SMART MANUFACTURING ADOPTION STUDY 2024

ICAMS

Interdisciplinary Center for
Advanced Manufacturing Systems

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In recent years, mainstream media has portrayed digital manufacturing, Industry 4.0 (I-4.0), and Smart Manufacturing as on the verge of full realization [1]. However, there is growing recognition that the manufacturing sector still faces significant barriers before reaching an actual "tipping point." Small and medium-sized manufacturers (SMMs), which account for over 95% of the U.S. industrial base [2], continue to lag behind larger Original Equipment Manufacturers (OEMs) and first-tier suppliers in adopting these technologies [3].

This study seeks to assess and analyze the current state of technology adoption among U.S. manufacturers—particularly SMMs—and to identify the key motivators and obstacles that must be addressed to accelerate adoption. It is the third installment of a five-year longitudinal study that tracks year-over-year progress in adopting smart manufacturing technologies through an annual survey.

The findings highlight the current business challenges, drivers, and barriers to adopting key technologies, including additive manufacturing, artificial intelligence (AI), automation, big data, sensors/Internet of Things (IoT), and predictive analytics. Adoption is measured across five stages: awareness, researching, evaluating, implementing, and using. SMMs can use this data to benchmark their progress against industry peers, while the insights also provide the Department of Defense (DoD) with a clearer picture of the industrial base's readiness for digital manufacturing.

This year's study highlights the growing interest in artificial intelligence (AI), which is hampered by limited business cases and skilled labor, and how automation remains the most valued technology despite its high cost and workforce barriers. This report also calls attention to how the U.S. government can learn from South Korea's successful, government-driven smart manufacturing model.

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EXECUTIVE SUMMARY

The Interdisciplinary Center for Advanced Manufacturing Systems (ICAMS) is conducting this longitudinal research program designed to generate insights that enhance both the depth and scale of smart manufacturing adoption, ultimately strengthening the competitiveness of U.S. manufacturing. The program focuses on small and medium-sized manufacturers (SMMs), representing over 95% of all U.S. manufacturing firms [2].

Accelerating smart manufacturing adoption requires a clear understanding of the current technology adoption landscape and U.S. manufacturers' progress. This report- the third annual installment in an ongoing study- tracks and quantifies technology adoption across the U.S. industrial base. It offers valuable insights into the motivations and barriers SMMs face when adopting each smart manufacturing technology.

The six smart manufacturing technologies analyzed in this study are:

- Additive Manufacturing
- Artificial Intelligence (AI)
- Automation
- Big Data
- Sensors/Internet of Things (IoT)
- Predictive Analytics

The framework used to assess technology adoption levels is based on the five-stage model developed by Dr. Everett Rogers [4], which includes awareness, researching, evaluating, implementing, and using.

This research identifies the primary business challenges manufacturers face, the perceived value of each of the six key technologies, and the current adoption stage for each. It also includes a year-over-year comparison to monitor the progress of technology adoption across the U.S. industrial base.

This year's study and survey analysis resulted in three key findings:

1. Artificial intelligence (AI) is gaining traction in manufacturing, with companies progressing in their adoption. However, a lack of business cases and skilled workers continue to impede the adoption of AI.
2. Automation remains the most valued and widely adopted manufacturing technology, but its high cost and inability to find skilled workers hinder its successful adoption.
3. The U.S. should seek to learn from South Korea's manufacturing success, which stems from a well-funded, government-led initiative that has significantly boosted manufacturing efficiency, innovation, and global competitiveness.

From the findings, the ICAMS team prepared recommendations for government, industry, and academia:

- Government: The U.S. government should invest in two key areas: (1) funding manufacturers' significant capital improvement needs, and (2) funding automation implementation and upskilling the workforce in knowledge of both automation and AI. We recommend the government use South Korea's efforts as a benchmark.
- Industry: To accelerate the adoption of AI, large manufacturers should willingly share success stories with their supply chains. Companies should also promote the benefits and opportunities of the manufacturing sector to accelerate workforce growth.
- Academia: Educators should help address workforce skill deficits by offering accessible and flexible credential programs that focus on teaching students about smart manufacturing technologies.

