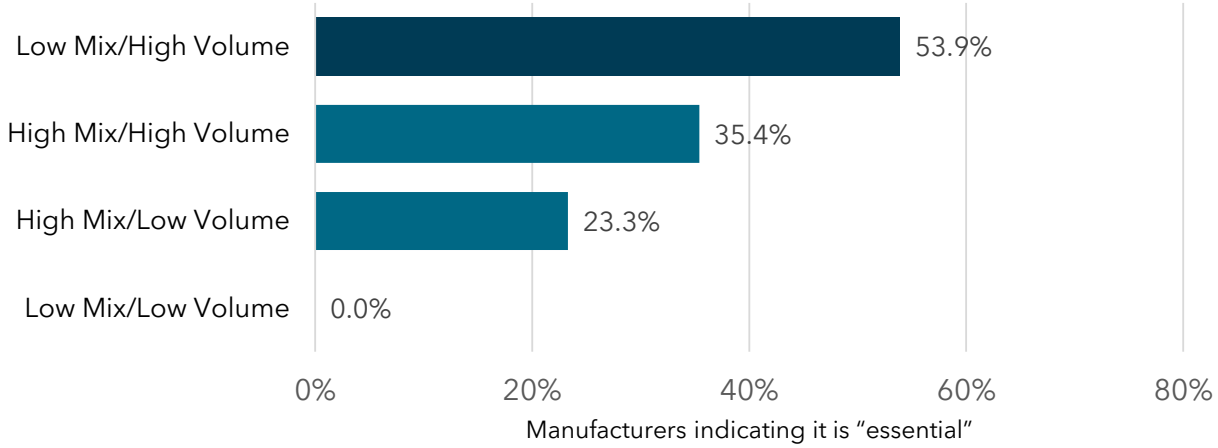
84.6% cited this as a benefit, compared to 75.0% of high mix/low volume facilities and 72.9% of high mix/high volume facilities. Just under 4 in 10 (35.0%) high mix/low volume facilities and 3 in 10 (30.1%) low mix/high volume facilities cited the ability to respond more quickly to customers as a benefit of adopting advanced manufacturing technologies and processes. In contrast, only 1 in 10 (12.5%) of high mix/high volume facilities cited this benefit. Meanwhile, one in five (20.0%) of high mix/low volume manufacturers indicated that increased revenue/sales was a benefit of implementing advanced manufacturing technologies or processes. This was much higher than for either high mix/high volume manufacturers (14.6%) or low mix/high volume manufacturers (7.7%).

A much higher percentage of high mix/low volume manufacturers (46.7%) and low mix/high volume manufacturers (46.2%) cited uncertain economic benefit or return on investment as an obstacle than did high mix/high volume manufacturers (27.1%). In terms of the adoption of specific technologies, more than 4 in 10 manufacturers (46.7%) having facilities with high mix/low volume operations indicated that they intended to implement or had already implemented additive manufacturing technologies (3D printing). This tracks with the ability of that technology to provide high levels of product customization.

For the competitive advantage of advanced manufacturing technologies to be realized, manufacturers must use production technologies that best fit their production process.

Manufacturers engaging in low mix/high volume operations were the most

Low mix/high volume facilities were the most likely to indicate adopting advanced manufacturing technologies was "essential" to the long-term strategy of their business.



likely to indicate that adopting advanced manufacturing technologies and processes was an "essential" component of their long-term strategy, with 53.9% indicating so. When it came to technology adoption, low mix/high volume facilities were the most likely to indicate they intended to implement or had already implemented machine-to-machine technologies, a technology that helps facilitate efficient processes and constant monitoring, which would specifically benefit this type of facility. The need for these machines to communicate with each other is likely the reason nearly one-third (30.8%) of low mix/high volume manufacturers indicated that data security and data privacy issues were obstacles to implementing advanced manufacturing technologies and processes---the most of any facility type.

Why this matters:

The production process of the manufacturer impacts what technologies and processes are adopted.

Production process represents an important factor in the ability of manufacturers to adopt certain technologies. Manufacturers that create high-mix/low-volume products, for example, face barriers in technology adoption because the products created generally have low levels of repeatability, meaning that few tasks are likely to benefit from automation (Buschle, et al., 2018). Meanwhile, manufacturers that create high-mix/high-volume strategies are likely to benefit immensely from automation because of the repeatability and large scale of their production process. The production process of the manufacturer impacts what technologies and processes are adopted.

Bottom line for businesses:

Deploying advanced manufacturing technologies will also mean that manufacturers will need to examine the implications for their business models, how they integrate operational and information technology, and invest in workforce training.

Potential policy opportunities:

Supporting non-glamorous investments, such as process improvements, measuring and control instruments, and better technical data, that comprise the technological infrastructure is greatly valuable to companies of all types.

7 Process first, technology second.

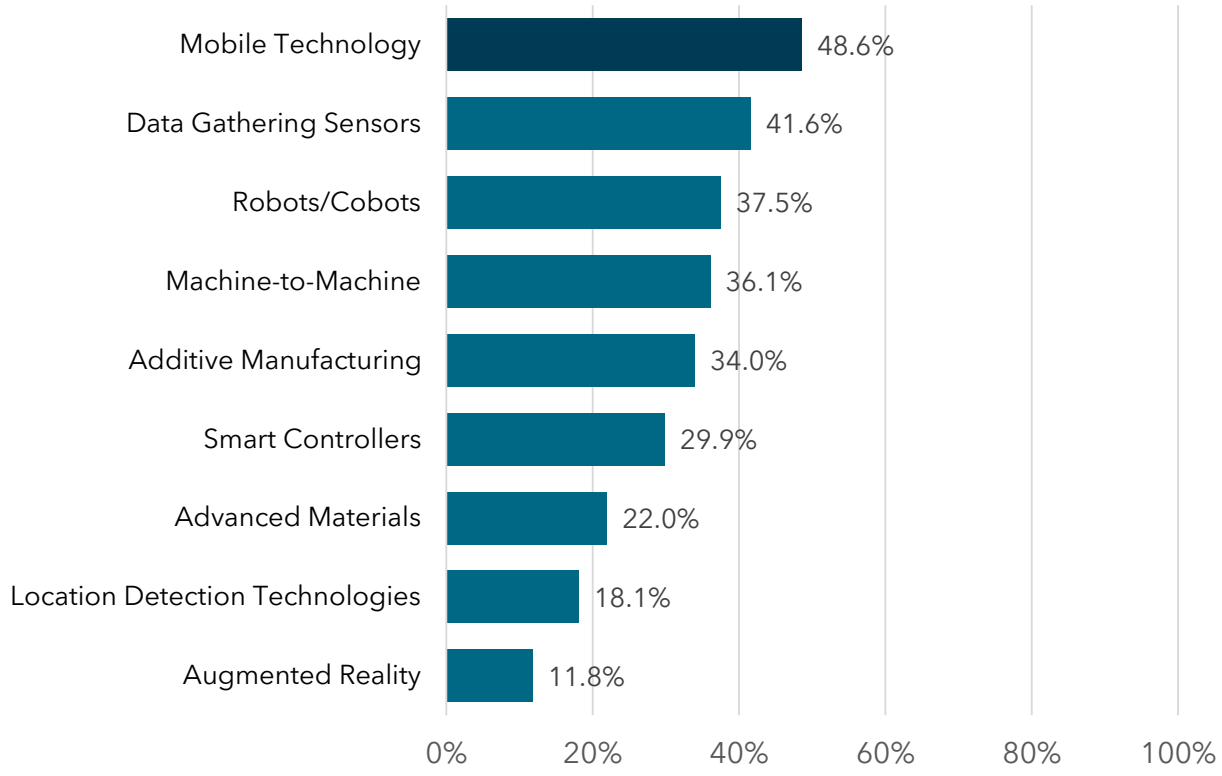
Key Points:

- Manufacturers are working to implement or have fully implemented a median of two advanced manufacturing technologies.
- The technologies manufacturers were most likely to report adopting were mobile technology, data-gathering sensors, and robots/cobots.
- Manufacturers are working to implement or have fully implemented a median of 4.5 advanced manufacturing processes.
- The processes manufacturers were most likely to report adopting were enterprise resource planning, cybersecurity, and cloud computing.

The implementation of advanced manufacturing can be divided into two primary categories: 1) technologies and 2) processes. Technologies are defined as the equipment used in the design, manufacture, or handling of a product. The term "processes" refers to the production activities used to design, manufacture, or handle a product. Overall, this represents the flow of products versus the flow of data/information through the production process. It can also be conceptualized as hard tech vs soft tech (ie - lean principles). Integrating innovative technologies and processes represents the core of advanced manufacturing.

Manufacturers indicating they were implementing advanced manufacturing technologies were asked to what extent their business was currently using or not using certain advanced manufacturing technologies as part of the production process. Just under half (48.6%) of manufacturers were in the process of implementing or had fully implemented mobile technology, while four in ten manufacturers (41.6%) were in the process of implementing or had fully implemented data-gathering sensors, and one in three (37.5%) were in the process or had implemented robots/cobots. Augmented reality was the technology least likely to be in the process

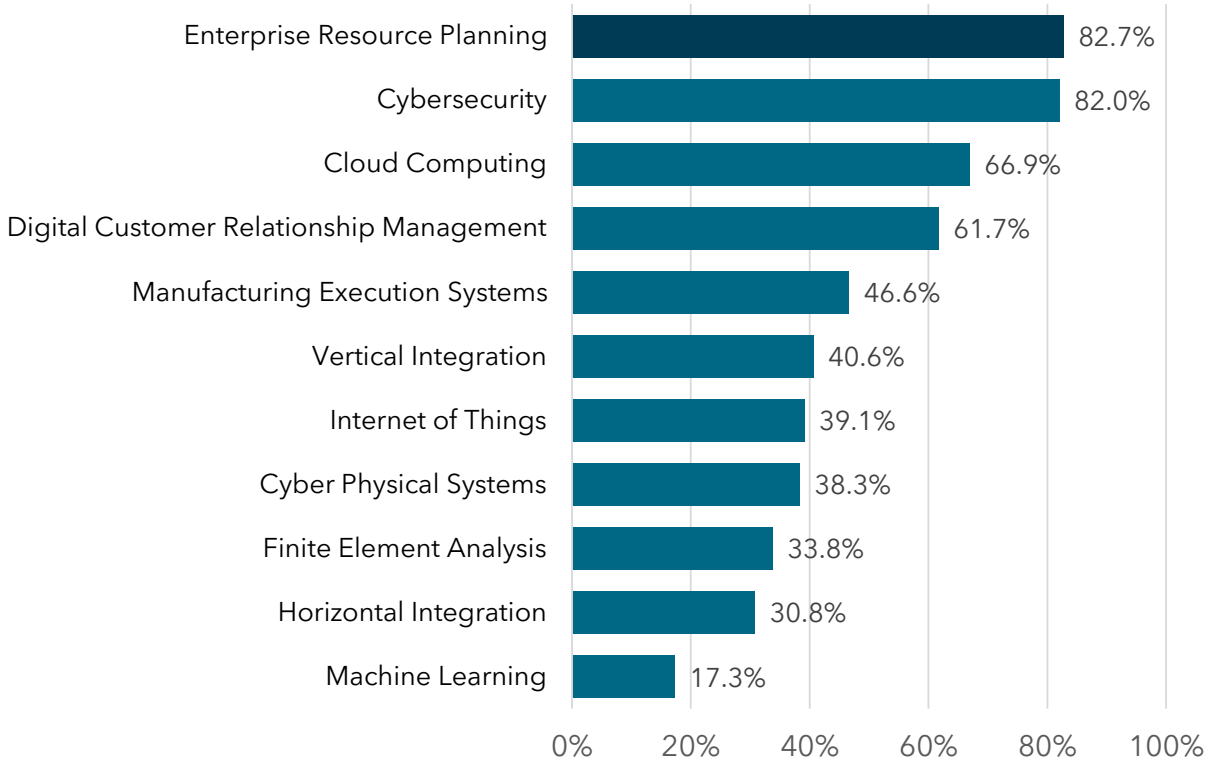
Mobile Technology, Data Gather Sensors, and Robot/Cobots are the advanced manufacturing technologies most likely to be in the process of being implemented or fully implemented by manufacturers.



of being implemented or to have been fully implemented by manufacturers. The median number of technologies manufacturers reported they were in the process of implementing or had fully implemented was two. Only 1.3% of manufacturers indicated they were in the process of implementing or had fully implemented all nine technologies asked about in the survey.

Next, manufacturers who indicated they were implementing advanced manufacturing were asked to what extent their businesses were currently using or not using certain advanced manufacturing processes. The vast majority (82.7%) of manufacturers said they were in the process of implementing or had fully implemented enterprise resource planning, and a similar proportion (82.0%) were in the process of implementing or had fully implemented cybersecurity. Machine learning was the process least likely (17.3%) to be implemented by manufacturers. The median number of processes manufacturers reported they were in the process of implementing or had fully implemented was 4.5. Just 4.6% of manufacturers indicated they were in the process of implementing or had fully implemented all 11 processes asked about in the survey.

Enterprise Resource Planning, Cybersecurity, and Cloud Computing are the advanced manufacturing processes most likely to be in the process of being implemented or fully implemented by manufacturers.



Why this matters:

Advanced manufacturing is not just about investing in technology; it is also about revolutionizing the entire ecosystem in which manufacturing operates.

The distinction between technologies and processes is important for a variety of reasons. First, technologies and processes interact to improve manufacturing efficiency. Technology serves as the instrument for achieving the goal, but processes represent the actual system that allows for the benefit to be produced.

While a manufacturer can make many investments in technology, without process improvements, those technological investments may not realize their full potential.

Why this matters (continued):

While a manufacturer can make many investments in technology, without process improvements, those technological investments may not realize their full potential. Second, fiscal constraints are more likely to impact technology purchases than they are to affect process changes. Many of the technologies highlighted in this study require substantial capital expenditures, while process improvements are often a more cost-effective way of realizing the benefits of advanced manufacturing. Finally, it is important to note that advanced manufacturing is not just about investing in technology; it is also about revolutionizing the entire ecosystem in which manufacturing operates. Asking only about technology investments does not provide a full picture of the operational improvements made by manufacturers.

Bottom line for business leaders:

Successful companies are not necessarily those that create new technologies but those that can rapidly absorb and deploy advanced manufacturing technologies.

Potential policy opportunities:

Providing technical assistance to support manufacturers as they deploy new processes and technologies in their production lines is beneficial to manufacturers.

