

# SMART MANUFACTURING ADOPTION STUDY 2022



Interdisciplinary Center for  
Advanced Manufacturing Systems



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Although the mainstream press states that the industrial base is at a tipping point for adopting digital manufacturing, Industry 4.0 (I-4.0), or Smart Manufacturing, indications are that this is not true beyond the Original Equipment Manufacturers (OEMs) and the large first-tier companies. There is a digital divide emerging in industry between large defense and commercial manufacturers, OEMs, and the Small and Medium-sized Manufacturers (SMMs) that, based upon the source referenced [1] [2], makes up 90% or more of the industrial base.

The purpose of this study is to understand the current state of technology adoption in the industrial base, particularly SMMs, and to identify the motivators and barriers that must be addressed to accelerate adoption. This report is the first of a five-year longitudinal study that will provide actionable insights and measure the progress made over the five-year period. The focus of this survey is on SMMs, which we gain access to through OEMs, regional economic development organizations, industry associations and more.

The results of this study will uncover adoption motivations and barriers and shed light on important factors, such as awareness, technology, workforce, culture, and more. The study will identify the phase the SMMs are in regarding the process of technology adoption: Knowledge, Persuasion, Decision, Implementation, or Confirmation. By quantifying the depth and breadth of adoption year-to-year, we will be able to measure progress and adjust activities to strengthen weak areas. Additionally, the study will provide a gauge for SMMs to determine where they are in I-4.0 technology adoption compared to their peers. And finally, it will provide information to the Department of Defense (DoD) on the actual state of the industrial base as to readiness for digital manufacturing.

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### AUTHORS

**Chris Peters** (*The Lucrum Group, CEO*)

**Ashley C. Yarbrough** (*Auburn University, Ph.D. Candidate and Graduate Research Assistant*)

**Gregory A. Harris** (*Auburn University, Associate Professor and Director of ICAMS*)

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## EXECUTIVE SUMMARY

The purpose of the Interdisciplinary Center for Advanced Manufacturing Systems (ICAMS) longitudinal research program is to provide the insights that will accelerate the depth and breadth of smart manufacturing adoption to increase U.S. manufacturing competitiveness.

The first required insight is the current state of adoption of smart manufacturing technologies to establish a baseline. Secondly, an understanding is needed of the target audience's motivations and barriers to adopt each technology. Finally, defining and tracking the proper adoption metrics will increase success by quantifying progress and identifying where adjustments are needed.

Targeting small- to medium-sized manufacturers (SMMs), the program's qualitative and quantitative studies uncovered valuable insights about the current state of adoption. The six smart manufacturing technologies at the heart of this research are:

- 3D printing
- Artificial intelligence
- Automation
- Big data
- Machine sensors/Internet of Things (IoT)
- Predictive analytics

Adoption stages follow the work of Dr. Everett Rogers [3] and are segmented by little awareness, actively researching, evaluating, implementing, and using.

Results from this research paint a picture of lagging adoption of smart manufacturing by SMMs in the United States industrial Base. While the adoption of automation and machine sensors/IoT were the exception with about 50% of respondents indicating that they are implementing or using the technologies, most SMMs are in the very early stages of adoption for the other technologies listed above.

One of the key findings is that most respondents place a low value on 3D printing, artificial intelligence, big data, and predictive analytics. Not surprisingly, the most frequently cited barriers to adoption of these technologies were lack of awareness and relevant business cases. Conversely, a high value was placed on automation, with the leading adoption barriers being lack of capital and cost. Machine sensors/IoT also scored high in value, although the leading adoption barriers were lack of capital and workforce skills.

Research showed interesting differences between companies of different sizes. One example is that the large companies placed little to no value on artificial intelligence, big data and predictive analytics, while SMMs found measurable value in big data. As for the adoption status, SMMs were further along in the adoption process of predictive analytics than were the larger companies.

Segmentation of companies between those that produce high-volume/low-mix (HV/LM) versus low-volume/high-mix (LV/HM) also provided valuable insights. Nearly 50% of the respondents chose LV/HM as their primary production type, with close to the same number indicating they do both. Only 12% focused on HV/LM.

A notable difference is that HV/LM respondents rated workforce-operations as the top challenge by far, while those with a LV/HM production mix ranked operational efficiency and revenue profits as their top challenges.

Analysis of the data resulted in four key findings that, if addressed, would help accelerate adoption of smart manufacturing technologies.

1. There is a lack of perceived value of smart manufacturing technologies. Adoption of any technology starts with understanding the technology and its value.
2. There are significant barriers to overcome. Adoption will only happen when the motivations to adopt the technology are greater than the barriers.
3. Adoption is impacted by availability and applicability of resources. Identifying and making available the resources needed at each stage can help accelerate adoption.
4. Workforce is a significant barrier to adoption. Workforce was cited as a barrier to adopting nearly all technologies, with skillsets rated higher than quantity of workers.

After reviewing and analyzing the results, the ICAMS team has developed recommendations for government, industry, and academia.

The government recommendations include the need to develop a smart manufacturing adoption plan similar to other countries, lest the U.S. fall further behind. Government also can make a big impact by developing programs that help reduce the cost barriers for capital expenditures, whether that be low-interest loans, tax incentives or similar efforts.

Industry associations can play a very large role in accelerating smart manufacturing adoption by serving as a knowledge hub. Gathering and disseminating information about government-led programs requires little effort and cost yet can have a significant impact. Collecting business case studies and telling the stories of peer success help raise awareness of smart manufacturing and increase its perceived value.

Academia serves as a trusted source of meaningful research that can help increase the motivation to adopt these new technologies while reducing the barriers to adoption. Peer acceptance is the leading driver of adoption [3], and universities can be a great source of aggregated and anonymized insights, increasing the willingness of companies to share their successes.

The starting point for these recommendations likely would be a roadmap of smart manufacturing technologies and the sequence in which they should be adopted. Meaningful metrics will help a company measure its progress against the roadmap while providing government with insights that help it fine-tune various adoption programs. By repeating this survey every year, ICAMS will be an invaluable resource to accomplish both.

## OBJECTIVE

Until this research there has not been a comprehensive study to date of the adoption paths and rates of smart manufacturing by an industry. Such information is crucial to identify the status and state of industry in the technology adoption process. The insights from this research can be used to accelerate the depth and breadth of adoption and accurately measure adoption progress.

This longitudinal study is designed to collect information on smart manufacturing adoption annually for the next five years with a focus on Small- and Medium-sized Manufacturers (SMMs). This distinction is important in the understanding of the current state and status of the manufacturing industrial base in the United States. For the last ten years, reporting of the adoption of smart manufacturing technologies has been focused on large manufacturers that have the resources and talent available to take on digitalization initiatives. This level of resources and support does not exist for SMMs [4] [5].

The design of the qualitative and quantitative instruments will remain relatively consistent to help better gauge year-over-year advancements in the adoption process. The outcomes of this effort include:

- Greater ability to accelerate smart manufacturing adoption by U.S. manufacturers;
- Quantitative evidence of the success of acceleration efforts and where to adjust; and
- Data-driven recommendations for government funding and programs.

## METHODOLOGY

The genesis of this initiative was in the desire to understand the true state of technology adoption in the United States industrial base. The beginning of the research involved the development of a qualitative research instrument that would lead an interviewer and their subject through a series of broad questions dealing with business challenges and smart manufacturing topics. Originally envisioned as in-person interviews, these sessions were conducted by phone due to the pandemic. Eight interviews were conducted with a cross-section of company sizes and industries served. The answers were consistent and informed the revised approach in the design of a quantitative survey instrument.