OBJECTIVE

The desire to better understand the current state of technology adoption by U.S. manufacturers began in 2021 when the media painted a false picture that Industry 4.0 was nearing its peak [1]. At the time, no study revealed the adoption progress of technologies such as additive manufacturing, AI, automation, big data, sensors/IoT, and predictive analytics. To combat this and help inform government policies and academic efforts, the Interdisciplinary Center for Advanced Manufacturing Systems (ICAMS) Smart Manufacturing Adoption Study was born.

Expanding and accelerating the growth of U.S. manufacturing requires insights that help inform government policies and funding. ICAMS Smart Manufacturing Adoption Study is designed to do just that. By developing quantitative data about the adoption of smart manufacturing in the U.S. and comparing it to regions that are more advanced, ICAMS can provide recommendations that help U.S. manufacturers become more globally competitive. Doing so also supports ICAMS' overall goal of accelerating smart manufacturing adoption by U.S. manufacturers, especially SMMs, who historically have fewer resources and support, even though they are the backbone of the U.S. economy [5], [6].

METHODOLOGY

The study began with interviews of manufacturers in 2021. The findings informed the creation of a quantitative survey approved by Auburn University's Institutional Review Board and launched in late 2021. The first annual report was published in 2022, and the second in 2023. This report is the 3rd annual report, revealing the results of the 2024 survey that launched in April of 2024. Qualtrics was the survey platform used to administer this survey.

The following organizations helped attract survey participants by publicizing the effort to their members:

- America Makes
- Economic Development Partnership of Alabama (EDPA)
- Global Electronics Association (Formerly IPC)
- National Center for Defense Manufacturing and Machining (NCDMM)
- North Alabama Works Manufacturing Cluster
- Society of Manufacturing Engineers (SME)
- Steel Founders Society

RESULTS

Overview

The following data analyses are a result of the 3rd annual ICAMS Smart Manufacturing Adoption Survey. The results section will show a year-over-year analysis from the inaugural survey in 2022 to 2024, emphasizing this year's results. This study reveals the top challenges manufacturers face and presents the technologies on which manufacturers place the most value in overcoming their challenges.

The results also reveal which of the five stages manufacturers are in adopting the six manufacturing technologies: awareness, researching, evaluating, implementing, or using. We then disclose which barriers are impeding adoption the most: lack of awareness, lack of business cases, lack of capital, high cost, lack of peer experience, lack of resources, lack of workforce, or lack of workforce skill set. These results are then disaggregated and segmented by order mix and company size to reveal any differences those factors might cause.

As of September 10, 2024, there were 103 partially completed survey responses and 83 fully completed. The number of responses, n, is indicated for each figure and table.

Demographics

The population of survey respondents spanned 30 U.S. states. (See Figure 1: States of Respondents

Respondents represented a cross-section of industries: aerospace, automotive, consumer goods, defense, energy, medical, transportation, and other. Many respondents serve more than one industry, resulting in a summation of categories that is greater than 100%. (See Figure 2: Industry Breakdown)