8 Digital technologies - the "great equalizer" for small manufacturers.

Key Points:

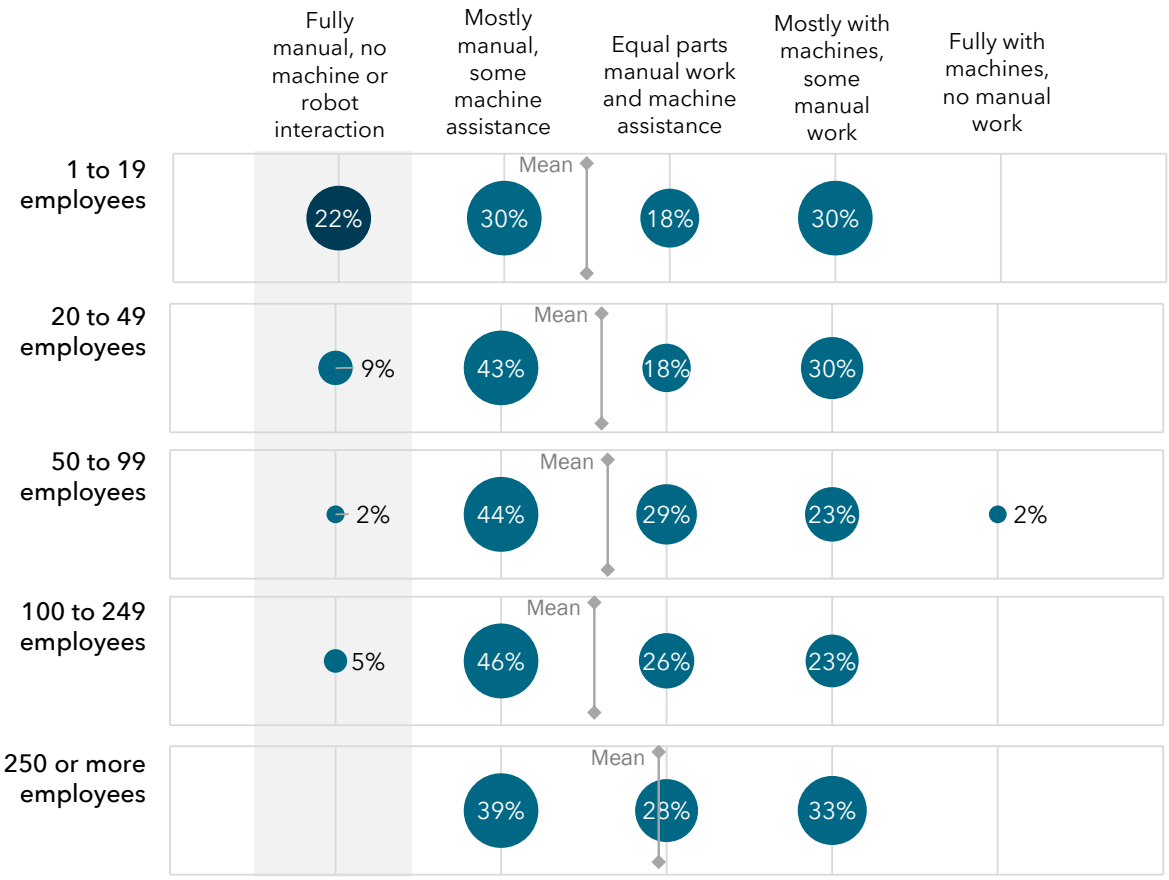
- The smallest manufacturers (1 to 19 employees) reported the lowest levels of manual automation.
- There was virtually no difference between small and large manufacturers in their level of cognitive automation.

Manual automation is the extent to which the physical tasks in the production process are mechanized. It measures the replacement of manual tasks once performed by humans with machinery or robots. Generally, when people refer to automation, they are talking about manual automation.

Only about one in five (22.2%) of the smallest manufacturers (1 to 19 employees) indicated the physical tasks within their production process were performed fully manually, with no machine or robot interaction, compared to none (0.0%) of the largest manufacturers (250 or more employees). On average, medium-sized manufacturers (50 to 249 employees) indicated the physical tasks within their production process were mostly performed manually, with some machine assistance, or were performed with equal parts manual work and machine assistance. There was not a significant difference between medium and large manufacturers in terms of the level of physical automation. Only the smallest manufacturers were much more likely to have their production processes performed fully manually.

The embrace of digital technologies, especially the computerization of the production processes, is a positive development and may serve as a "great equalizer" for small manufacturers.

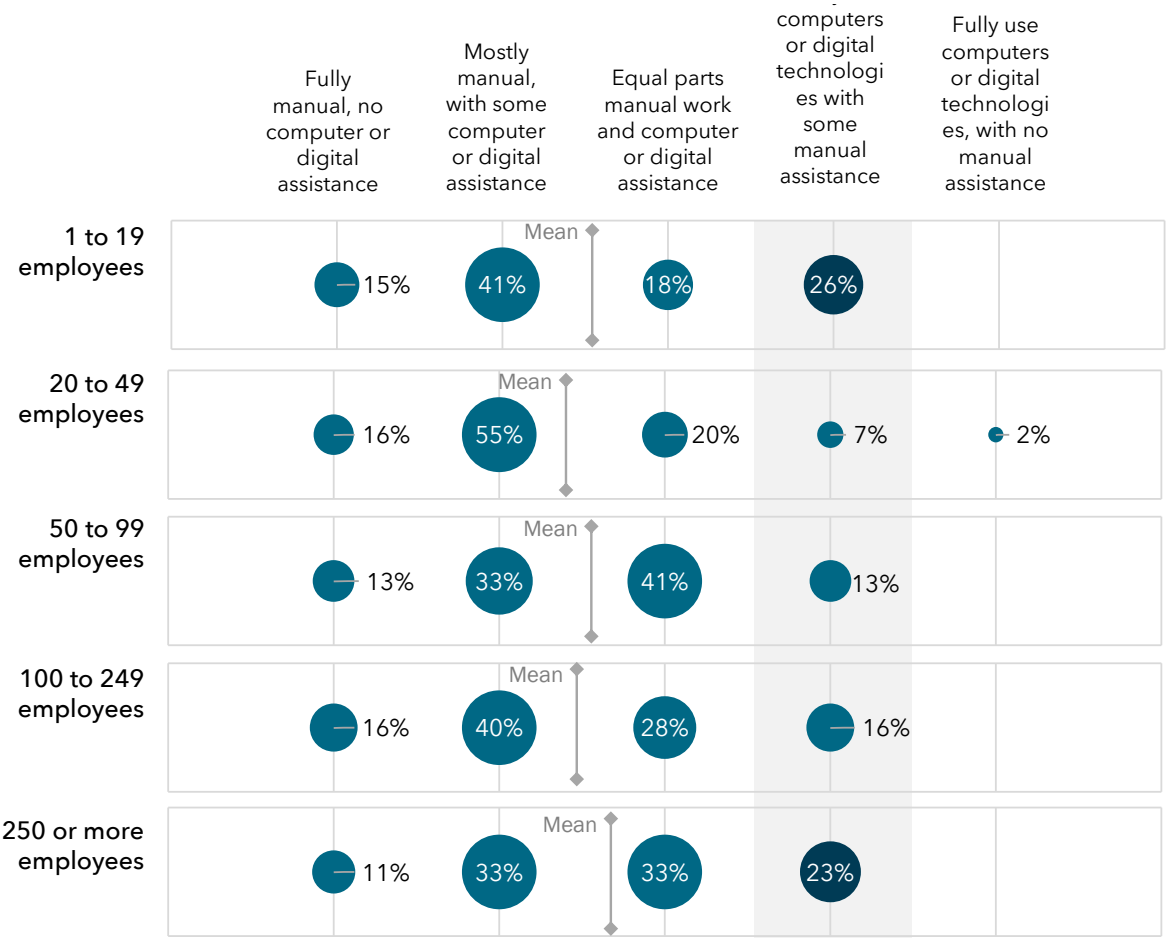
The smallest manufacturers (1 to 19 employees) were the most likely to indicate the physical tasks within their production process were performed fully manually, with no machine or robot interaction.



Cognitive automation or digitalization is defined as the extent to which mental tasks are computerized. Digitalization measures the collection, storage, and analysis of data by computers to monitor and control the production process. When people talk about Industry 4.0, generally they are referring to cognitive automation, which includes emerging technologies such as artificial intelligence and machine learning.

The smallest manufacturers (those having 1 to 19 employees) were just as likely as the largest manufacturers (250 or more employees) to indicate the critical-thinking, problem-solving, and troubleshooting tasks within their production processes were performed mostly using computers or digital technologies, with some manual assistance. The smallest and largest manufacturers were more likely to indicate they used cognitive automation than were mid-sized manufacturers, who, on average, indicated that the cognitive tasks within their production process were mostly performed manually, with some computer or digital assistance, or were performed with equal parts manual work and computer or digital assistance. Unlike manual

The smallest manufacturers (1 to 19 employees) were just as likely as the largest manufacturers (250 or more employees) to indicate the critical thinking, problem solving, and troubleshooting tasks within their production process were performed mostly using computers or digital technologies with some manual assistance.



automation, digitalization did not vary across manufacturing size. It is likely that the cost of adopting software to automate cognitive tasks is far lower relative to the much higher costs of creating a customized physical interface to automate a manual task.

Why this matters:

For the smallest manufacturers, embracing digital technologies may serve as an opportunity for these companies to fill more niches by providing specialized, industry-specific products, services, and applications.

Small manufacturers adopt technology at the slowest rate. Manufacturers with slower rates of technology adaptation average lower rates of employment and revenue growth (Rückert, Veugelers, & Weiss, 2020). Many small manufacturers lack an incentive to constantly acquire new technology so long as customers return. Thus, many small

Why this matters (continued):

manufacturers adopt new technologies more slowly compared to large manufacturers (Glassmeier, et al., 1998). The piecemeal investment strategy of most small manufacturers hamstrings the adoption of integrated advanced manufacturing systems (Waldman-Brown, 2020). As a result, many small and medium-sized manufacturers struggle with effectively investing in technological improvements (Rückert, Veugelers, & Weiss, 2020).

For the smallest manufacturers, embracing digital technologies may serve as an opportunity for these companies to fill more niches by providing specialized, industry-specific products, services, and applications (Sturgeon, 2019). Small manufacturers cannot always compete with large, mass manufacturers, so many emphasize quality and customization rather than quantity or price. Additionally, small and medium-sized enterprises may be unable or unwilling to invest in technology that supports automation of manual functions until proper processes are in place (Faller, 2015). The embrace of digital technologies, especially the computerization of the production processes, is a positive development and may serve as a "great equalizer" for small manufacturers.

Bottom line for businesses:

Incorporating advanced manufacturing technologies provides manufacturers the ability to improve productivity, create new opportunities for growth, and generate higher returns regardless of firm size.

Potential policy opportunities:

Supporting innovation in research and development, particularly for small and medium sized manufacturers is essential for helping such manufacturers improve their operational and business performance.

9 Short term financial uncertainty prevents manufacturers from realizing long-term productivity gains.

Key Points:

- Among manufacturers that do not intend to implement advanced manufacturing technologies, high financial investment was the most cited reason for making this choice, with 24.0% of manufacturers citing the cost.
- Additionally, among manufacturers who do intend to or are implementing advanced manufacturing technologies, the majority (50.4%) cited high financial investment requirements as one of the largest obstacles to implementation.
- The primary driver for manufacturers implementing advanced manufacturing technologies and processes was improved productivity, as more than four-fifths of manufacturers (84.6%) cited this as a reason.
- Over three-quarters (76.0%) of manufacturers believed that increased productivity was a primary benefit of implementing advanced manufacturing technologies and processes.

Digitization of information can reduce costs, increase productivity, and help manufacturers respond more efficiently to consumer demand. With better connectivity, more ideas can be created, tried, and implemented, all while the knowledge base is expanding (Carlsson, 2004). However, the high up-front costs of many technologies may serve as a disincentive for manufacturers to invest in these technologies.

Among manufacturers indicating they did not intend to implement advanced manufacturing technologies or processes, one in four (24.0%) cited high financial investment as the primary reason for not doing so. This mirrors the primary obstacle

Among all manufacturers, high financial investment was cited as the top obstacle to investing in advanced manufacturing technologies.

	Firms not investing in advanced manufacturing		Firms investing in advanced manufacturing
1	**High financial investment**	1*	**High financial investment**
2	Need more information	1*	Insufficient talent
3*	Specialized product	3	Unable to integrate products
3*	Not interested	4	Uncertain economic benefit
5	Not possible	5	Inability to hire outside talent

*Tie

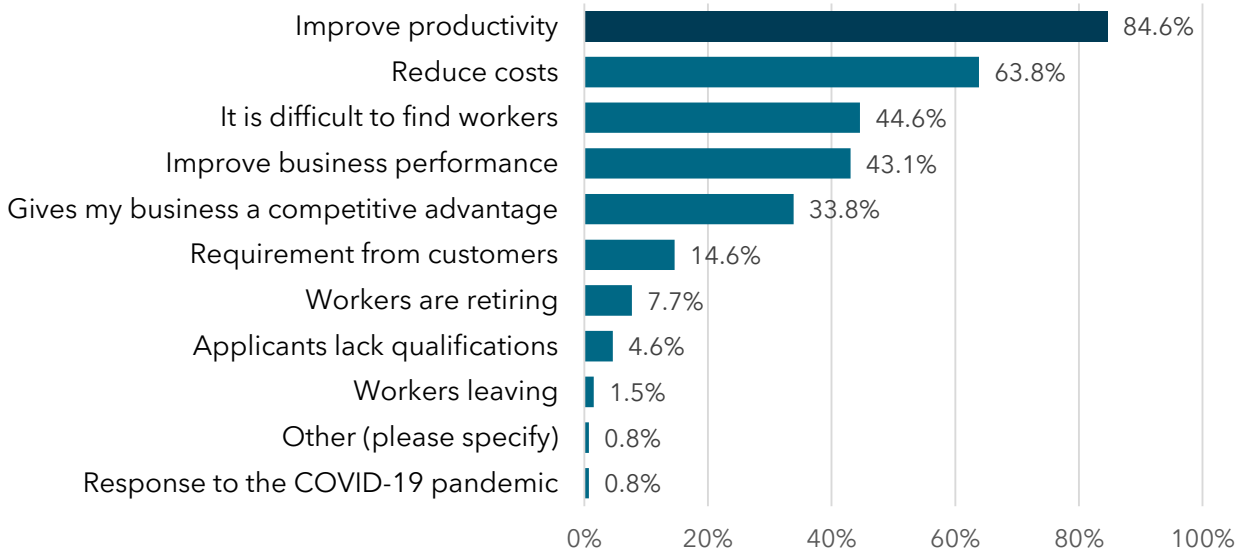
cited by manufacturers that did intend to implement advanced manufacturing technologies or processes: for them, too, high financial investment was one of the top cited obstacles to investing in advanced manufacturing technologies and processes, as just over half of these manufacturers (50.4%) cited this an obstacle. This reason tied for the top spot with having insufficient talent within the organization for executing tasks.

Overall, it appears manufacturers find themselves in a difficult situation. Advanced manufacturing technologies and processes have the ability to reduce costs, but the upfront investment is often too high for many firms. Manufacturers that touted reduced costs as a driving motivation were the most likely to also cite high financial investments as an obstacle, and reduced costs as a benefit, to implementing advanced manufacturing technologies and processes.

When asked what they believed to be the primary benefits of advanced manufacturing technologies and processes, just over three-quarters (76.0%) responded that increased productivity was a primary benefit---again, the top answer. Manufacturers that cited improved productivity as a driver for implementing advanced manufacturing technologies and processes were most likely to cite high financial investments as an obstacle, and, fittingly, increased productivity as a benefit.

This drive for productivity may help explain why productivity-boosting advanced manufacturing processes were more likely to be pursued by manufacturers than advanced manufacturing technologies.

Improved productivity was the top primary driver for implementing advanced manufacturing technologies and processes.