The quantitative survey was conducted by Auburn University after approval by its Institutional Review Board. Qualtrics was the survey platform used and the survey was launched in April 2021. The following organizations helped attract participants by publicizing the effort to their members.

Economic Development Partnership of Alabama (EDPA)  
Manufacturing x Digital Institute (MxD)  
National Center for Defense Manufacturing and Machining (NCDMM)  
National Center for Manufacturing Sciences (NCMS)

As of November 17, 2021, there were 73 partially completed survey responses and 44 fully completed. Only the fully completed surveys were used in the calculations in this report. The high abandon rate will need to be examined in the next iteration of this survey.

# RESULTS

## Overview

This initiative began with interviews that asked broad questions about the challenges they are facing and the subject's thoughts on smart manufacturing or Industry 4.0. When asked what Industry 4.0 meant to the interviewee, the most common response was sharing of data and increased productivity. The follow-up question asked what technologies they relate to Industry 4.0. A few interviewees touched on several of the core Industry 4.0 technologies, but there was little consistency or depth in the answers.

One small company reported having three people focused on Industry 4.0 and provided great insights into the technologies, but they were most definitely an outlier. Another interviewee in the electronics industry had a good grasp on smart manufacturing and asked a poignant question, "Where do smart factories fit in the U.S. when most of the world is high-volume production and we're not?" Through these interviews, it became clear that most companies were interested in leveraging smart manufacturing technologies but didn't yet fully understand what they were or the value they could deliver.

To learn more about the current state of technology adoption in SMMs insights from these initial interviews were then used to develop a quantitative survey that would provide greater detail. The results of the survey provided insights into the audience's perceived value of six smart manufacturing technologies, what adoption phase participants are in, and what are their greatest barriers. The survey also captures the resources that the subjects are most likely to turn to when learning about, deciding on or implementing these technologies.

The survey findings provide information that can help understand how to accelerate the depth and breadth of adoption for these six technologies. Coupling that information with a recommended prioritization of the six technologies provides a roadmap that can help inform government programs and funding. When conducted yearly, this survey will provide quantitative evidence of how far the U.S. industrial base will have progressed in their adoption of these technologies and the success of those government efforts.

Several organizations assisted in this research by asking their constituents to participate in this survey. The aggregate of those responses is contained in this report. A separate report is being provided to those organizations with a breakdown comparing results from its members against the aggregated responses. As expected, there are interesting differences in the results between the organization respondents. In general, participants in organizations centered on advanced manufacturing are further along in the adoption of smart manufacturing.

## Demographics

The population of the survey respondents provide a solid cross section of commercial and defense industries, company sizes and industries served. While most of the respondents are from the southeastern United States, largely due to this being an Auburn University-led effort, manufacturers from the northeast, Midwest and west coast also responded. Chief executive officers and senior executives made up 43% of the responders.

SMMs are the main target for this study and is defined as such using the National Institute for Standards and Technology (NIST) Manufacturing Extension Partnership metric for SMMs, based upon the Small Business Administration definition of a Small and Medium Enterprise. Companies considered SMMs for this report employ from 1 to 1,500 and generate revenue of up to \$100 million.

One of the most interesting demographic data elements captured was whether a company's production was primarily low-volume/high-mix (LV/HM), high-volume/low-mix (HV/LM), or both. Approximately 45% produce LV/HM and 43% report they do both. Only 12% produce HV/LM. The resulting analysis based on production volume offers insights not found in the literature search.

A significant percentage of the respondents were small- to medium-sized manufacturing firms, with 52% between 50-250 people and 31% with less than 50. Following that pattern, 62% of those surveyed represent firms with revenues between \$10 million and \$100 million, while 24% realize less than \$10 million. Nearly 55% manufacture mechanical parts and assemblies, while 21% manufacture combined mechanical and electronic products. The distribution between automotive, aerospace and defense industries was nearly even. (See Figure 1: Industry Breakdown)

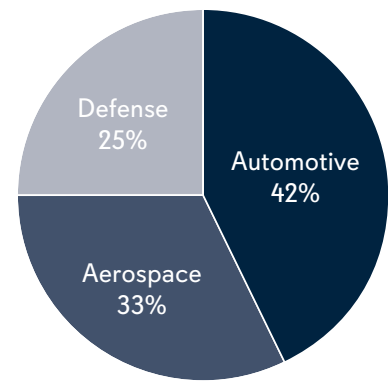


Figure 1: Industry Breakdown

## Top Challenges

Companies were asked “What are the top three challenges your business faces?” and provided with six options from which to choose. (See Table 1: Top Business Challenges)

The top challenge was overwhelmingly workforce-operations, with 33% citing that as the number one issue. (Workforce was divided into those roles that are engineering-focused and typically require a degree versus those roles operating equipment on the factory or shop floor.) Operational efficiency followed as the top choice with 19%. However, when looking at the number one, two and three choices for challenges, operational efficiency consistently scored in the top two.

**NOTE:** In this table and those that follow, conditional formatting was used to highlight in orange the top two highest responses per row.

Table 1:  
Top Business  
Challenges

	Access to Capital	Capital Improvements	Competitive Pressure	Operational Efficiency	Revenue/ Profits	Sales/ Marketing	Workforce- Engineering	Workforce- Operations
#1	10%	0%	10%	19%	14%	12%	2%	33%
#2	2%	5%	10%	26%	10%	12%	19%	17%
#3	17%	12%	10%	19%	17%	7%	7%	12%

## Challenges: Workforce

Workforce is a challenge cited by many manufacturers. The survey asked about the level of experience needed and the types of skills being sought. Despite workforce rating so high in business challenges, less than half of the respondents provided answers on the experience and skills needed.

Experience was decomposed into trainees, less than five years, more than five years or upskilling the existing workforce. Those who answered indicated a comparable level of need across all groups. In fact, most of those who responded listed a need for workers at all four experience levels. One interviewee discussed the need to “de-skill” their positions by increasing automation so that they could hire lower-skilled labor that was more readily available. “If a real machinist walked in our doors, they’re hired.”

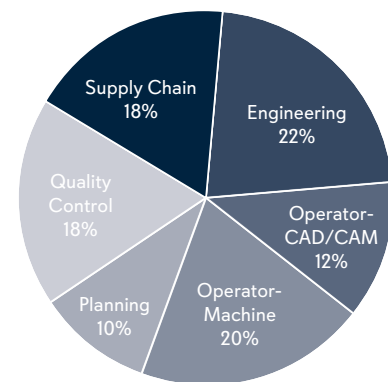


Figure 2: Workforce Skills Needed

When asked about the skills needed, the responses were evenly distributed with engineering and operator-machine being in the top two spots at 21% and 19% respectively. (See Figure 2: Workforce Skills Needed) Quality control and supply chain both came in at 17%. One interesting note is that the more recent participants in the survey, which ran from April to November, ranked the need for supply chain skills higher than did the earlier participants. Most of the responses indicated a need for several of these skill sets, with many expressing a need for nearly all of them.



## Smart Manufacturing Component Value

Participants were asked to rank the importance (1, 2, and 3) of six smart manufacturing components in their ability to help address the business challenges they identified. The results in this section indicate which of the technologies the respondents believe can help in overcoming their challenges. The following section on adoption status will provide a clearer indication of where respondents are focusing their resources.