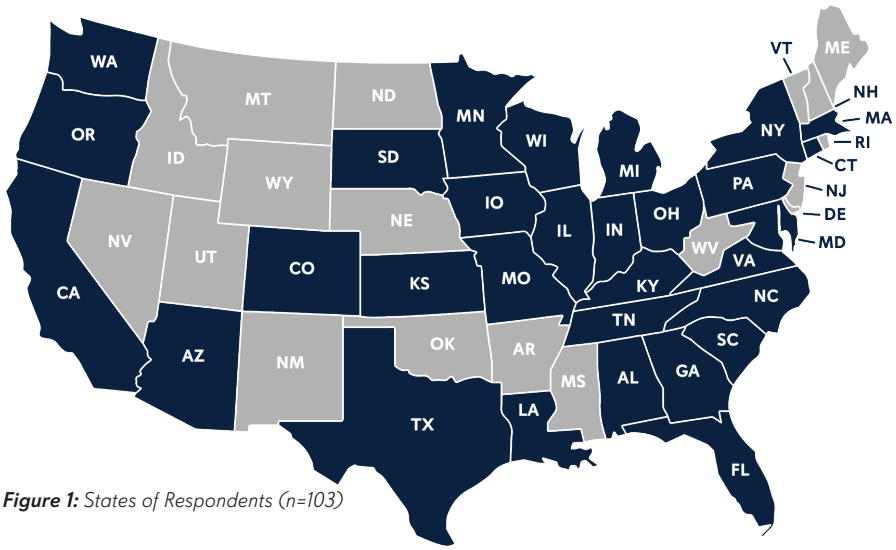


Figure 1: *States of Respondents (n=103)*

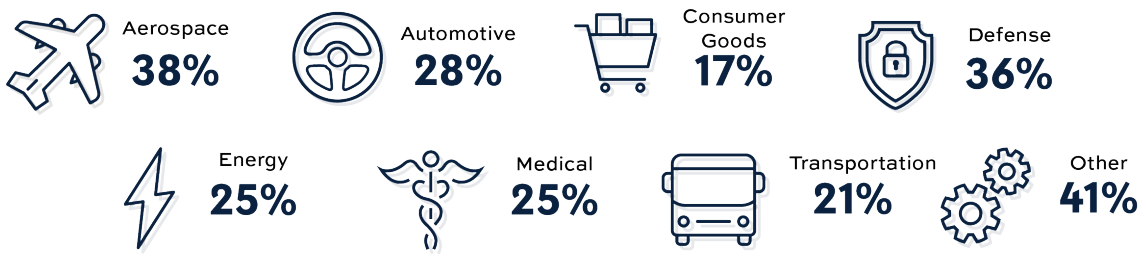


Figure 2: *Industry Breakdown (n=103)*

For this study, an SMM is defined as having under 500 employees and an annual revenue of under $100 million. SMMs represented a majority of the survey respondents, with 35% having less than 50 employees, 41% having between 50 and 250 employees, and 10% having between 250 and 500 employees; approximately 85% of respondents qualify as an SMM based on the number of employees. Of the respondents, half have an annual revenue of under $100 million. (See Figure 3: Number of Employees at Respondent's Location and Figure 4: Company Revenue)

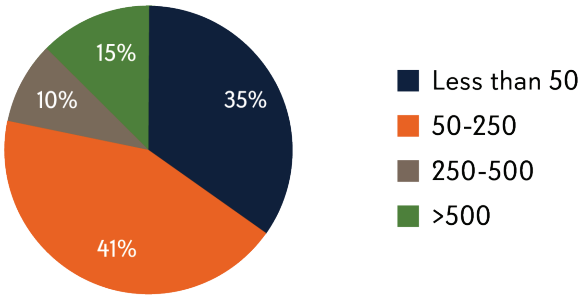


Figure 3: *Number of Employees at Respondent's Location (n=103)*

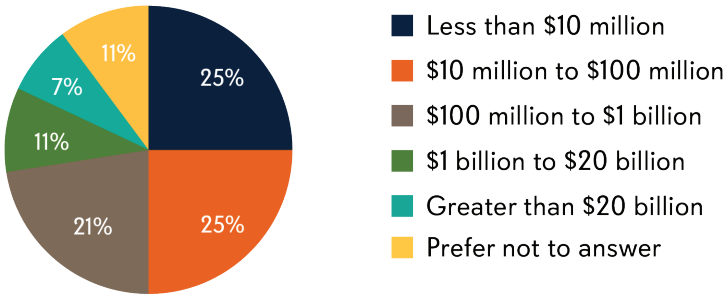


Figure 4: *Company Revenue (n=103)*

Top Challenges

Participants were asked, "What are the top three challenges your business faces?" They were provided six options from which to choose: access to capital, capital improvements, competitive pressure, operational efficiency, revenue/profits, sales/marketing, workforce- engineering, and workforce- operations. Workforce was divided into engineering-focused roles that typically require a degree and roles operating equipment on the factory or shop floor. (See Table 1: Top Business Challenges)