Additionally, when asked what drove manufacturers to implement advanced manufacturing technologies and processes, more than four-fifths of manufacturers (84.6%) cited improved productivity. This was the top answer. The smallest manufacturers (1 to 19 employees) were the least likely to cite increased productivity as a motivation for adopting advanced manufacturing technologies and processes---only 62.5% of the smallest manufacturers cited this as a reason, compared to 94.1% of the largest manufacturers (250 employees or more).

This drive for productivity may help explain why productivity-boosting advanced manufacturing processes were more likely to be pursued by manufacturers than advanced manufacturing technologies. This may be the result of a need to create the proper environment and therefore implement appropriate processes before implementing (more expensive) advanced manufacturing technologies.

While advanced manufacturing brings with it many advantages, there are several basic requirements for the introduction of advanced manufacturing technologies that businesses must contend with. These include the ability to introduce such technology into existing plants, ensuring the stability of the systems so that they provide reliable, robust results in real time; guaranteeing the protection of company data; and overseeing the installation of cybersecurity systems to prevent unauthorized access to production systems (Drath & Horch, 2014).

Why this matters:

Manufacturers are adopting many advanced manufacturing processes to boost productivity, but achieving long lived improvements may require integrating operational and information technologies.

Why this matters (continued):

Only 8% of manufacturers expect their current business model to remain viable throughout the digital age (Mahoney & Kota, 2020). However, despite the ubiquity of technological change, many manufacturers remain hesitant to install advanced manufacturing technologies (Rückert, Veugelers, & Weiss, 2020). One reason for this hesitance is the monetary cost of implementing advanced manufacturing technologies and processes.

The basis of advanced manufacturing is the establishment of intelligent products and production processes. It requires the creation of collaborative networks that facilitate customized products through intelligent automation and the reorganization of labor within the production system (Brettel et al., 2014). This includes digitization of the supply chain; the introduction and improvement of advanced manufacturing technologies; the provision of digital products, services, and business models; and the use of data analytics as a central tenet of business management. The introduction of internet technologies into industry serves as the technical background for advanced manufacturing (Drath & Horch, 2014). These overlapping technologies touch every aspect of industrial production, ultimately harmonizing manufacturing with seamless transmission of data from the supplier though the production process to the customer (McKinsey Digital, 2015). The benefits of advanced manufacturing primarily accrue through productivity gains and lower labor costs (Mahoney & Kota, 2020; McKinsey Digital, 2015).

Improving the information flow among business management, the production line, and supply chain has the potential to improve productivity and lead to more transparent and organized industrial management (Lee et. al., 2014). Digitization of information can reduce costs, increase productivity, and help producers respond more efficiently to consumer demand. With better connectivity, more ideas can be created, tried, and implemented, all while the knowledge base is expanding (Carlsson, 2004). Manufacturers are adopting many advanced manufacturing processes to boost productivity, but achieving long lived improvements may require integrating operational and information technologies.

Bottom line for businesses:

Making small, incremental investments in advanced manufacturing technologies and processes is a valuable way to demonstrate the value of such expenditures before spending higher amounts on unknown concepts.

Potential policy opportunities:

Helping manufacturers manage the uncertainty and risk of making the necessary investments in productivity enhancing technologies and processes will be important to the long-term competitiveness of manufacturers.

10 There is still so much to learn about advanced manufacturing technologies, and so many ways to do it.

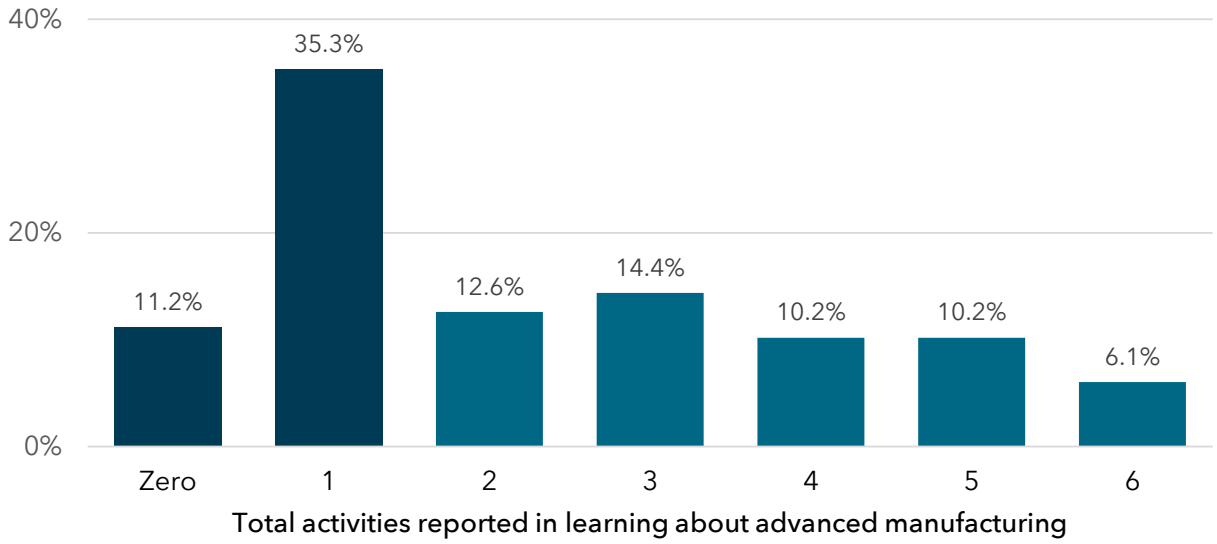
Key Points:

- Needing more information about advanced manufacturing technologies and processes was cited as the second most common reason (after cost) for not implementing advanced manufacturing technologies or processes.
- Just over half of manufacturers (53.5%) had become familiar with advanced manufacturing technologies through multiple avenues.
- The more avenues of learning about advanced manufacturing technologies and processes a manufacturer reported they engaged in, the more likely they were to intend to implement or to have already implemented advanced manufacturing technologies or processes.

Lack of familiarity with advanced manufacturing technologies and processes can serve as a barrier for implementation. Among manufacturers indicating they did not intend to implement advanced manufacturing technologies or processes, one-fifth (20.0%) said they needed more information. This was the second most commonly cited reason for not intending to do so.

Overall, most (88.8%) manufacturers reported familiarity with advanced technologies through at least one avenue of information. When asked how they would best describe their familiarity with advanced manufacturing technologies and processes, nearly two-thirds of manufacturers (64.2%) answered that they had read news articles. About two-fifths (41.9%) had attended presentations or discussions regarding new technologies, while another two-fifths (40.0%) had researched components of advanced manufacturing. Just over one-quarter of manufacturers (27.4%) participated in industry group discussions regarding advanced manufacturing technologies, and just under one in three (28.4%) of manufacturers reported they became familiar with advanced manufacturing technologies by actively using them.

Most manufacturers became familiar with advanced manufacturing technologies and processes through multiple activities.



Just over half of manufacturers (53.5%) had become familiar with advanced manufacturing technologies through multiple avenues. The more avenues of learning about advanced manufacturing technologies and processes a manufacturer had engaged in, the more likely that manufacturer was to intend to implement—or to already be implementing---advanced manufacturing technologies or processes. Participating in industry group discussions and attending presentations/talks about the topic were the most likely ways of learning for the same manufacturer to engage in. Another common pair of actions that manufacturers reported using to become familiar with the topic were through researching components of the topic and participating in demonstrations. Fully half (50.0%) of the largest employers (250 employees or more) reported that they became familiar with advanced manufacturing technologies by researching components of the topic. They were the group most likely to report having used this avenue to acquaint themselves with the topic. The smallest employers (1 to 19 employees) were the least likely to report they became familiar with advanced

The more avenues of learning about advanced manufacturing technologies and processes a manufacturer had engaged in, the more likely that manufacturer was to intend to implement—or to already be implementing-advanced manufacturing technologies or processes.

manufacturing technologies by participating in the industry group discussions, participating in demonstrations, or attending presentations/talks about the topic.

Why this matters:

Programs targeted at bolstering research and development activity introduce manufacturers to advanced manufacturing technologies.

It is difficult to tease out exactly the relationship between increased information and the willingness to invest in advanced manufacturing technologies. While it is possible that more information will spur manufacturers to invest in such technologies, it is also possible that the inverse is true---that manufacturers who are more motivated to invest in advanced manufacturing seek out more information on the subject.

Nevertheless, it is important to remember that while technology allows things to be done more cost effectively and with improved quality, it also opens up the potential for new business models to satisfy previously unknown or unidentified needs. For many manufacturers, understanding the potential of this technological investment is key, and programs that bridge the gap between basic academic research and late-stage commercial development can introduce skeptical manufacturers to advanced manufacturing technologies (U.S. Government Accountability Office, 2017). Specialized institutes such as the Manufacturing USA network allow manufacturers to pool research funding to mitigate risk (National Academies of Sciences, Engineering, and Medicine, 2017; Ezell, 2020). Similarly, many manufacturing extension partnerships (MEPs) offer assessments to prepare manufacturers for advanced manufacturing systems (Mahoney & Kota, 2020; Ezell, 2020). Programs targeted at bolstering research and development activity introduce manufacturers to advanced manufacturing technologies.

Bottom line for businesses:

Identifying the opportunities and technologies that best fit the production process is critical in understanding what investments will have a demonstrable business value to the company.

Potential policy opportunities:

Crafting programs that help manufacturers make well-reasoned investment decisions and decode the tangible benefits of investing in advanced manufacturing technologies will be critical to implementation.

Bottom line for businesses - Summary

This report suggests key takeaways for manufacturers to consider as they integrate advanced manufacturing technologies into their company and production process:

- Firms with an advanced manufacturing technology infrastructure already in place had a competitive edge enabling them to weather the economic uncertainty created by the COVID-19 crisis.
- Developing a strategy for implementing advanced manufacturing technologies and processes is critical to making the initial investment.
- Investing in advanced manufacturing technologies, regardless of firm size, creates a competitive advantage for manufacturers.
- Upskilling the workforce is an essential part of investing in advanced manufacturing technologies and processes.
- Creating a culture that embraces change and innovation is important in supporting a company's advanced manufacturing technology strategy.
- Deploying advanced manufacturing technologies will also mean that manufacturers will need to examine the implications for their business models, how they integrate operational and information technology, and invest in workforce training.
- Successful companies are not necessarily those that create new technologies but those that can rapidly absorb and deploy advanced manufacturing technologies.
- Incorporating advanced manufacturing technologies provides manufacturers the ability to improve productivity, create new opportunities for growth, and generate higher returns regardless of firm size.
- Making small, incremental investments in advanced manufacturing technologies and processes is a valuable way to demonstrate the value of such expenditures before spending higher amounts on unknown concepts.
- Identifying the opportunities and technologies that best fit the production process is critical in understanding what investments will have a demonstrable business value to the company.

For manufacturers, it is vital to understand what improvements can be made to the company to make it essential now and in the future. Innovation and technology investments can be incorporated into all business strategies. Overall, investments in advanced manufacturing technologies yield positive results for businesses.

Potential policy opportunities - Summary

This report also suggests key takeaways for policy makers to consider in how public policies can be crafted to support firms as they adopt and deploy advanced manufacturing technologies:

- Improving the overall innovative capacity of companies is important for economic resilience.
- Encouraging manufacturers to invest in advanced manufacturing technologies requires providing opportunities to test and access cutting edge technologies and processes.
- Using policies, such as tax incentives, grants, loans, and vouchers to support investments in training and equipment can help manufacturers as they integrate advanced manufacturing technologies into their operations.
- Building the pipeline of skilled workers requires developing educational and training programs that enable workers to gain the skills needed for jobs utilizing advanced manufacturing technologies.
- Developing innovative policies to support manufacturers as they invest in adopting advanced manufacturing technologies will be important now and in the future.
- Supporting non-glamorous investments, such as process improvements, measuring and control instruments, and better technical data, that comprise the technological infrastructure is greatly valuable to companies of all types.
- Providing technical assistance to support manufacturers as they deploy new processes and technologies in their production lines is beneficial to manufacturers.
- Supporting innovation in research and development, particularly for small and medium sized manufacturers is essential for helping such manufacturers improve their operational and business performance.
- Helping manufacturers manage the uncertainty and risk of making the necessary investments in productivity enhancing technologies and processes will be important to the long-term competitiveness of manufacturers.
- Crafting programs that help manufacturers make well-reasoned investment decisions and decode the tangible benefits of investing in advanced manufacturing technologies will be critical to implementation.

There are multiple avenues policymakers can use to support manufacturers as they invest in advanced manufacturing technologies. The instruments are far ranging and can include everything from direct funding of R&D efforts to tax incentives to subsidies for investment and technical assistance. Additionally, the transfer of technology and access to data held by governments also serves as way to support innovation and investments. Cataloging advanced manufacturing technology assets held in a variety of organizations and demonstrating how they can be applied and utilized can also be beneficial. Funding for education and training to help create the skilled workforce needed for work in advanced manufacturing is also essential.

Conclusion

Manufacturing is important to the Illinois economy. It accounts for nearly 600,000 direct jobs and 12 percent of the state's annual gross domestic product (GDP) (Moutray, 2019). Advanced manufacturing is the next paradigm in the digitization of manufacturing (Baur & Wee, 2015; McKinsey Digital, 2015). Virtually every segment of manufacturing reaps advantages from advanced manufacturing technologies, though the magnitude of benefits varies significantly by sector. A 2021 McKinsey & Company report projected that innovations in advanced manufacturing could contribute $185 billion to the American economy by 2030 (Manyika, et al., 2021).

This survey highlights a nuanced picture of the adoption of advanced manufacturing technologies and processes in Illinois. Overall, manufacturers see the value of advanced manufacturing technologies, but have been slow to implement them. Just over two-thirds (71.6%) of manufacturers report they intend to implement advanced manufacturing technologies and processes. Lack of knowledge regarding advanced manufacturing and up-front costs are reasons cited by some manufacturers for why they have not adopted advanced manufacturing. Improving the awareness of advanced manufacturing technologies for smaller firms and creating programs to reduce initial costs of implementation may improve adoption.

This distinction between advanced manufacturing technologies and processes is important. Manufacturers are more likely to invest in advanced manufacturing processes than in advanced manufacturing technologies. This may be a reflection of manufacturers being in the beginning stage of adoption, because the appropriate processes need to be in place in order to create the environment for advanced manufacturing technologies to thrive. Processes are an essential component of enabling technologies to work. Firm size plays a large role in this, as larger and more established manufacturers are more likely to adopt advanced manufacturing technologies and processes. This is likely due to a combination of factors, although the ability to afford such investments is a primary reason.

Virtually every segment of manufacturing reaps advantages from advanced manufacturing technologies.

This reasoning is supported by our finding: financial investment is the biggest obstacle for manufacturers in adopting advanced manufacturing technologies. For both manufacturers intending to implement advanced manufacturing technologies and those not intending to implement advanced manufacturing technologies, the monetary cost of such investments was seen as a barrier. Productivity gains were the most likely reason cited by manufacturers for investing in advanced manufacturing technologies. This drive for productivity may also help explain why productivity-boosting advanced

manufacturing processes were more likely to be pursued by manufacturers than were advanced manufacturing technologies. However, financial investment is likely still a factor in this decision making, as the financial investment in process innovations is generally smaller than the investment in technology innovations.