Automation and machine sensors were ranked as the number one choice at 52% and 24% respectively. These two technologies also scored the top spots for the second choice. (See Table 2: Perceived Value of Smart Manufacturing Technologies) Surprisingly, 3D printing scored very low in perceived value, despite its ubiquitous presence in manufacturing-related articles.

Table 2:  
Perceived Value of  
Smart Manufacturing  
Technologies

	3D Printing	Artificial Intelligence	Automation	Big Data	Machine Sensors/IoT	Predictive Analytics
#1	10%	2%	52%	2%	24%	7%
#2	10%	14%	24%	5%	31%	12%
#3	2%	2%	0%	5%	7%	12%

## Smart Manufacturing Component Adoption

A major objective of this study is to quantitatively define what stage of adoption respondents are in their implementation of six smart manufacturing components. These results provide a benchmark that, when repeated yearly, will demonstrate what progress has been made in accelerating the depth and breadth of adoption across entire industries.

The survey was structured to roughly follow the five stages of adoption laid out by Dr. Everett Rogers in his book Diffusion of Innovations [3]. Those five stages are knowledge, persuasion, decision, implementation, and confirmation. Each of these five stages require different tools and methods to help a subject advance to the next level. In the survey outcomes, the five stages of adoption are Little Awareness (knowledge), Actively researching (persuasion), Evaluating (decision), Implementing (implementation), and Using (confirmation). Those tools and methods will become more apparent in the following section on adoption barriers.

As expected, based on perceived values defined in the previous section, the two components with the greatest level of adoption are automation and machine sensors/IoT. Just over 56% of the respondents are implementing or using machine sensors and the Internet of Things (IoT) while 50% of the respondents are doing the same with automation. Predictive analytics is the next furthest along, with 49% researching and evaluating the technology. (See Table 3: Smart Manufacturing Technology Adoption)

The poor showing for artificial intelligence is not unexpected due to the lack of consistent definitions and relatable case studies in commonly read manufacturing publications [6] [7] [8] [9]. What was surprising is that 42% of the respondents indicated they had little awareness of 3D printing and only 19% are researching or evaluating the technology. (For a more detailed breakdown by company size, see APPENDIX B – Adoption Comparison By Company Size.)

Table 3:  
Smart Manufacturing  
Technology Adoption

	3D Printing	Artificial Intelligence	Automation	Big Data	Machine Sensors/IoT	Predictive Analytics
Little Awareness	42%	47%	12%	35%	2%	23%
Actively Research	5%	26%	21%	16%	23%	26%
Evaluating	14%	14%	14%	21%	16%	23%
Implementing	12%	9%	21%	16%	28%	14%
Using	26%	2%	30%	9%	28%	12%

## Smart Manufacturing Adoption Barriers

Accelerating the depth and breadth of adoption requires that the motivation or desire to use an innovation be greater than the barriers to using it. The Prospect of Adoption equation can be understood in the context of Value and Burden (EQ. 1) with a positive prospect of adoption if the equation is satisfied, and the greater the number, the higher the prospect.

$$\text{Prospect of Adoption: (IF) Value}^{(1)} - \text{Burden}^{(2)} > 0 \text{ (EQ. 1)}$$

(1) Value may be determined by both an individual and the organization and may include additional or improved profits, less effort, lower costs, personal recognition, etc.

(2) Burden may be determined by both an individual and the organization and may include organizational resistance to change, fear of loss of job, lack of workforce skills, lack of knowledge about the technology, etc.

In this section the focus is on identifying what the respondent perceives as barriers to adoption of each of the six smart manufacturing components. This information then provides guidance on where programs or funding can be applied to have the greatest impact on lowering adoption barriers.

A weighted score was used to create rankings for each of the six components. Where a respondent ranked an issue as number one, five points were assigned. Three points were assigned for a number two ranking and one point for a number three. The weighted scores are then used to help identify the greatest barriers. As a check, the percentage of respondents' answers for each issue also were calculated to validate the weighted rating.

### Adoption Barriers: 3D Printing

The barriers to 3D printing that rated the highest are 1) the lack of a business case and 2) cost. (See Table 4: Adoption Barriers for 3D Printing) The lack of a business case aligns with the 3D Printing technology being one of the least adopted, with most respondents being at the stage of little awareness of the technology. Relevant business cases are often one of the greatest means to raise awareness of an innovation, whether those cases appear in publications or are relayed by industry peers.

Somewhat puzzling is that cost was rated as the second highest barrier, yet so few companies indicated they were in the stage of researching or evaluating the technology (Table 3). It could be the fact that the respondents perceived the cost to be high due to their lack of knowledge about the technology. One way to address this in future surveys may be to add an option under the adoption stage question where respondents can indicate that they evaluated the technology and decided it wasn't a fit with their strategy or business model.

Table 4:  
Adoption Barriers  
for 3D Printing

	3D Printing							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	48	97	57	76	21	9	23	47
Percentage	13%	26%	15%	20%	6%	2%	6%	12%

## Adoption Barriers: Artificial Intelligence

The hurdles for adoption of artificial intelligence are clearly the lack of relevant business cases and awareness, or understanding of the technology, as they were cited as the top two barriers. (See Table 5: Adoption Barriers for Artificial Intelligence) When the respondents were asked about the stage of their adoption of artificial intelligence (Table 3), the result showed that artificial intelligence was the highest scoring technology in the “little awareness” category indicating it is the technology farthest away from adoption. For technology adoption to proceed, the organization must move past Awareness to Persuasion, the second stage, which typically leads to actively researching an innovation. One of the key drivers of that persuasion is relevant business cases, of which there seem to be very few for artificial intelligence.

Table 5:  
Adoption Barriers for  
Artificial Intelligence

	Artificial Intelligence							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	99	104	28	33	23	18	25	48
Percentage	26%	28%	7%	9%	6%	5%	7%	13%

## Adoption Barriers: Automation

Automation was ranked as one of the most adopted of the smart manufacturing technologies. The barriers of lack of capital and cost seem to be holding back some manufacturers interested in adopting the technology. (See Table 6: Adoption Barriers for Automation) Not enough workforce and workforce skill set issues are close behind, which was confirmed in the phone interviews conducted with various manufacturers. While many companies seem to be aware of the value of this technology, these barriers are holding back its adoption.

Table 6:  
Adoption Barriers  
for Automation

	Automation							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	27	50	75	74	10	35	46	61
Percentage	7%	13%	20%	20%	3%	9%	12%	16%

## Adoption Barriers: Big Data

Big data is another technology that was not perceived by manufacturers to be of great value and for which there was little progress in adoption. Much like artificial intelligence, the adoption of big data suffers from little awareness and the lack of relevant business cases. (See Table 7: Adoption Barriers for Big Data) Without those two elements, awareness or knowledge of the technology and a relevant business case for the technology, it will be very difficult to drive the adoption by SMMs. Notably, lack of a workforce skill set was the third highest rated barrier to adoption.

Table 7:  
Adoption Barriers  
for Big Data

	Big Data							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	95	84	27	48	27	12	35	50
Percentage	25%	22%	7%	13%	7%	3%	9%	13%

## Adoption Barriers: Sensors/IoT

Sensors and IoT technologies are one of the most widely adopted of the smart manufacturing technologies but is still held back by challenges in a lack of workforce skill sets and access to capital. (See Table 8: Adoption Barriers for Sensors/IoT) Cost is close behind, which would be expected with lack of capital. What was unexpected is that the lack of relevant business cases and little awareness ranked as high as they did for such a widely adopted technology.