The top three challenges businesses are facing are (1) workforce- operations, (2) operational efficiency, and (3) workforce-engineering. These top three issues remained the same, including the same order as last year. Two years ago, in 2022, operational efficiency and workforce- operations were in the top two spots, with all other issues falling far below. This year, **workforce- operations continues to be a sizeable issue, with 61% of respondents ranking it as a top-three challenge.** (See Figure 5: Top Business Challenges Year-Over-Year)

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

2024	Access to Capital	Capital Improvements	Competitive Pressure	Operational Efficiency	Revenue/ Profits	Sales/ Marketing	Workforce- Engineering	Workforce- Operations
#1	11%	16%	10%	18%	7%	11%	8%	17%
#2	3%	10%	12%	17%	14%	7%	17%	18%
#3	6%	9%	9%	15%	11%	9%	14%	26%

Table 1: *Top Business Challenges (n=98)*

- **Access to capital, revenue/profits, and sales/marketing** have slightly decreased as issues year-over-year since 2022. Of the three, sales/marketing has changed the least.
- **Capital improvements** is a challenge that has seen significant growth since 2022, with an increase of 19 percentage points in those that rank it as a top three business challenge. The emergence of this issue was noted in 2023's report, and it continues to grow.
- **Competitive pressure** has seen little change year-over-year. It has consistently been one of the lower-ranked challenges.
- **Operational efficiency** continues to be a leading issue. However, it has seen a decline of 13 percentage points since 2022.
- **Workforce- engineering** saw a jump in standing from 2022 to 2023. However, it remained stable from 2023 to 2024. Aside from capital improvements, workforce- engineering has grown the most as a challenge, with an increase of 11 percentage points from 2022.
- **Workforce- operations** continues to be a significant issue year-over-year, similar to operational efficiency. However, it has not seen a decline like operational efficiency.