This financial barrier to technology adoption also helps explain why small manufacturers lag behind large manufacturers in automating the physical work done by production workers but are just as likely as large firms to adopt cognitive automation processes. For small manufacturers, the cost of adopting software to automate cognitive tasks is low relative to the much higher costs of creating a customized physical interface to automate a manual task. This is not necessarily a negative thing, as it creates an opportunity for these companies to provide specialized products and fill specific niches within the manufacturing landscape.

Product customization was also identified as an important determinant of the technology investment decisions of manufacturers who are embracing technologies that best support their unique production processes. In this context, advanced manufacturing technology and process adoption decisions are determined by the particular operational needs of the manufacturer. Another important factor was competitive strategy; this influences specifically which manufacturers are prioritizing advanced manufacturing technologies. Manufacturers adopting an

This survey of select manufacturers found ten important things to know about advanced manufacturing technologies in Illinois:

1. Advanced manufacturing technologies helped with pandemic resilience.
2. Two-thirds of manufacturers have made modest to minimal progress in adopting advanced manufacturing technologies.
3. Smaller manufacturers lag behind larger manufacturers in the adoption of advanced manufacturing technologies.
4. It's automation AND workforce: Drivers and barriers to adoption.
5. Strategy matters: Manufacturers using an innovation strategy invest heavily in advanced manufacturing technologies.
6. Technology to meet mix and volume.
7. Process first, technology second.
8. Digital technologies - the "great equalizer" for small manufacturers.
9. Short term financial uncertainty prevents manufacturers from realizing long-term productivity gains.
10. There is still so much to learn about advanced manufacturing technologies, and so many ways to do it.

innovation strategy were 2.5 times more likely to adopt technologies than their peers, with a median adoption rate of five technologies, compared to two for all other business strategies. While firm size helps explain some of the differences between manufacturers, the specialization of the manufacturer, both in production process and competitive strategy, is also centrally important in explaining the investments made in advanced manufacturing technologies.

Although monetary cost and productivity gains are important factors in the decision to implement advanced manufacturing technologies, workforce issues are also both an obstacle to and a driver of adopting advanced manufacturing. Highly skilled workers are needed to work for more technologically advanced manufacturers, but finding and cultivating that talent can be difficult. On the other hand, increased levels of automation may mean manufacturers need fewer workers to complete the same number of tasks. Indeed, the inability to find workers was cited as a reason for investing in advanced manufacturing technologies by one-third of manufacturers. This investment may be beneficial in overcoming some of these workforce challenges, as manufacturers who invested in certain advanced manufacturing technologies reported they had fewer workforce issues as a result of COVID-19. The past year has demonstrated the benefits of advanced manufacturing in helping manufacturers weather shocks---specifically, the COVID-19 pandemic.

For business leaders, there are many organizational changes that can be made to help facilitate the adoption of advanced manufacturing. These include learning about advanced manufacturing, creating a plan for adoption, and making changes to the organizational culture of the business. Small, incremental changes have large payoffs in the adoption of advanced manufacturing technologies.

For policy makers, there are multiple policies that can be employed to help facilitate the adoption of advanced manufacturing technologies. These range from tax incentives and subsidies to direct funding through grants and loans. Policy makers should consider catalyzing and supporting organizations and programs that enhance collaboration and provide the needed technical expertise and assistance to manufacturers as they develop a road map and adopt advanced manufacturing technologies that will be key to manufacturing's long-term success and viability. For advanced manufacturing to thrive, innovative policy solutions are needed to make the investment worthwhile to manufacturers.

Overall, this study finds that the adoption of advanced manufacturing is not a "one size fits all" proposition. Firm characteristics such as size, production process, and business strategy are important in understanding which technologies and processes are adopted. Also important are resource limitations, such as the ability to make financial investments and the quality and supply of workers. Looking toward the future, it remains unclear how technologies will develop, the costs of such innovations, and their accessibility to manufacturers. However, one theme that emerges is this: there are multiple advantages to adopting advanced manufacturing technologies and processes; among these are increased productivity, efficiencies, and durability for firms. Manufacturers that do not modernize will face competitive challenges in the future. Building the infrastructure and resources necessary for manufacturers to continue to adopt advanced manufacturing technologies is vital to the future economy of Illinois.

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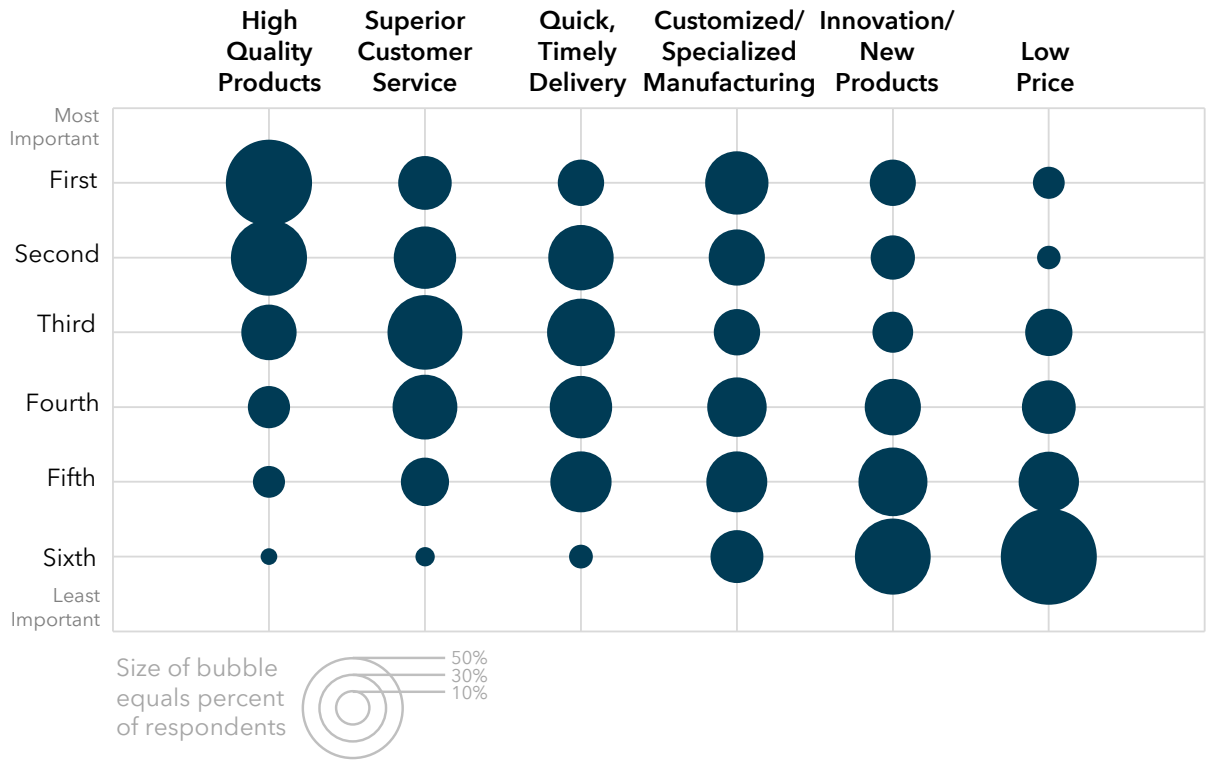
APPENDIX A - Survey Responses

Business Strategy

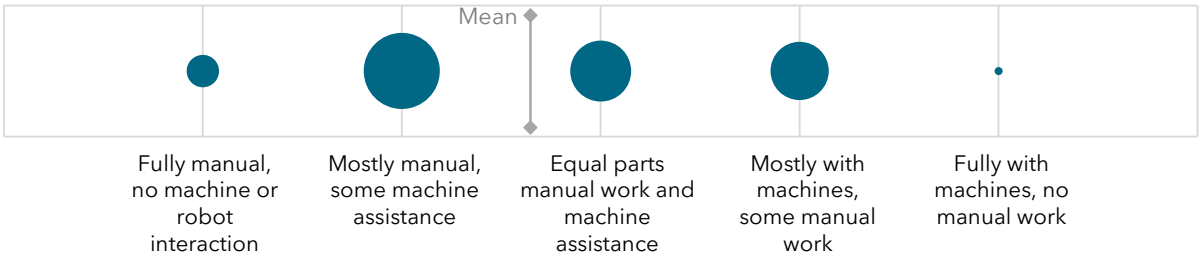
Please RANK, in order of importance, the following factors according to how your facility competes in the marketplace for sales. 1=most important, 6=least important.



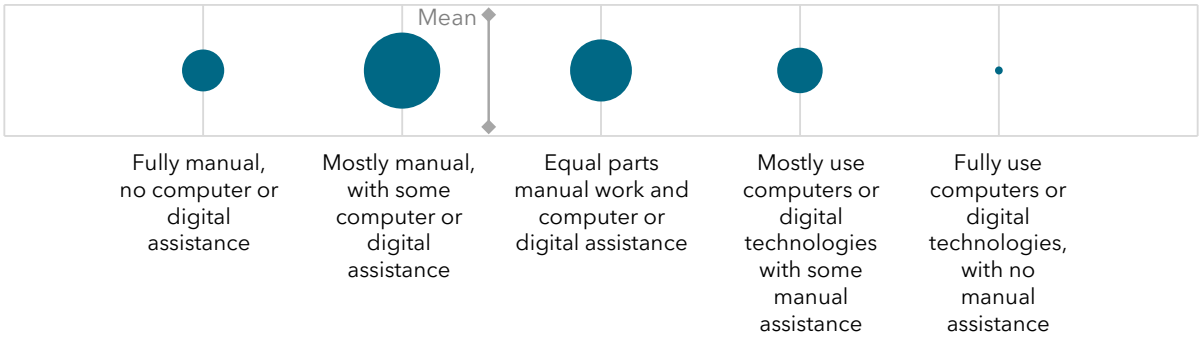
APPENDIX A - Survey Responses

Current Levels of Automation and Digitalization

To what extent are the physical tasks within your production process performed by machinery or robots?



To what extent are the critical thinking, problem solving, and troubleshooting tasks within your production process computerized or aided with digital technologies?



APPENDIX A - Survey Responses

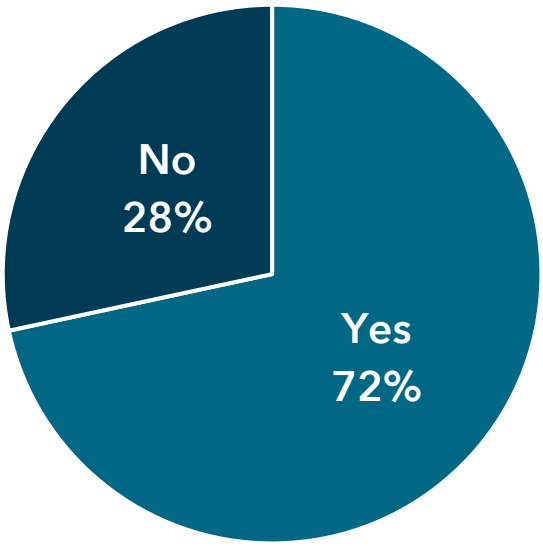
Knowledge of Advanced Manufacturing

How would you best describe your familiarity with advanced manufacturing technologies & processes? [Check all that apply]

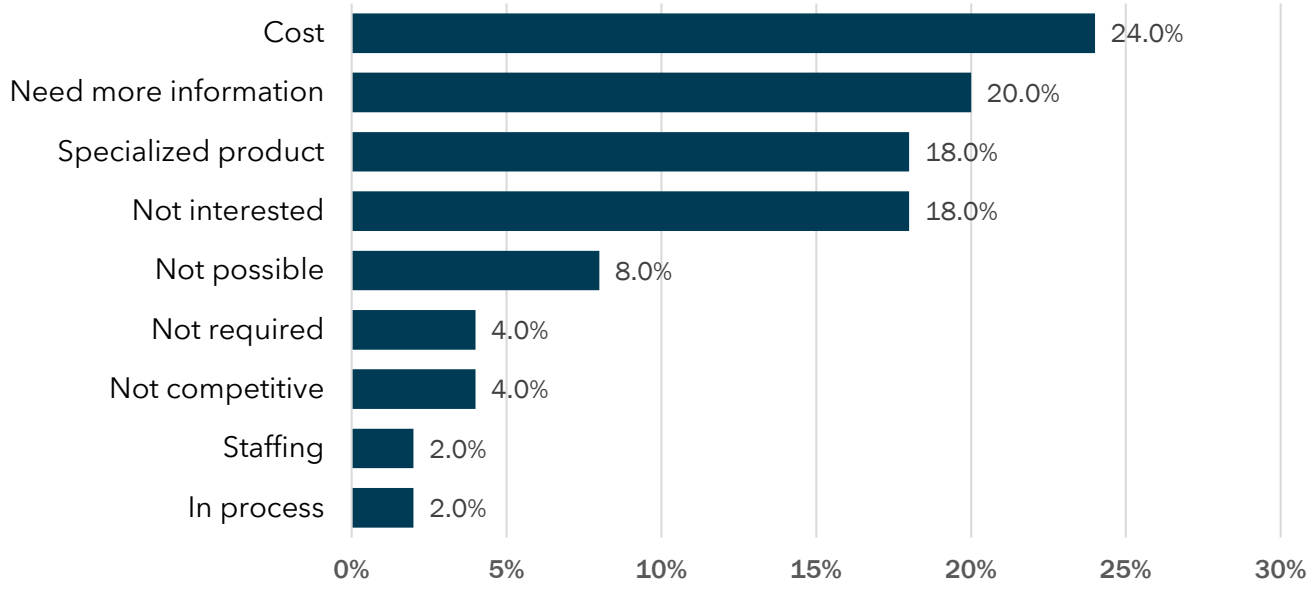
APPENDIX A - Survey Responses

Implementation Plan

Have you implemented or do you intend to implement advanced manufacturing technolo & processes?



Why do you not plan on implementing advanced manufacturing technologies & processes?



APPENDIX A - Survey Responses

Advanced Manufacturing Technologies and Processes

To what extent is your business currently using or not using the following advanced manufacturing technologies as part of the production process?