Table 8:  
Adoption Barriers  
for Sensors/IoT

	Sensors/IoT							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	50	59	62	53	12	21	43	78
Percentage	13%	16%	16%	14%	3%	6%	11%	21%

## Adoption Barriers: Predictive Analytics

Much like some of the other lesser adopted technologies, the top-rated barriers for predictive analytics are the lack of relevant business cases and low levels of awareness. (See Table 9: Adoption Barriers for Predictive Analytics) In this case, other factors such as workforce availability and cost weren't close, even though predictive analytics is slightly further along in adoption than is artificial intelligence.

Table 9:  
Adoption Barriers for  
Predictive Analytics

	Predictive Analytics							
	Awareness	Business Case	Lack of Capital	Cost	Lack of Peer Experience	Can't find resources	Not enough workforce	Workforce skill set
Weighted rating	100	106	31	31	19	13	26	52
Percentage	26%	28%	8%	8%	5%	3%	7%	14%

## Resources to Learn

To overcome the barriers to adoption, it is important to understand what resources people use when learning about, deciding on or implementing technology into their operations. The first adoption stages identified earlier were awareness and researching. To achieve these levels of adoption requires learning, which is the subject of the first of the three resource questions. The following insights provide direction on where to best allocate resources to overcome the various barriers.

Response to questions regarding the resources needed for technology adoption employed a weighted score approach where a number one ranking was worth ten points, number two was worth eight, number three worth six, number four worth four, number five worth two and a number six ranking was worth just one point.

Learning about an innovative technology and how it might benefit the organization and the individual requires access to relevant information that the individual trusts and readily comprehends. For instance, an academic paper may do little to help inform an operations technician. The most influential information will be delivered by a trusted source in a familiar vernacular.

The two most valued resources to learn about smart manufacturing technologies are peer experience and business articles. (See Table 10: Resources to Learn) Case studies and vendors were close behind, offering a variety of potential sources to tap in advancing technology adoption.

Table 10:  
Resources to Learn

	Learn						
	Academic Papers	Business Articles	Case Studies	Consultants	Peer Experience	Vendors	Other
Weighted rating	121	226	178	100	232	164	12
Percentage	12%	22%	17%	10%	22%	16%	1%

## Resources to Decide

Deciding to adopt an innovation involves evaluation that can define the benefits of a technology, motivate the adoption of the technology, and provide guidance and insight for overcoming the drawbacks that could be barriers [3]. Benefits that could be realized by the organization range from lower costs to improved competitive positioning. Individual benefits could be learning a new skill set, earning a promotion, or improved job satisfaction.

Correspondingly, there could be barriers for both organizations and individuals. Organizational barriers could include costs, lack of access to capital, or the lack of a workforce with the right skills. Barriers for individuals involved in the decision-making process may be less obvious but can be equally powerful in hampering adoption. Examples include resistance to change, perceived increase in effort, or even fear of losing their job.

Once again, learning of relevant experience from trusted peers is the top resource when deciding to adopt a solution, with case studies close behind. (See Table 11: Resources to Decide) The score for trusting vendors to provide information increased slightly in the Decide phase from Learning, which is to be expected since they would likely need to provide information about pricing and implementation in addition to benefits.

Table 11:  
Resources to Decide

	Decide						
	Academic Papers	Business Articles	Case Studies	Consultants	Peer Experience	Vendors	Other
Weighted rating	78	148	216	120	244	179	6
Percentage	8%	15%	22%	12%	25%	18%	1%

Resources to Implement

At this point in the adoption process, the decision has been made in favor of adopting a technology and now the effort is focused on a successful implementation. While it may seem like the hard part is now past, there is still plenty of opportunity for anyone from decision influencers to management to hamper or even halt implementation. Consequently, those doing the implementation often need to rely on resources that will help ensure a successful implementation.

The shift to implementation is evident in this question as the most prominent resources relied upon to assist are vendors and consultants (See Table 12: Resources to Implement). Peer experience is close behind, which could be a benefit in understanding the implementation process or provide guidance in selecting the right consultant and vendor.

Table 12:  
Resources to Implement

	Implement						
	Academic Papers	Business Articles	Case Studies	Consultants	Peer Experience	Vendors	Other
Weighted rating	54	78	136	213	172	261	18
Percentage	6%	8%	15%	23%	18%	28%	2%

Software Used

Survey participants were asked which software platforms and tools they use as a way to gauge readiness to adopt smart manufacturing technologies. Enterprise Resource Planning (ERP) software is seen by many as the foundation for incorporating smart manufacturing technologies, as evidenced by countries like Korea and the United Kingdom underwriting the cost of ERP to advance their manufacturing industries [10].

A significant majority of the respondents indicate they use ERP and MES systems, with 71% reporting use of each. (See Figure 3: Software Used) Participants were given the opportunity to provide the brand of the actual software, but only a quarter of the respondents did so. The brands were diverse with no one provider dominating the field.

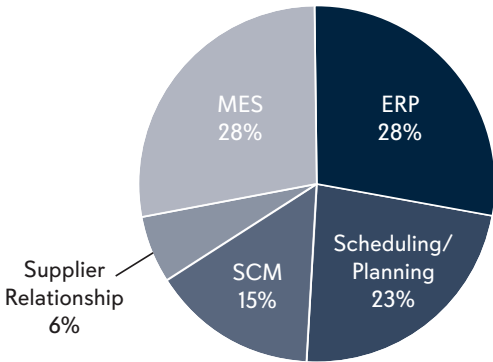


Figure 3: Software Used

One interesting note is that 38% of those surveyed indicated they have Supply Chain Management (SCM) software. What is not clear is whether the SCM is actually part of the ERP software.

## Differences Between HV/LM and LV/HM Responses

When reading these results, it must be remembered that most of the respondents (45%) chose LV/HM as their primary production type. A smaller number (43%) indicated they perform both and the smallest group represented (12%) was HV/LM.

The first difference noted is in the top business challenges. The HV/LM respondents rated workforce-operations the top challenge by far, while those that categorized themselves as both HV/LM and LV/HM rated workforce-operations number one by a lower margin. Those manufacturers with a LV/HM production mix ranked both operational efficiency and revenue/profits as their number one challenges, with access to capital and workforce-operations tied at number two.

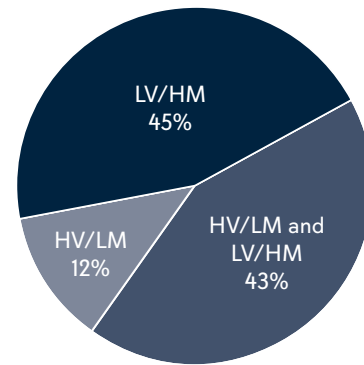


Figure 4: HV/LM Differences and LV/HM Responses

The next difference was observed in ranking the six technologies for their ability to help with the business challenges. While both groups containing LV/HM participants ranked automation and machine sensors the highest, there were a few votes for a smattering of other technologies. The HV/LM group overwhelmingly valued automation (80% ranked it number one) and the remainder of the first-place votes went to predictive analytics.