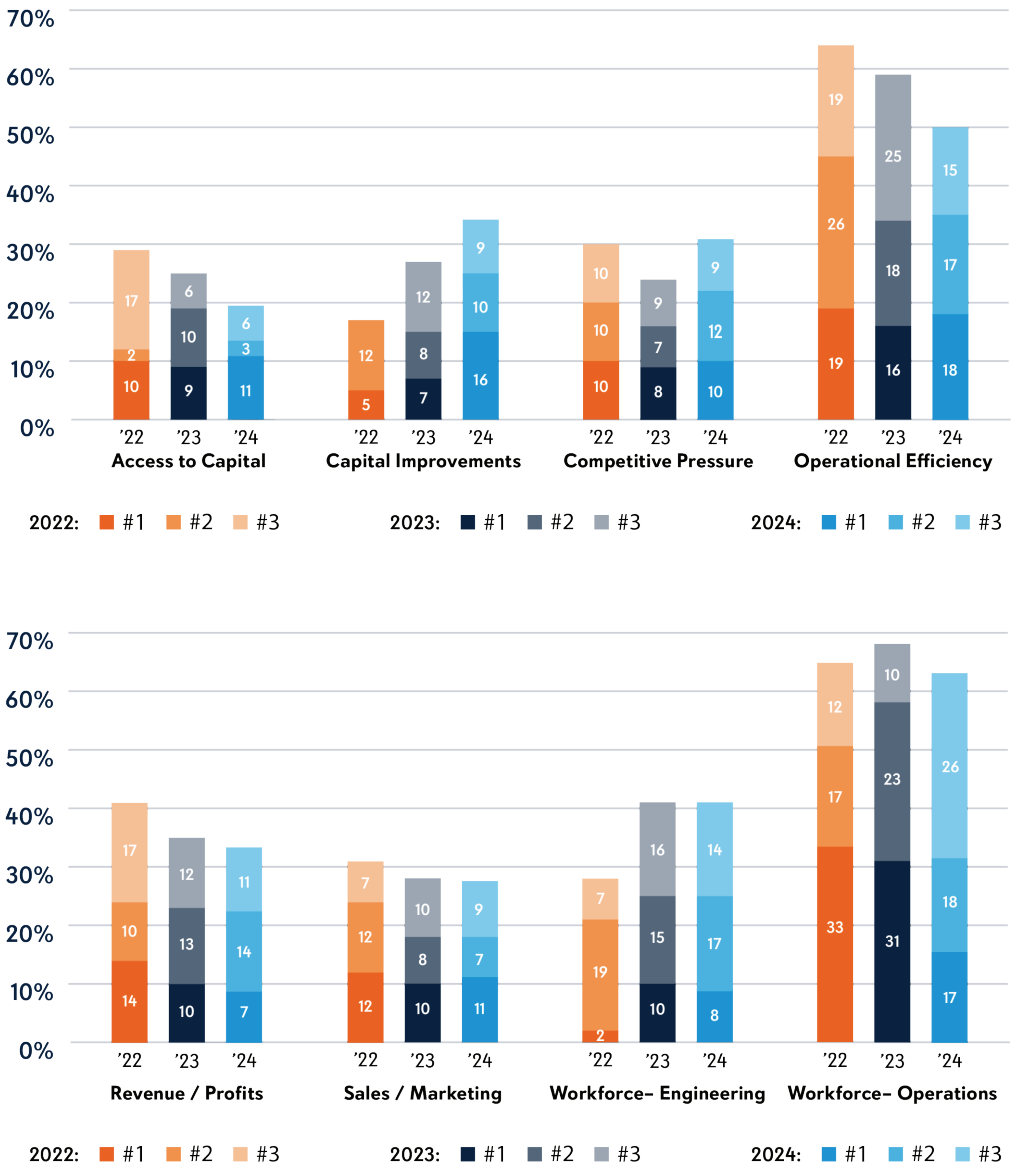


Figure 5: *Top Business Challenges Year-Over-Year (n=98)*

After respondents were asked about their biggest challenges, they were asked to share if those challenging issues are improving, staying the same, or worsening. This year, 22% of respondents said "better," 48% said "same," and 30% said "worse." Overall, this is an encouraging result because this is a considerable improvement from 2022, in which 48% of respondents believed their circumstances were worsening. (See Figure 6: Circumstances Driving Top 3 Challenges) Ideally, respondents would indicate that their challenges are lessening and getting better. However, the following sections of this report will reveal the barriers impeding manufacturers' ability to adopt and implement new technologies.