	No plans to use	Not in use, but intend to adopt in the next 5 years	In the process of Implementation	Fully implemented	Not applicable/ unable to implement
ADDITIVE MANUFACTURING (3D PRINTING)	27.8%	24.3%	11.8%	22.2%	13.9%
ADVANCED MATERIALS	33.3%	26.4%	7.6%	14.6%	18.1%
ROBOTICS/COBOTS	16.0%	38.2%	26.4%	11.1%	8.3%
AUGMENTED REALITY	47.9%	23.6%	9.7%	2.1%	16.7%
DATA GATHERING SENSORS	12.5%	38.9%	21.5%	20.1%	6.9%
LOCATION DETECTION TECHNOLOGIES	33.3%	35.4%	10.4%	7.6%	13.2%
MACHINE TO MACHINE (M2M)	19.4%	37.5%	14.6%	21.5%	6.9%
MOBILE TECHNOLOGY	5.6%	41.0 %	22.9%	25.7%	4.9%
SMART CONTROLLERS	18.8%	47.2 %	18.8%	11.1%	4.2%

APPENDIX A - Survey Responses

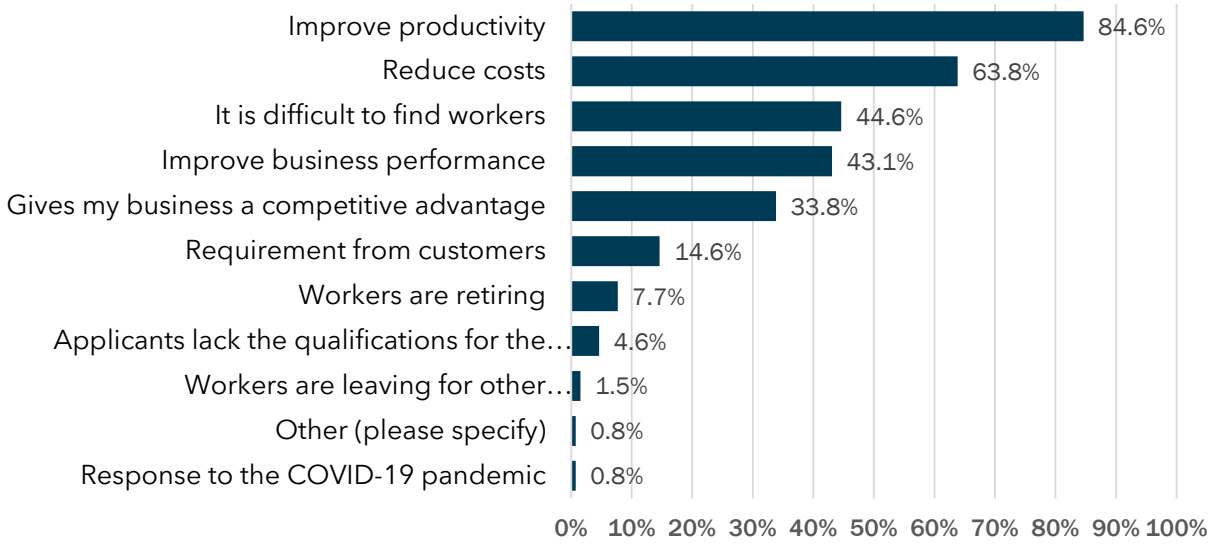
To what extent is your business already using or not using the following types of advanced manufacturing processes as part of the production process?

	No plans to use	Not in use, but intend to adopt in the next 5 years	In the process of Implementation	Fully implemented	Not applicable/ unable to implement
CLOUD COMPUTING	14.3%	17.3%	25.6%	41.4%	1.5%
CYBER PHYSICAL SYSTEMS	24.1%	33.1%	20.3%	18.0%	4.5%
CYBERSECURITY	2.3%	13.5%	22.6%	59.4%	2.3%
DIGITAL CUSTOMER RELATIONSHIP MANAGEMENT	17.3%	19.5%	28.6%	33.1%	1.5%
ENTERPRISE RESOURCE PLANNING	7.5%	9.8%	15.8%	66.9%	0.0%
FINITE ELEMENT ANALYSIS	33.1%	19.5%	10.5%	23.3%	13.5%
HORIZONTAL INTEGRATION	29.3%	30.1%	21.8%	9.0%	9.8%
INTERNET OF THINGS	14.3%	40.6%	22.6%	16.5%	6.0%
MACHINE LEARNING	33.1%	41.4%	11.3%	6.0%	8.3%
MANUFACTURING EXECUTION SYSTEMS	18.0%	30.8%	21.1%	25.6%	4.5%
VERTICAL INTEGRATION	22.6%	28.6%	18.0%	22.6%	8.3%

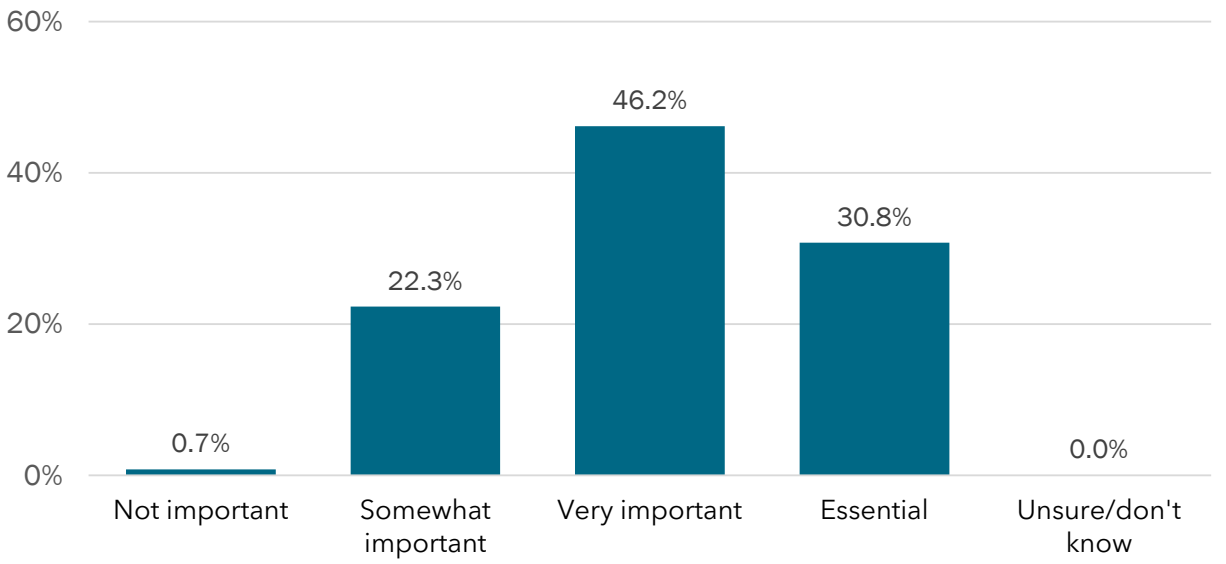
APPENDIX A - Survey Responses

Implementing Advanced Manufacturing

What are the primary drivers for your business in implementing advanced manufacturing technologies & processes? (Please select your top 3).

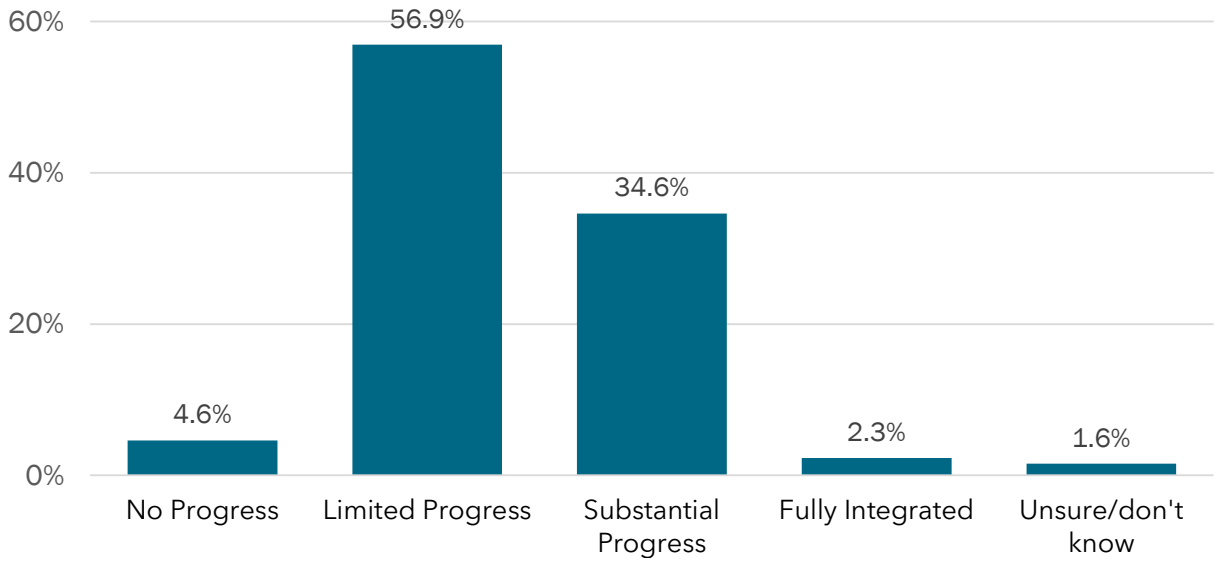


How important are adopting advanced manufacturing technologies & processes to the long-term (next 3-years) future strategy of your business?



APPENDIX A - Survey Responses

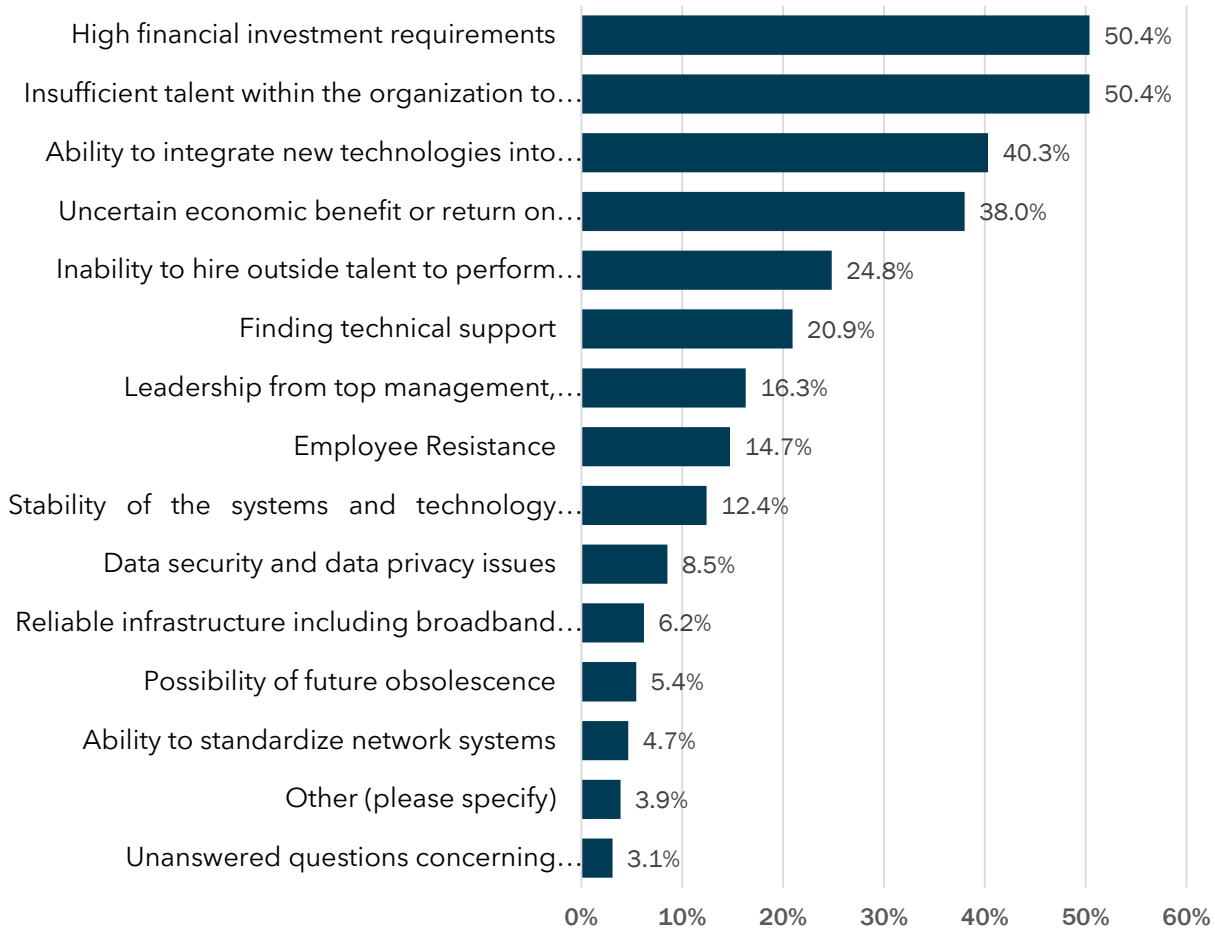
How would you rate your business' progress in implementing advanced manufacturing technologies & processes this year?



APPENDIX A - Survey Responses

Implementing Advanced Manufacturing Obstacles

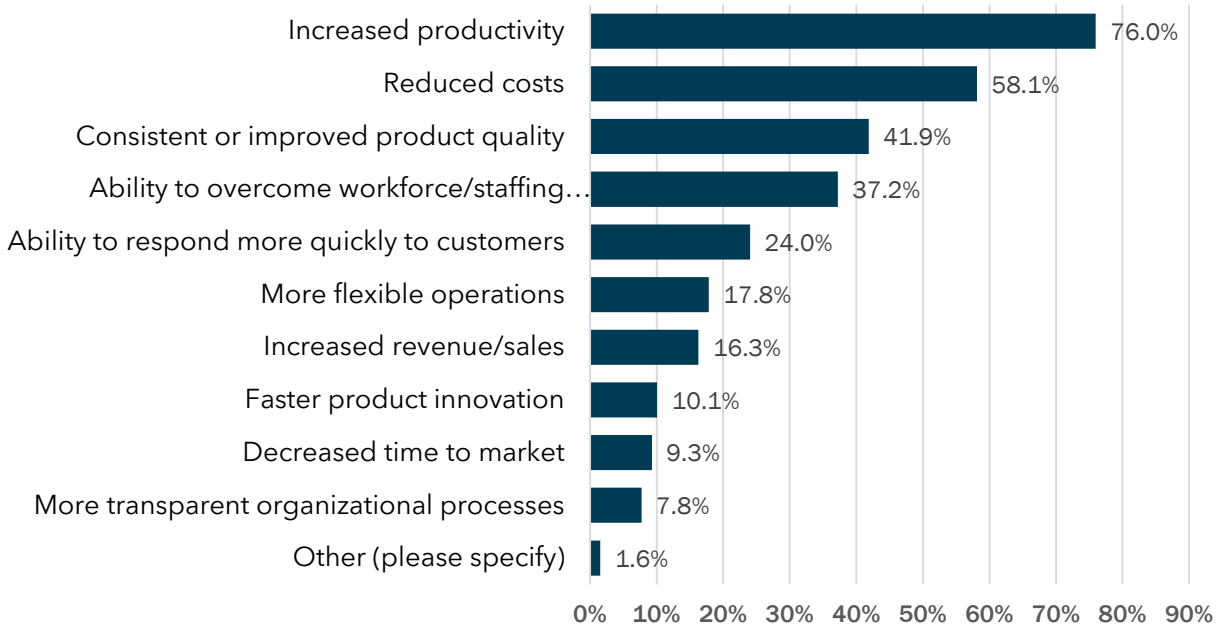
What are the biggest obstacles your business faces in implementing advanced manufacturing technologies & processes? [Please select your top three reasons]



APPENDIX A - Survey Responses

Implementing Advanced Manufacturing Benefits

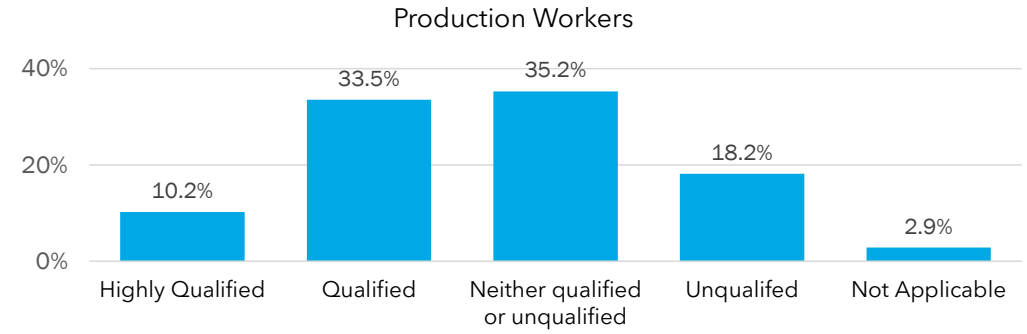
What do you believe are the primary benefits in implementing advanced manufacturing technologies & processes? [Please select your top three reasons]