One of the most telling areas of difference was in the stage of adoption of the survey participants with regard to the smart manufacturing technologies. The LV/HM group is much further along in their use of 3D printing, with 42% currently using it and only 21% having little awareness. Meanwhile, 60% of the HV/LM group and 61% of the group with both HV/LM and LV/HM production types have little awareness of 3D printing.

When looking at barriers to adoption of 3D printing, those companies producing HV/LM or both production types ranked little awareness and lack of relevant business cases as the top barriers. Companies producing LV/HM ranked lack of capital and costs as the top barriers. This would follow as the LV/HM companies are further along in their adoption of 3D printing.

All groups ranked lack of awareness and relevant business cases as the top barriers for adoption of artificial intelligence technologies. Barriers to automation for the LV/HM audience were predominantly lack of capital followed by lack of business cases. The group producing in both HV/LM and LV/HM types ranked workforce skill set as the number one issue (34%) and cost as the second (31%). The HV/LM group ranked cost as number one (18%) with can't find resources and not enough workforce tied at second with 7% for each.

Sensors/IoT was another technology where there was a difference between the groups in the major barriers to adoption. Companies that do both LV/HM and HV/LM production types indicated the greatest barrier was workforce skill set with awareness a close second. This would indicate that there is a schism in this group – nearly half that are at the very early stage of adoption and the other half that is ready to adopt but can't find the workforce. Companies that produce primarily in a LV/HM environment ranked lack of capital (36%) and business case (31%) as the highest barriers.

## Differences By Company Size

The survey captured the number of employees at the participant's location and the total number of employees at all locations. The breakdown by company size for this report uses the total number at all locations as even small locations will benefit from a large national or global firm. Company size was decomposed into four categories:

- Less than 50 employees
- 50-250 employees
- 250-500 employees
- More than 500 employees

When looking at the perceived value of the smart manufacturing technologies by company size, several results stand out. One is that companies with more than 500 employees placed little to no value on artificial intelligence, big data, and predictive analytics. Another is the only group that found measurable value in big data was companies with less than 50 employees. (See Figure 4: Perceived Value of Technologies - Note that scoring for these categories combined the top two vote percentages, so some may show greater than 100%.)

This does not mean that companies are not adopting these technologies. Rather, it seems to indicate a lack of connection between these technologies and how they might help address a company's top three challenges. (See APPENDIX A – Technology Adoption Barriers) This may represent an opportunity for education that better identifies how each smart manufacturing technology can help solve specific business challenges.

The state of adoption for each smart manufacturing technology becomes particularly interesting when decomposed by company size. As shown in APPENDIX B – Adoption Comparison By Company Size, there are significant differences. Some of these are expected, like companies with 250-500 employees being much further along in the adoption of automation than companies with fewer than 50 employees. Other findings are surprising, as in the companies with more than 500 employees lagging all the other size groups in the adoption of artificial intelligence.

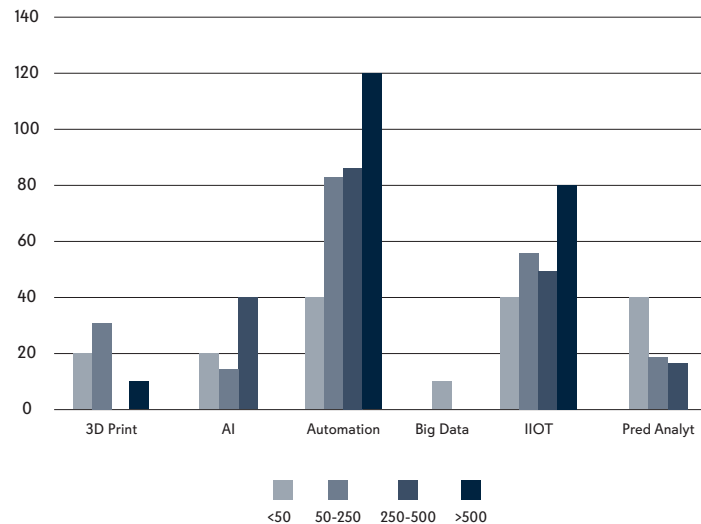


Figure 4: Perceived Value of Technologies

As noted in Smart Manufacturing Component Adoption section earlier, nearly half of the subjects report they have little awareness of 3D printing. The breakdown by company size shows that lack of awareness is even more pronounced between manufacturers with more than 250 employees and those companies with less than 250 employees with the later further ahead in the use of 3D printing.

Another important finding is that firms with less than 500 employees are evaluating or implementing artificial intelligence at some level. The companies with greater than 500 employees report no efforts in evaluating or implementing AI technology. One possible explanation for this result may be that the subject wasn't aware of all activities occurring within the organization. Future studies should seek multiple inputs within the organization to help avoid that issue.

One of the most encouraging findings is the state of adoption for machine sensors and IoT. All four company size groups report significant adoption of sensors and IoT capabilities, with most in the latter stages of implementing and using the technology. Only a few of the companies with less than 50 employees reported lack of awareness while the other three size groupings had no reports of lack of awareness. Machine sensors and IoT provide much of the information needed for other technologies, like big data, predictive analytics, and artificial intelligence. In this sense, the widespread adoption of sensors and IoT helps lay the foundation, paving the way to accelerate the depth and breadth of adoption for the other technologies.

## ANALYSIS

### Overview

Previous works have identified that small- to medium-sized U.S. manufacturers are lagging in the adoption of smart manufacturing technologies [4] [5] [11] [12] [13]. This study confirms those findings and provides additional insight by identifying the adoption stage for six major smart manufacturing technologies. The data also identifies the top barriers for adopting each technology along with the preferred resources to learn about, decide on, and implement new technologies. These insights provide a roadmap for the development of policies and programs that can accelerate the depth and breadth of the adoption of smart manufacturing technologies.

### Finding #1: There is a lack of perceived value of smart manufacturing technologies

The survey subjects identified their most pressing business challenges, with the top highest ranked topics being the lack of an operations workforce and the need for greater operational efficiency. (Further research is needed to better understand what the respondents meant by “operational efficiency”). They were then asked to rank the importance of the six smart manufacturing technologies in helping address those business challenges. Automation ranked the highest by 52% of the survey respondents, which is logical given the difficulty in finding operations workforce. Automation is a common tool to reduce workforce requirements. In fact, one of the interviewees reported shifting their approach from looking for skilled people to hiring button pushers who could operate pre-programmed machines.

Machine sensors/IoT came in a distant second with 24% of the participants responding positively on its importance. This should be concerning as machine sensors/IoT technologies are crucial to enabling big data, predictive analytics, and even artificial intelligence – all of which can play a significant role in addressing operational efficiency. Yet machine sensors/IoT had just a moderate amount of perceived value in helping solve the business challenges. Some of this could be a result of the age of most equipment. The average age of a machine tool in the U.S. is more than 20 years old [14]. While the survey results show some adoption of this technology, educating the audience on its value in addressing specific business challenges could move it along even further.

Even more telling is that big data, predictive analytics, and artificial intelligence were rated in the low single digits for perceived value as well. When respondents were asked about the adoption stage for each of the six technologies, 47% of the respondents said that they had little awareness of artificial intelligence and 35% had little awareness of big data. That low awareness would help explain the low perceived value. (See APPENDIX A – Technology Adoption Barriers)

Predictive analytics was further along in the adoption process of most respondents, with 49% either researching or evaluating the technology. That raises a question of motivation for pursuing this technology since the audience does not place a high value (only 12% see value) on its ability to help overcome business challenges.