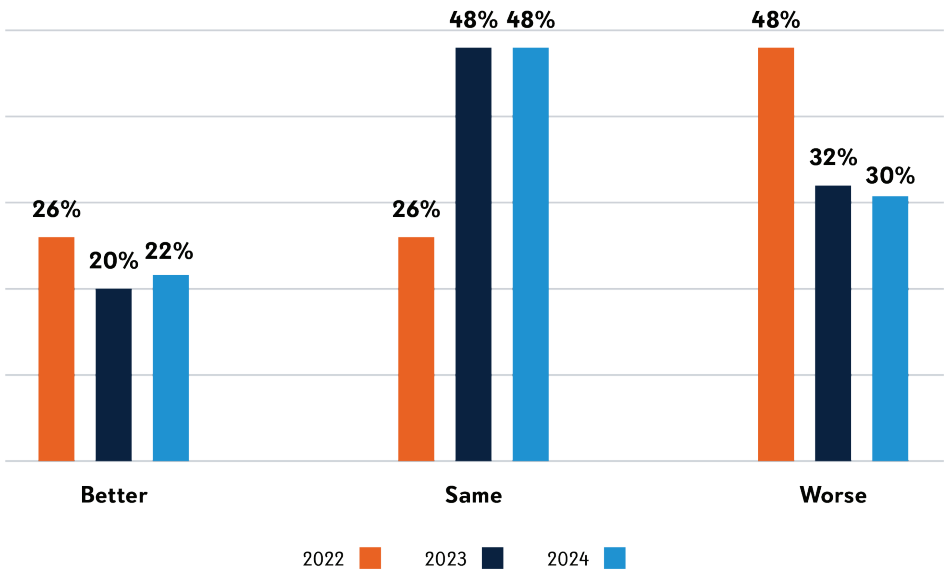


Figure 6: *Circumstances Driving Top 3 Challenges (n=103)*

Smart Manufacturing Component Value

After being asked about their largest challenges, respondents were asked to choose which technologies would help them overcome those challenges. While automation dropped almost two percentage points over last year's choice for the number one solution in perceived value by 38% of the respondents, it has grown significantly as the second (21%) and third (13%) choices. Overall, automation is now viewed as one of the top three technology solutions by 72% of the audience, surpassing last year's leading choice of sensors/IoT. This growth in the perceived value of automation corresponds to manufacturers' difficulty hiring operators. Increasing automation could be an essential solution to overcome workforce challenges. (See Table 2: Perceived Value of Smart Manufacturing Technologies)

2024	Additive Manufacturing	Artificial Intelligence	Automation	Big Data	Sensors/IoT	Predictive Analytics
#1	20%	12%	38%	13%	7%	11%
#2	12%	13%	21%	10%	16%	21%
#3	10%	8%	13%	11%	21%	24%

Table 2: *Perceived Value of Smart Manufacturing Technologies (n=92)*

An interesting dynamic of this shift is that ratings for sensors/IoT dropped considerably, from 16% as the first choice in last year's study to 7% this year. Second-choice ratings fell from 27% to 16%, and the third choice from 23% to 21%. These rankings resulted in a total drop of nearly 24% across all three options. This is somewhat surprising since sensors and IoT are essential automation enablers.

One explanation could be the increase in the lack of workforce as an adoption barrier, as noted in the section- Adoption Barriers: Sensors/IoT. Stand-alone sensors and IoT require a workforce to review, understand, and act on the outputs. Sensors and IoT components of an integrated automation solution installed by a vendor may not be viewed as requiring the same level of workforce attention.

Another significant change is the greater perceived value of additive manufacturing, which increased at all three choice levels. The rating for the first choice was a modest increase from 17% last year to 20% this year. Ratings for the second choice more than doubled, from 5% to 12%, and the third choice went from 6% to 10%. The perceived value of additive manufacturing is increasing, which is corroborated by the growth of respondents moving to the middle stages of adoption noted in the section- Adoption: Additive Manufacturing.

Perceived value ratings for the remaining solutions saw little change in 2024, except for predictive analytics moving into the number two position. (See Figure 7: Perceived Value of Smart Manufacturing Technologies Year-Over-Year)