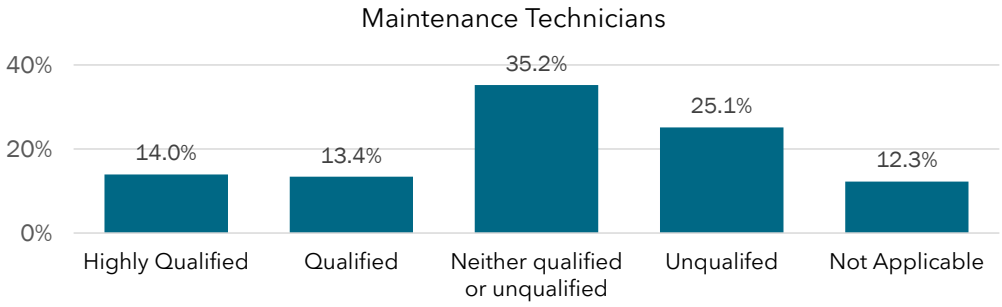


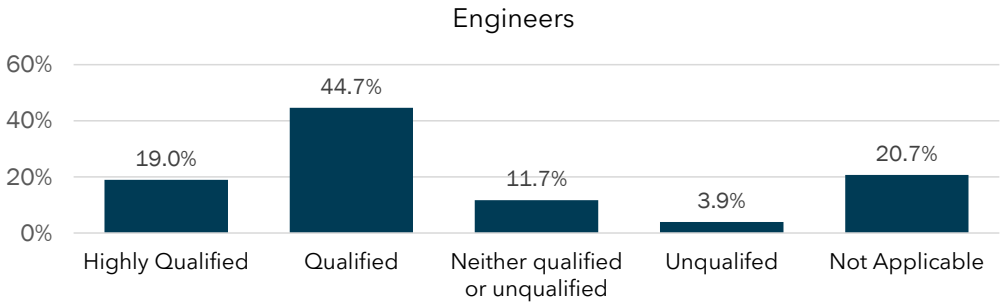
APPENDIX A - Survey Responses

Workforce Training and Development

Based on the pre-existing training they have received, how qualified or unqualified are the current applicants to your business in the following positions?

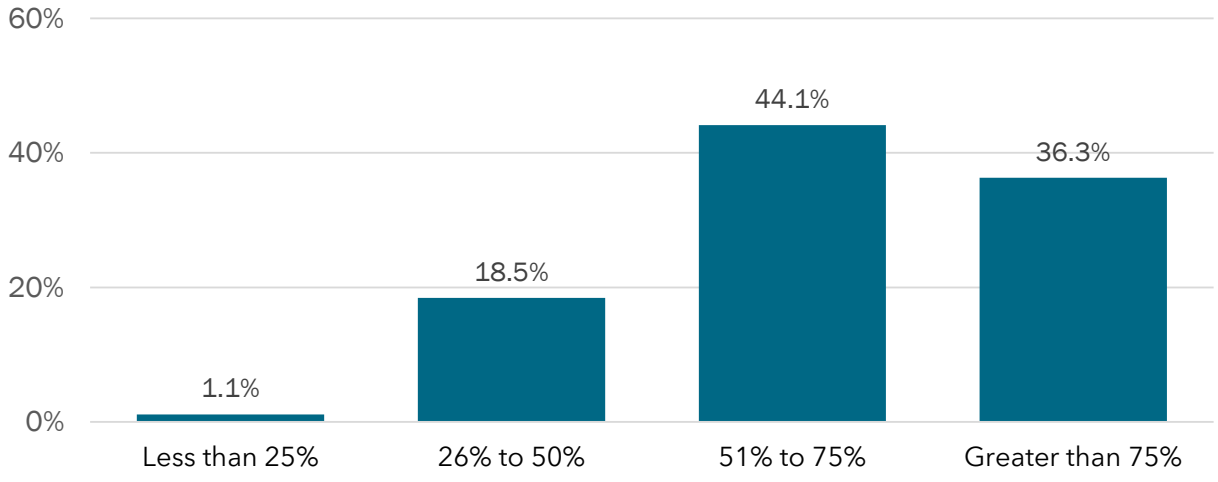




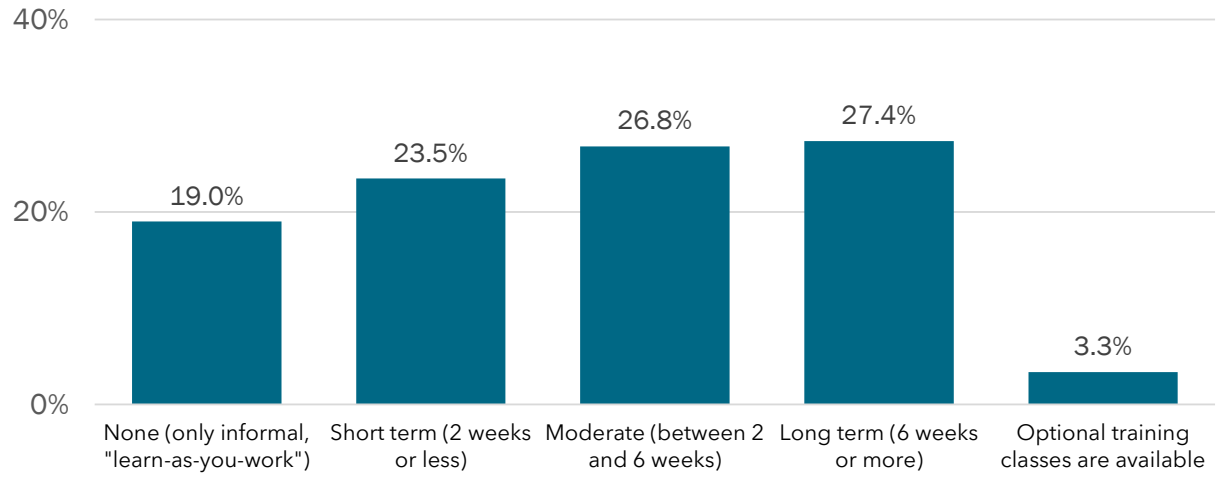


APPENDIX A - Survey Responses

What percentage of your workers would you regard as being fully proficient at their current jobs?



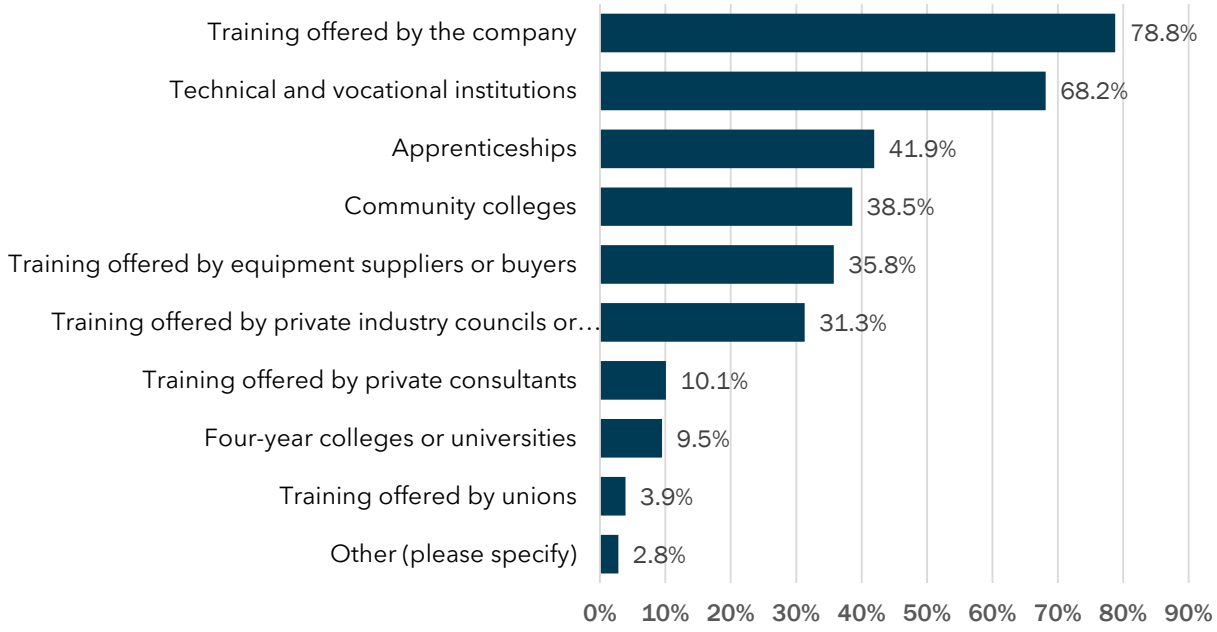
What is the typical type of formal training your business provides after an employee is hired for a production job?



APPENDIX A - Survey Responses

Workforce Training and Development

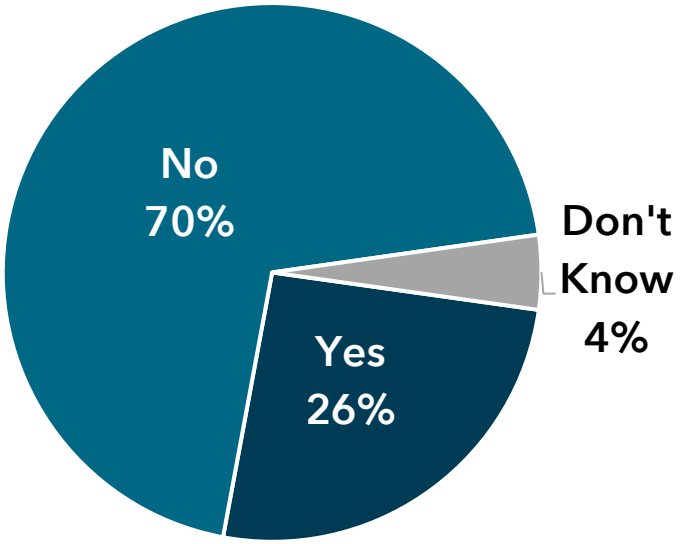
What do you think is the best way for potential production employees to acquire the specific skills required for future employment at your business? [Please check all that apply]



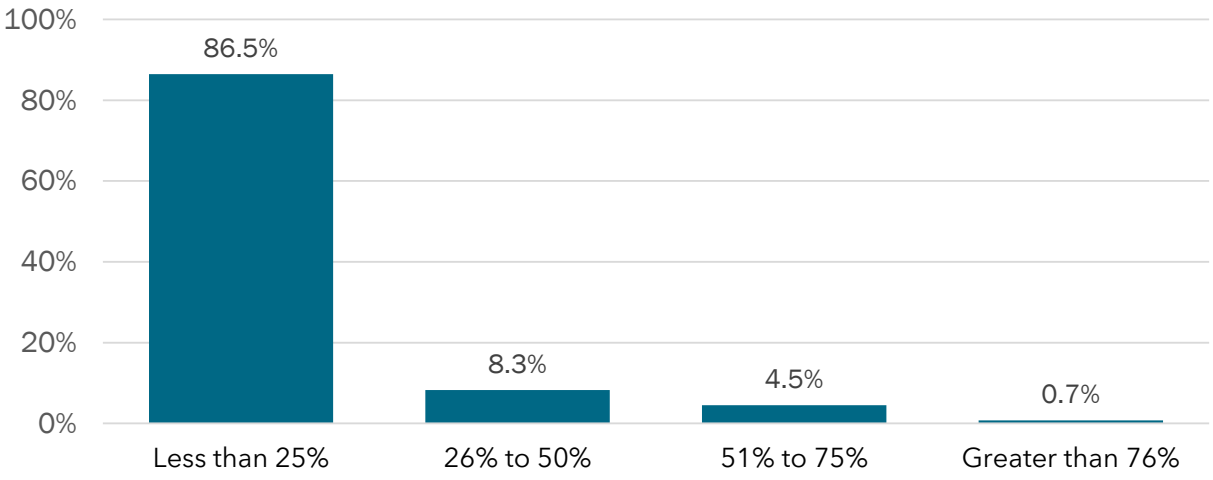
APPENDIX A - Survey Responses

Job Rotation

Does your business have a formal policy on job rotation for production worke



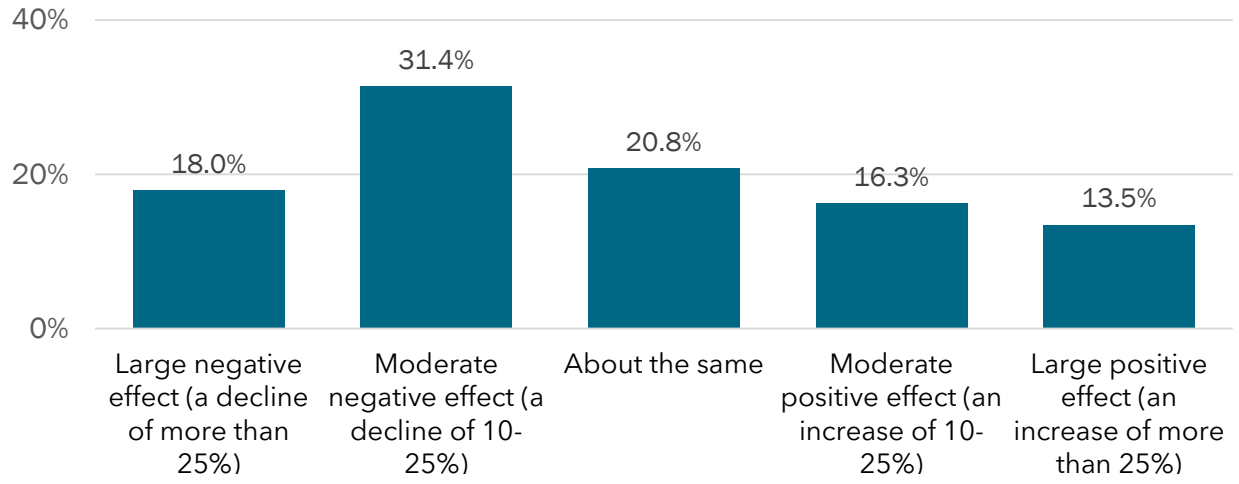
If yes, what proportion of your production workers are involved in job rotation?