Adoption of any technology starts with an understanding of the technology and recognition of its value. The low value placed on 3D printing, artificial intelligence, big data, and predictive analytics indicates that there is considerable work to be done if the adoption of these technologies is important to the U.S. industrial base and domestic supply chains.

One key finding offering great potential is that 48% of the respondents believe their top business challenges are getting worse. If smart manufacturing technologies were perceived to help overcome those challenges, the motivation to adopt those technologies would rise considerably.



## **Finding #2: There are significant adoption barriers to overcome**

Adoption requires the motivation or desire to use an innovation to be greater than the barriers to using it. Finding #1 discussed how addressing industry pain points can increase the motivation to implement technology. Finding #2 focuses on lowering the barriers to adoption.

The barriers to adoption are closely tied to the stage of adoption. For instance, companies in the early stages of adoption with little awareness or are actively researching a technology are often hampered by the lack of educational materials and case studies. Companies in the evaluation stage often lack relevant peer experiences that help them understand how the solution would perform in their environment. Those in the latter stage of implementing understand the value and want to adopt the technology, but often lack access to capital to afford the solution or simply do not have the right skill sets to implement or operate the technology.

Each of these barriers can be overcome with different resources and approaches. As an example, the lack of awareness can be addressed by a marketing campaign from a trusted source that explains how the technology works and describes its benefits. One key to success is that this must be done in a language the target audience understands.

Business cases and peer experience can take the form of stories in trade magazines, scholarly articles, or discussions at trade shows. One of the most effective forms is when the potential adopter can see the technology operating in an environment like their own. Korea does this very effectively by subsidizing the implementation of smart manufacturing technologies in exchange for the recipient to allow visits by peers so that they may see the technologies in operation [10].

The barriers of lack of capital and high costs often require an effort by government to make available small business grants or low-interest loans. However, getting the word out to SMMs about the availability of funding for innovation is difficult since there is no one source for information about such opportunities [15]. Another approach would be for a large Original Equipment Manufacturer (OEM) to work with its financial resources to extend favorable rates to the OEM's supply chain.

Perhaps the most challenging barriers to solve currently are those related to the workforce. Today's low unemployment rate coupled with fewer immigrants entering the country, the "Silver Tsunami" created by retiring baby boomers [16] [17], the smallest generation (Gen Z) entering the workforce since the Civil War, and increasing wages are difficult to overcome. This may lead many organizations to prioritize automation as the most effective means to lower the workforce-related barriers.

One note of caution is that the barriers identified in this survey are largely related to an organization. There are many barriers tied to individuals that, when impacting someone who influences or makes the adoption decision, can derail the best laid adoption plans. Any adoption efforts should seek to uncover those individual behaviors so that they may be mitigated to the greatest extent possible. There is current research being performed by Auburn University that is attempting to understand the readiness of workers to accept a technological innovation in their workplace.

Government programs and funding can play a significant role in lowering organizational adoption barriers faster than they may be lowered through an organic process (see sidebar on agricultural expansion). Any such programs should be targeted at specific barriers with key metrics that would indicate where adjustments are needed to increase effectiveness.

**The Smith-Lever Act was passed in 1914** “...to aid in diffusing among the people of the United States useful and practical information on subjects relating to agriculture, uses of solar energy with respect to agriculture, home economics, and rural energy, and to encourage application of the same...” [18] The resulting cooperative extension program demonstrated the ability to accelerate the depth and breadth of adoption of innovations. One example is increasing wheat acreage significantly, from an average of 47 million acres annually in 1913 to 74 million in 1919. [19]

The agricultural extension plays a significant role in farmers’ decisions. Any such programs can increase productivity, farming development, and profit by spreading information from local and global research to farmers in a rapid transferring of knowledge to help them manage better (Norton and Alwang 2020). An effective agricultural extension has the power to minimize the gap between discoveries in the laboratory with individual farmer’s fields by accelerating the convey of new information given from global knowledge or even local research. As this program is intended to convey new information, farmers are enabled to clarify their own goals and possibilities, educate on how to make better decisions that stimulate appropriate agricultural development [20].

Federal appropriation and states provide funding for the agricultural extension in the United States. Services in extension also have fees which is a very small amount in comparison to the total financial plan (Paine 2018). In the U.S. there are county extension advisory committees whose members are elected by people belonging to agricultural extension systems. They have to oversee the extension plan and define the program priorities to make sure that they met the needs of the citizens. While there is a close link between research and extension, many extension agents observed a lack of good programming incorporation between these two main entities which result in a delay in meeting clients’ needs. In the U.S., extension services did not meet small farmers’ needs. One reason might be that extension agents often used to associate with developed large farmers as the main strategy to apply for educational programs. Small farms are farmers with restricted resources including investment, land, skills, and labor. There are 2.1 million small farms in the U.S. which despite the challenges they faced to access extension services and useful resources, they have shown strong over time with their significant contribution to agricultural production, food security, and biodiversity preservation [21].

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### **Finding #3: Adoption is impacted by availability and applicability of resources**

Whether acting as individuals or on behalf of an organization, people are the key to driving adoption. Therefore, it is vital to understand what resources people turn to and trust when learning about, deciding on or implementing an innovation. This survey identified those resources at a high level.

Peer experience was rated as the top resource to learn about innovations. The COVID pandemic has likely stifled much of the interaction that would have provided access to peer experiences as trade shows were cancelled, and travel curtailed. While some of that interaction has been restored through digital forums and a limited return of in-person events, this may have had an impact on companies in the early stages of adoption.

Business articles were the second highest rated resource for learning. However, the lack of articles on artificial intelligence or big data in the popular trade publications may contribute to the lack of awareness. As an example, when searching the *Modern Machine Shop* and *American Machinist* web sites for “artificial intelligence,” there were very few articles. Those that were found typically related to how artificial intelligence was being used in much larger companies rather than providing examples of how the technology benefits machine shops – the target audience for those publications.

The general lack of awareness of smart manufacturing technologies indicates an opportunity to quickly accelerate adoption simply by educating the target audience. This can be accomplished cost effectively by leveraging traditional and social media along with targeted marketing campaigns, recognizing the level of understanding by the target audience.

According to Rogers [3], the evaluation and decision stages of adoption rely heavily on the adopter understanding how the innovation would benefit their organization and what effort is required. Thus, it follows that case studies and peer experience would be ranked high as resources to help with the decision. As with awareness, the resources used to help evaluate and decide on a technology should be tailored to the audience. The more relevant the case study or experience, the more readily a potential adopter can understand its role in their environment.

When reaching the implementation stage of adoption, the resources used shift considerably. At this point, the adopter seeks someone with experience who can help ensure a successful implementation. That is evidenced in the high ranking by survey respondents of consultants and vendors as the leading resources. Other resources ideally suited for the latter stages of adoption are organizations such as the Hollings Manufacturing Extensions Partnership (MEP) and the USA Manufacturing Institutes.

Given the broad workforce challenges, the number or expertise of consultants and vendors may be a limiting factor in accelerating smart manufacturing adoption. For instance, it would seem logical that many vendors and consultants specializing in machine sensors have experience in a manufacturing environment. That same logic can't be applied to companies or individuals specializing in artificial intelligence or big data, which aren't as grounded in manufacturing.