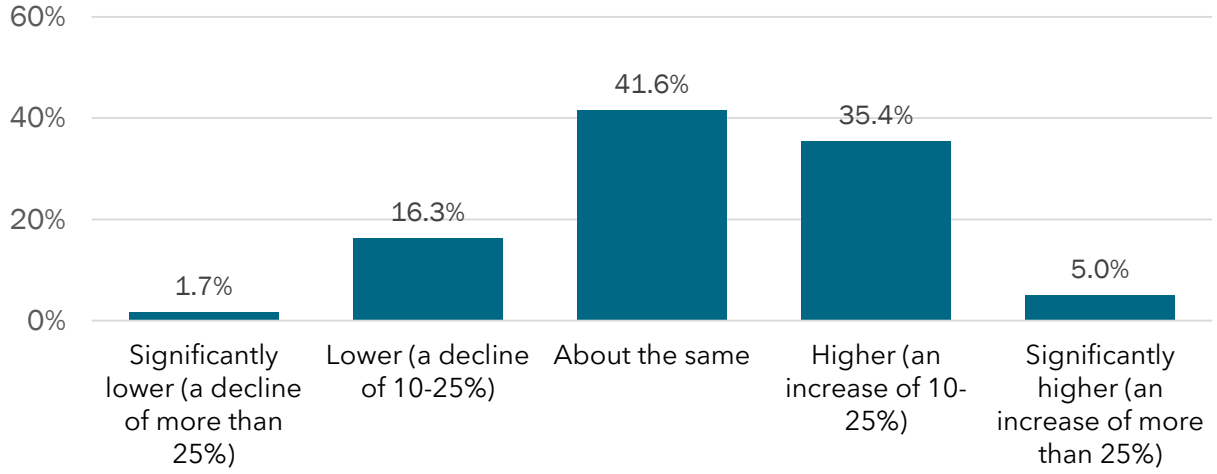
APPENDIX A - Survey Responses

Impact of COVID-19

Overall, how have your revenue/sales been affected by the COVID-19 pandemic?

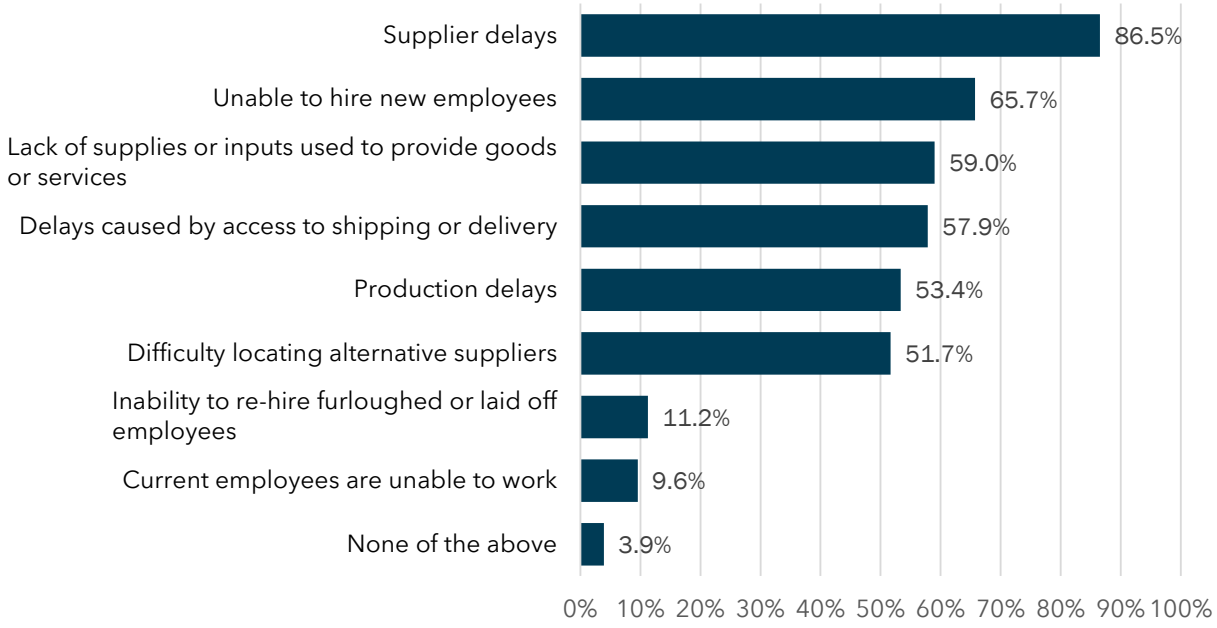


Which of the following bests describes your target employment level this year as compared to your February pre COVID-19 employment level?



APPENDIX A - Survey Responses

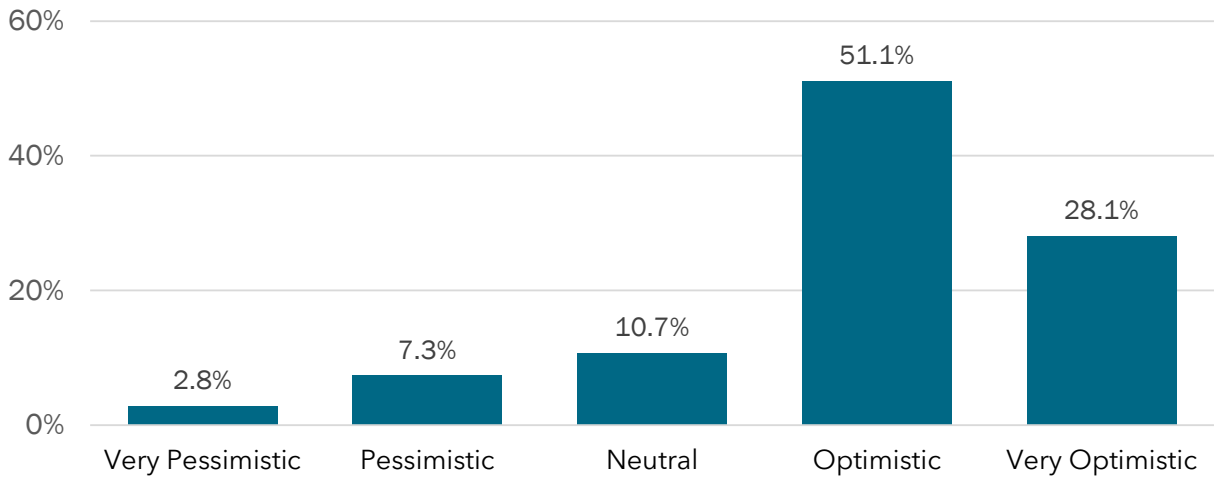
As a result of COVID-19, is your business experiencing any of the following issues? [Please check all that apply]



APPENDIX A - Survey Responses

Business Outlook

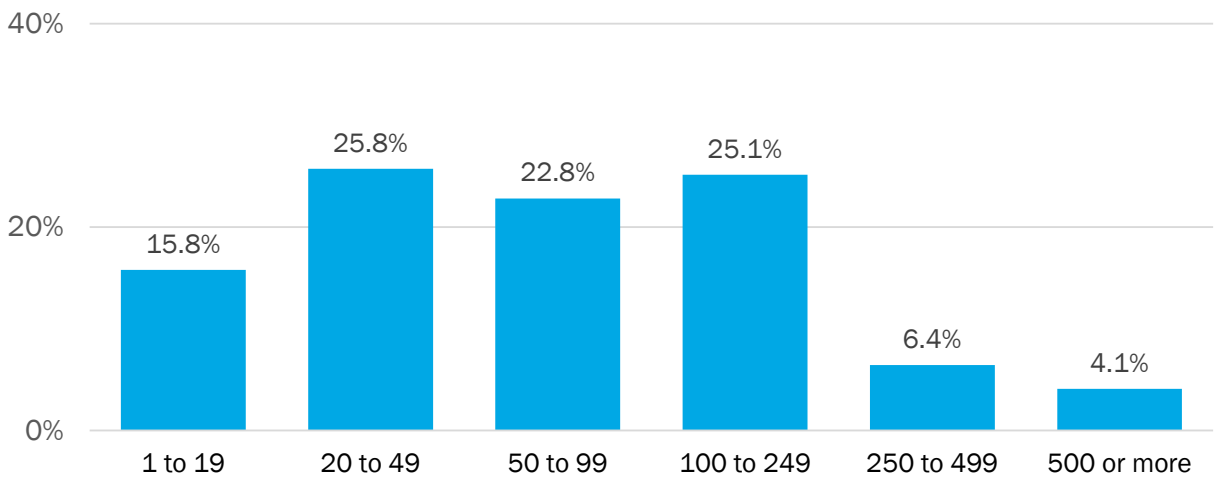
Overall, what is your business outlook for 2021?



APPENDIX A - Survey Responses

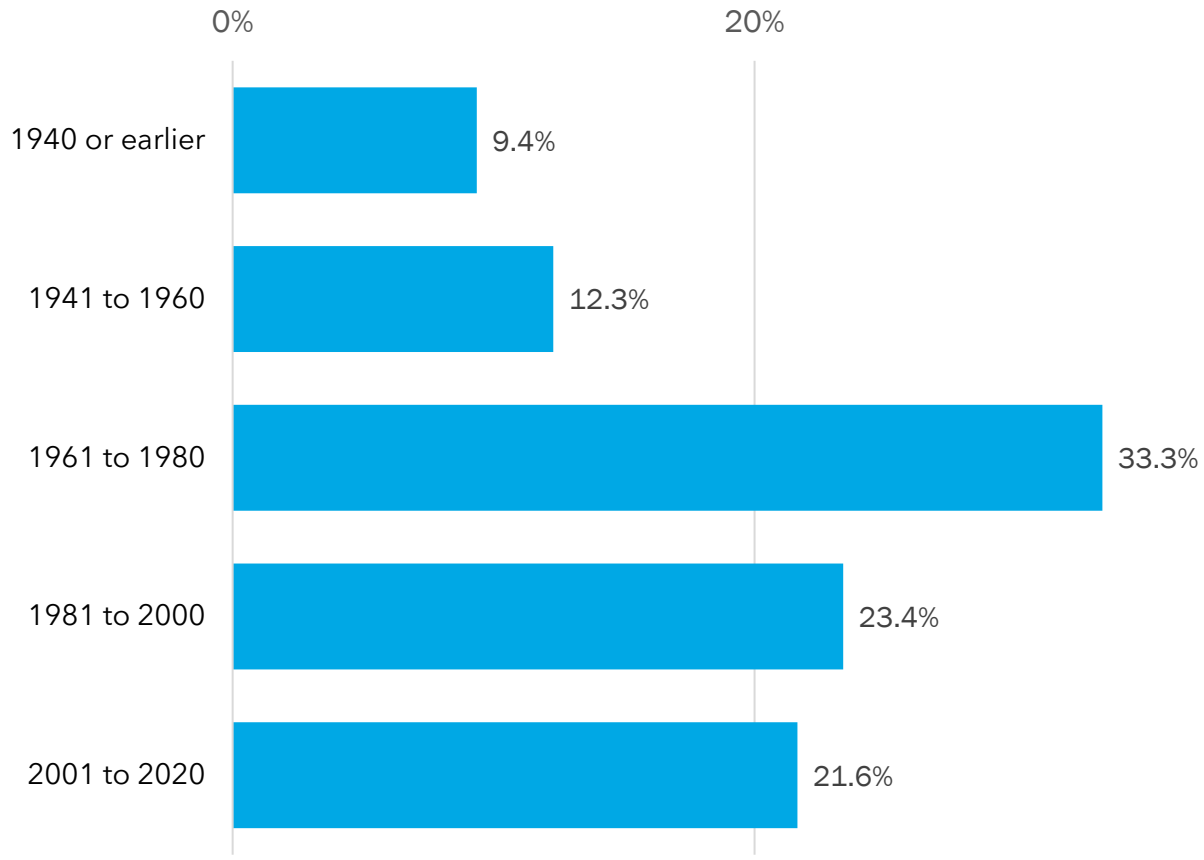
Firmographics

Please give your best estimate of how many people work at this specific facility?



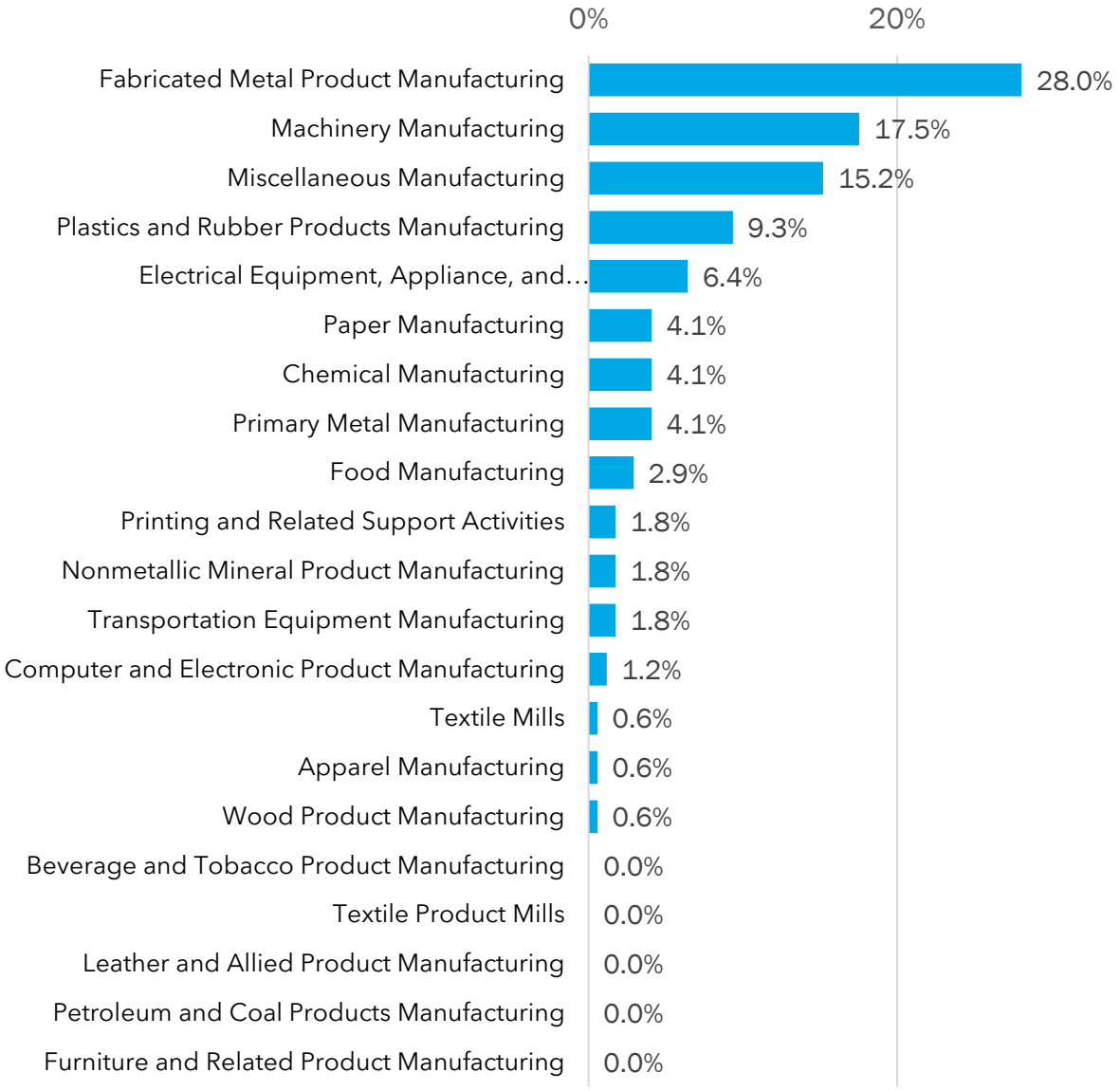
APPENDIX A - Survey Responses

In what year did this specific facility begin manufacturing?