#### **Finding #4: Workforce is a significant barrier to adoption**

Workforce was cited as a barrier to adoption of nearly all smart manufacturing technologies, with the workforce skillset typically rated a higher barrier than not enough workforce. One finding that should be noted is that the lack of workforce skill sets was rated the highest barrier for adoption of machine sensors and IoT. The respondents see value in the technology and are further along in its adoption than other technologies but are stymied by the workforce issue.

This is particularly important since data from machine sensors and IoT provide the foundation for other smart manufacturing technologies, such as big data, predictive analytics, and artificial intelligence. According to the ICAMS team, without the ability to leverage machine sensors and IoT, data is typically difficult to gather or unavailable. Without data implementation of many of the higher-level smart manufacturing technologies is infeasible, and is not only a barrier to adoption, but also detrimental to overall competitiveness.

## **RECOMMENDATIONS**

### **Government**

- The U.S. government should develop a smart manufacturing adoption plan for SMMs similar to what Korea and other countries have done, prioritizing the six identified technologies, identifying measurable “stages” of smart manufacturing, and executing a plan that has quantifiable metrics.
- The U.S. government should implement programs that reduce the cost and implementation barriers for capital expenditures. Such programs could include low- or no-interest loans, tax incentives, and so on for overcoming cost barriers, and development of expert services independent of particular hardware/software solutions to provide guidance and support for digital transitions. This could have a compound effect since access to capital and cost are the highest barriers to adoption of automation for SMMs. Lowering that barrier would allow for greater automation, which could also offset the workforce barriers in all technologies. Marketing and communications of the availability of these funds to SMMs should be a primary goal for this effort.

## Industry

- Industry associations should aggregate and disseminate information about government-led smart manufacturing programs and act as advocates for new programs and funding.
- Industry associations should aggregate and disseminate smart manufacturing technology business case information that will help constituents better understand what the technologies are and how they can be implemented.

## Academia

- Study the availability of relevant adoption resources by technology and audience. For instance, are there enough articles about the value of AI and big data as they relate to LV/HM manufacturing? Enough resources for assisting SMMs?
- Conduct research with firms that have adopted smart manufacturing technologies to develop business cases that will help others better understand the value and adoption of each technology. These business cases should be in a standard format with content that is easily searched to find the most relevant examples for a company or an individual. As a neutral third-party, academic institutions can anonymize the business names if that increases the willingness of a manufacturer to share its story.
- Perform research that automates the interface between systems, therefore eliminating the requirement to have a skilled worker acting as a non-value-added entity simply transferring data from one system format to another.

## Government, Industry and Academia

- Develop a roadmap of smart manufacturing technologies and an effective sequence in which they should be adopted for success. Include metrics that help a company measure its progress against the roadmap.
- Develop and widely disseminate educational materials and hold educational sessions that address the lack of awareness identified for the various technologies. These materials should be tailored for the audience. For instance, content for a small company would be different than for a very large company. Likewise, content for a senior executive will be different than that for a line manager or operator. See Resources to Learn earlier in this report to understand the sources of information most often referenced by the participants, providing a guide to achieving the greatest results.
- Design and deploy educational programs targeted at improving specific skill sets as identified by industry. As an example, workforce skill sets are the greatest barrier to the adoption of machine sensors and IoT. Educational programs geared to specific skill sets are more likely to appeal to workers than are broad, time-consuming programs. Micro-learning tools could help with the up-front education and be used while on-the-job for quick refreshers on specific topics.

## ACKNOWLEDGEMENTS

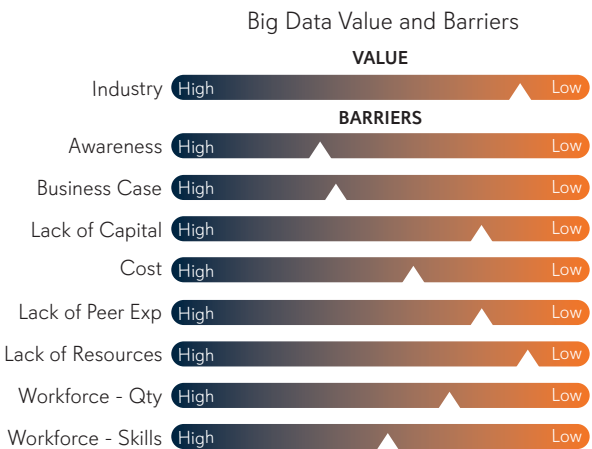
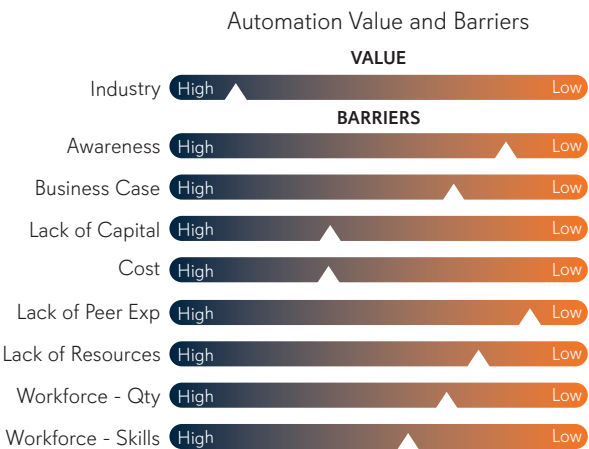
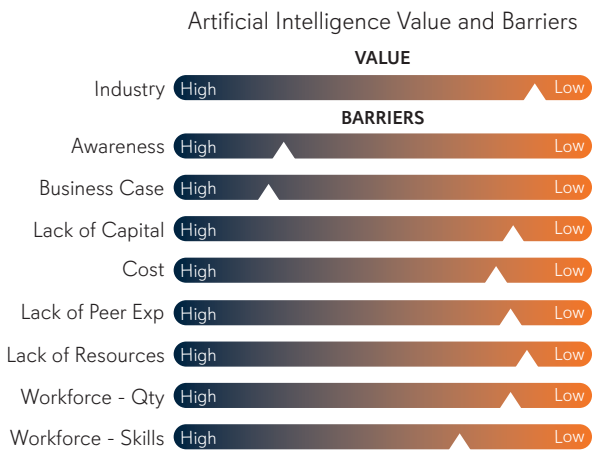
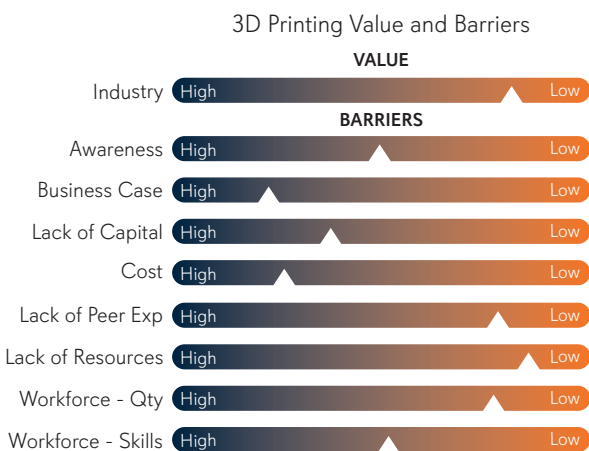
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- National Center for Manufacturing Sciences (NCMS)
- City of Auburn Industrial Development Board