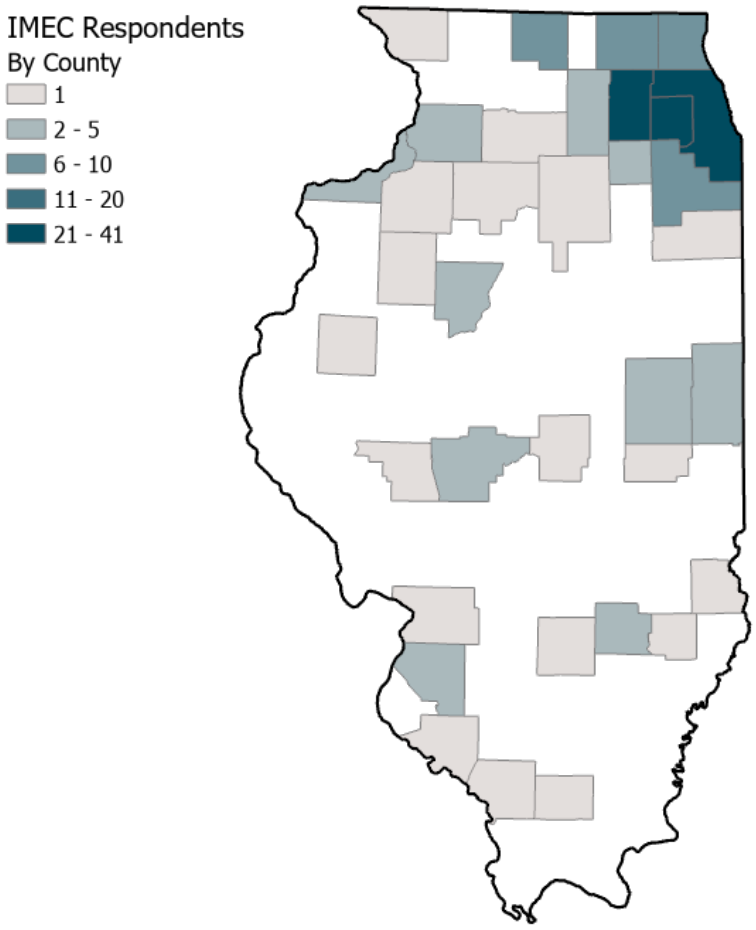
APPENDIX A - Survey Responses

What is your facility's main product or manufacturing activity?



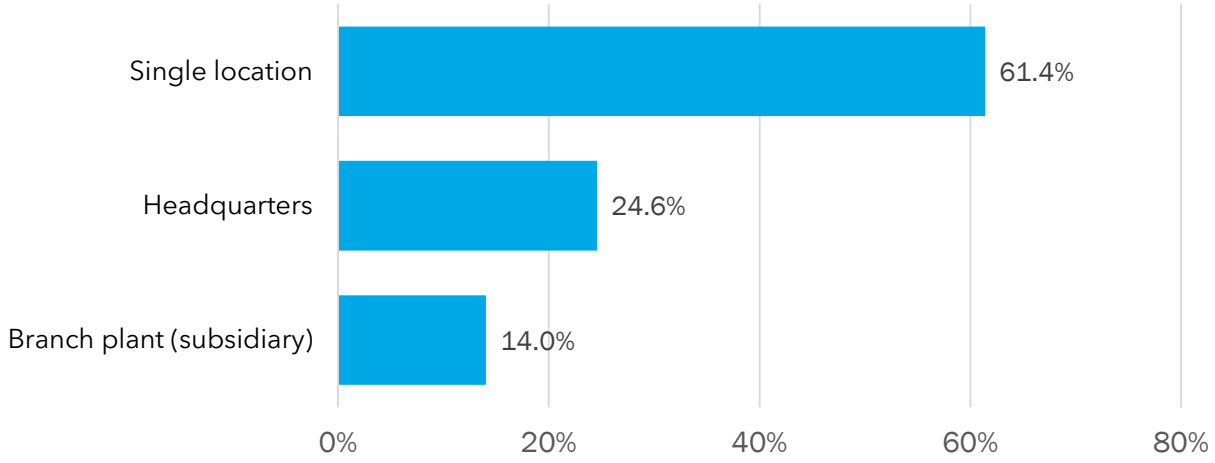
APPENDIX A - Survey Responses

In what county is this specific facility located?

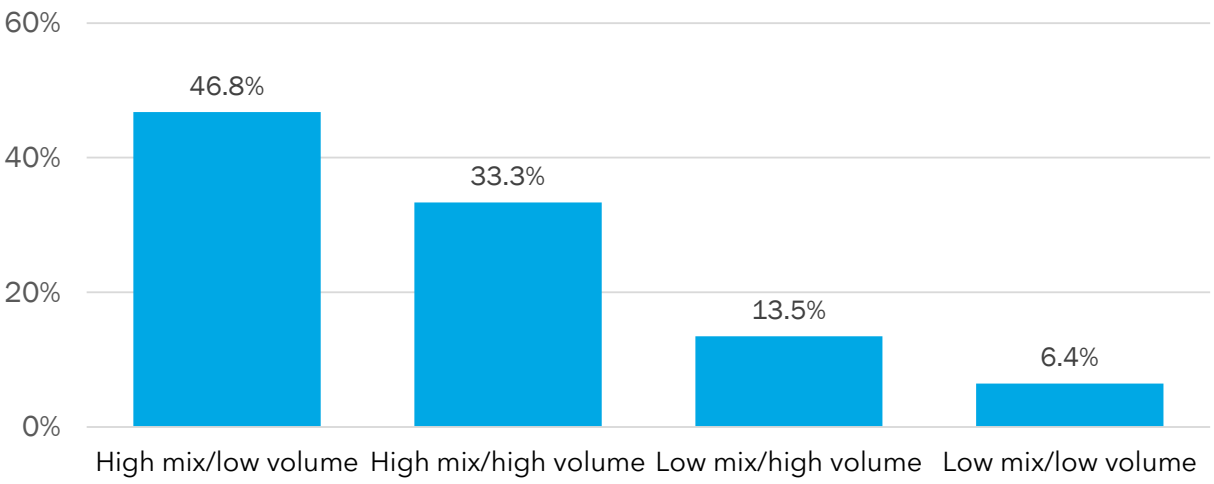


APPENDIX A - Survey Responses

Please select the option that best describes this specific facility.

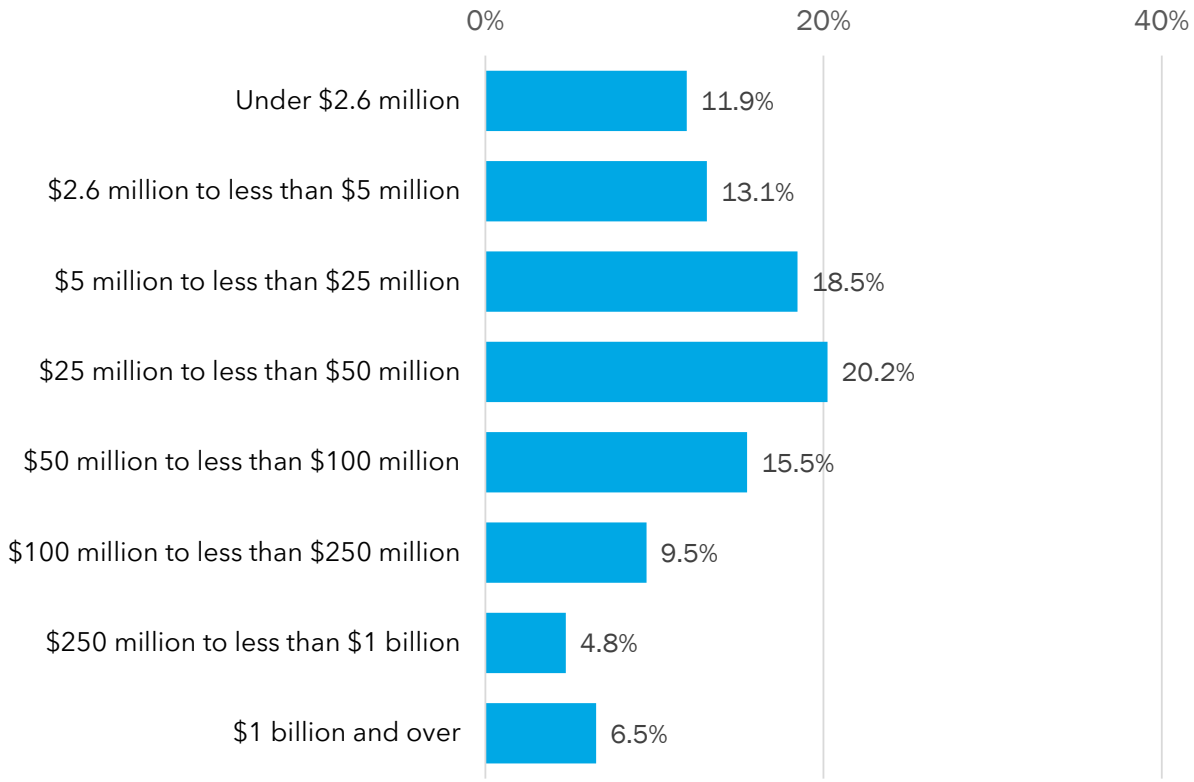


How would you best characterize operations at this specific facility?



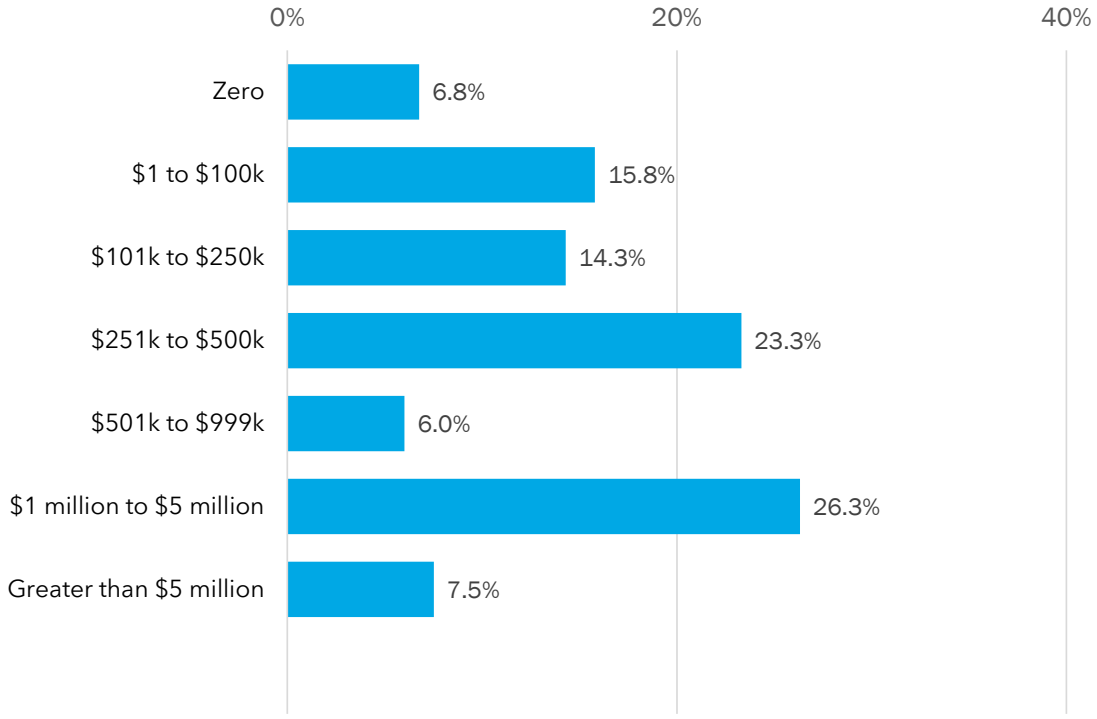
APPENDIX A - Survey Responses

Which range best represents the value of your total sales/shipments for the previous year?

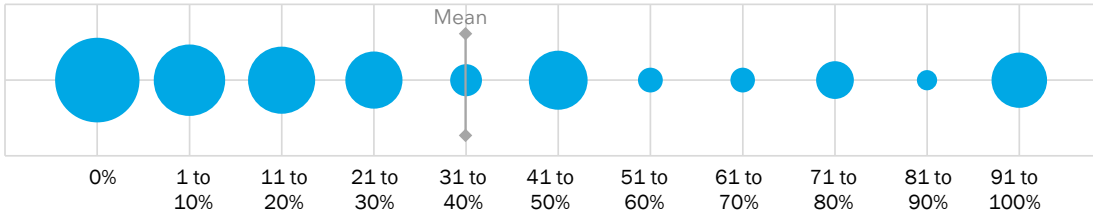


APPENDIX A - Survey Responses

What is your capital expenditure budget for this year?



About what percentage of your capital budget is allocated for advanced manufacturing technolog or process improvements?



APPENDIX B - Advanced Manufacturing Terms

Advanced Manufacturing Technologies

ADDITIVE MANUFACTURING (3D PRINTING) (A process of making three dimensional solid objects from a digital file.)

ADVANCED MATERIALS (The use of new materials, modifications to existing materials, or creation of composites and or nanotechnology to obtain superior performance from products.)

ROBOTICS/COBOTS (Networks of robots connected to the cloud and contributing mass amounts of insightful data on a standardized interface)

AUGMENTED REALITY (The integration of additional computer-generated information into the user's view of his current surroundings. For example, Google-Glass.)

DATA GATHERING SENSORS (Sensors which continuously detect errors that may lead to breakdowns, dangers or technical failures occurring in the production tool or to the product.)

LOCATION DETECTION TECHNOLOGIES (Technologies that provide real time information about the location of devices, and the location of users of the devices. For example, RFID chips)

MACHINE TO MACHINE (M2M) (Direct communication between devices)

MOBILE TECHNOLOGY (Use of portable hand-held internet-capable wireless computing devices)

SMART CONTROLLERS (Controllers that interact with their environment and can define their automated actions. For example, going into standby mode to save energy)

APPENDIX B - Advanced Manufacturing Terms

Advanced Manufacturing Processes

CLOUD COMPUTING (The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.)

CYBER PHYSICAL SYSTEMS (Computers and networks monitor and control physical processes with feedback loops; the physical system reacts; the system uses software to interpret action and tracks results.)

CYBERSECURITY (The state of being protected against the criminal or unauthorized use of electronic data, or the measures taken to achieve this.)

DIGITAL CUSTOMER RELATIONSHIP MANAGEMENT (The use of digital systems such as social media or apps to generate new customer data.)

ENTERPRISE RESOURCE PLANNING (A software application that integrates multiple business processes (inventory, purchasing, planning, marketing, sales, etc.) needed to run a company with a single system.)

FINITE ELEMENT ANALYSIS (A computerized method for predicting how a product reacts to real-world forces. It shows whether a product will break, wear out, or work the way it was designed.)

HORIZONTAL INTEGRATION (Connecting all functions and data across the value chain and covering all tasks of Manufacturing Execution Systems.)

INTERNET OF THINGS (Connection of all devices to the internet and each other.)

MACHINE LEARNING (Machines record their past actions and are thus able to self-perfect themselves in order to render their future actions more efficient and productive.)

MANUFACTURING EXECUTION SYSTEMS (computerized systems used in manufacturing to track and document the transformation of raw materials to finished goods.)

VERTICAL INTEGRATION (The merging of planning and development with the production i.e. allowing for customizable products.)