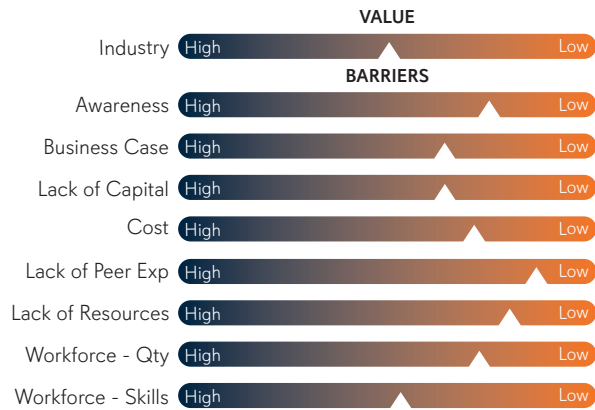
# APPENDIX A – Technology Adoption Barriers

These charts show two elements crucial to accelerating the depth and breadth of adoption of smart manufacturing technologies. The first bar shows the value industry places on that technology based on quantitative results from this study. The second bar shows the barriers to adoption that were identified in this study. These barriers provide indicators of where effort is needed to accelerate adoption. For instance, the two most prominent barriers for artificial intelligence are lack of awareness and the need for a business case. Lack of awareness can be overcome by wide distribution of education materials and sessions that resonate with the various manufacturing audiences. For instance, targeted messages and content should vary between small and large companies or between a senior executive and a line manager.

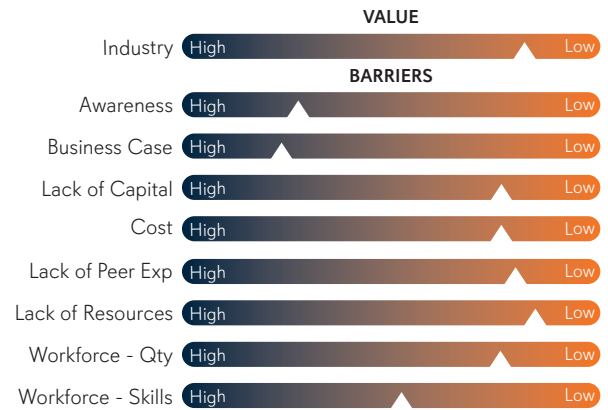
In the case of automation, the perceived value is high, so manufacturers are motivated to use the technology. However, the two leading barriers are lack of access to capital and cost. Lowering those barriers would likely require some type of program led by the government or large OEMs that improves access to capital.



### Sensors/IoT Value and Barriers

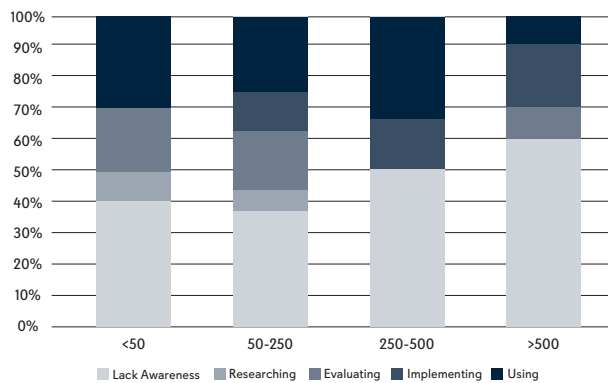


### Predictive Analytics Value and Barriers

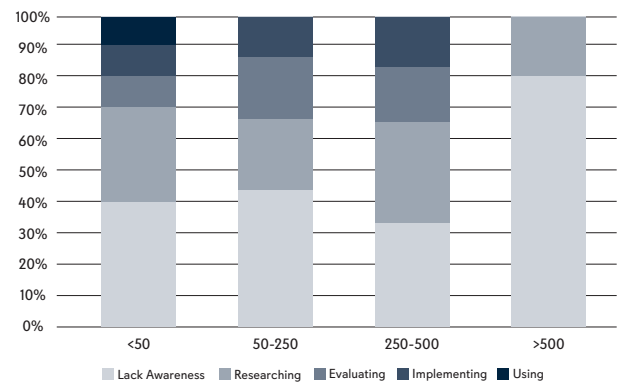


## APPENDIX B – Adoption Comparison By Company Size

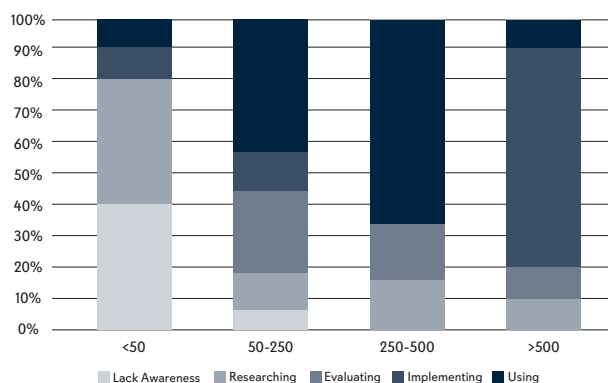
3D Printing Adoption by Company Size



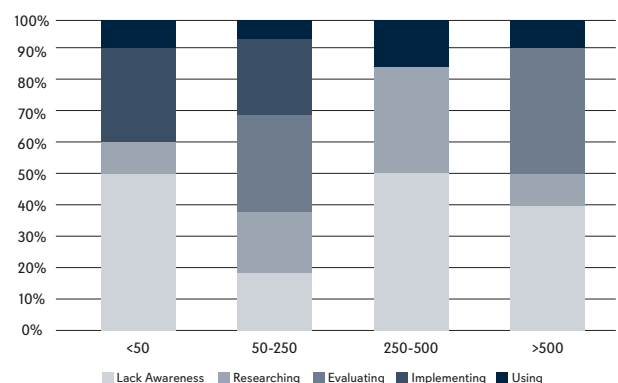
Artificial Intelligence Adoption by Company Size

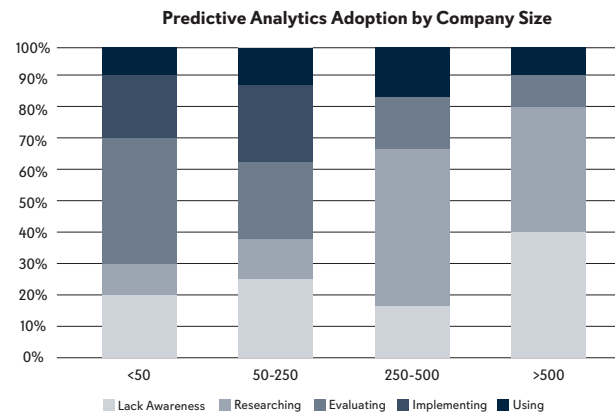
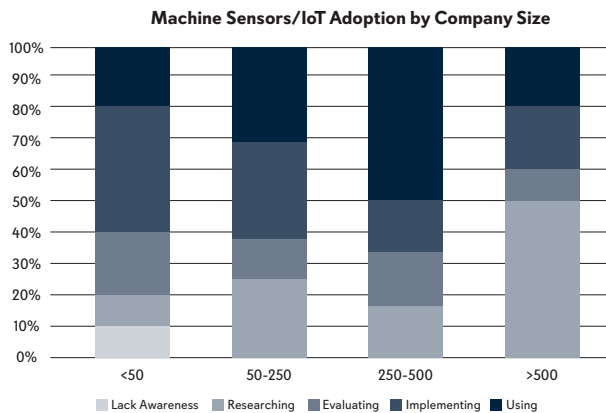


Automation Adoption by Company Size



Big Data Adoption by Company Size





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