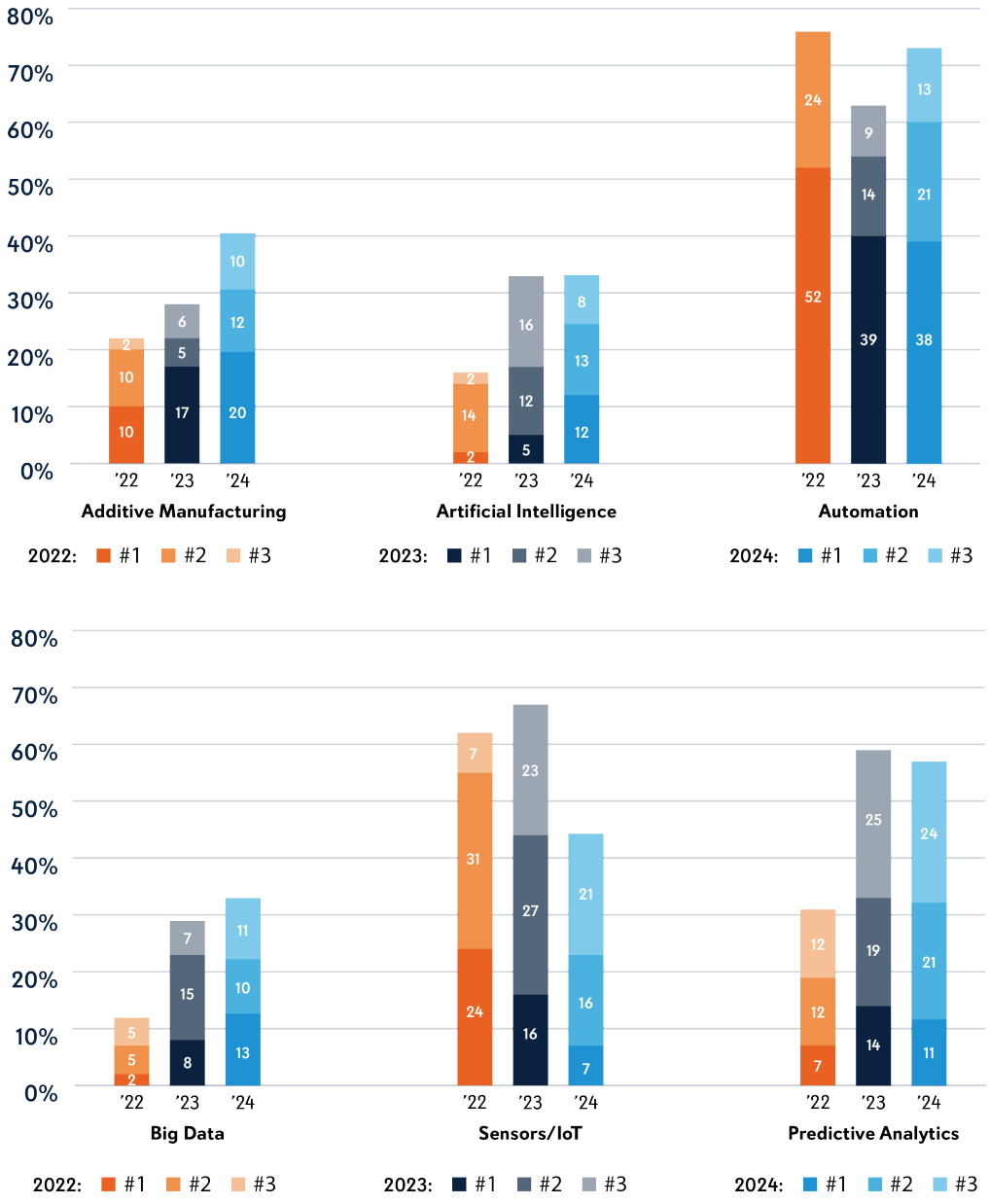


Figure 7: *Perceived Value of Smart Manufacturing Technologies Year-Over-Year (n=92)*

Smart Manufacturing Component Adoption

Participants were asked to assess where their firm is in adopting the six technologies: awareness, researching, evaluating, implementing, or using. This year, the technologies being implemented or used the most, being the furthest along in their adoption processes, are automation and additive manufacturing. More than half of the respondents (56%) are already using or implementing automation, and nearly half (49%) of respondents are using or implementing additive manufacturing. The technologies in their greatest infancy, being the most behind in their adoption processes, are artificial intelligence and predictive analytics, with big data processing and sensors/IoT following close behind. More than half of the respondents lack awareness or are just beginning to research artificial intelligence (58%) and predictive analytics (52%). (See Table 3: Smart Manufacturing Technology Adoption and Figure 8: Smart Manufacturing Technology Adoption)

2024	Additive Manufacturing	Artificial Intelligence	Automation	Big Data	Sensors/IoT	Predictive Analytics
Using	34%	8%	37%	10%	15%	9%
Implementing	15%	20%	19%	28%	26%	18%
Evaluating	11%	14%	18%	13%	12%	22%
Researching	26%	33%	14%	30%	28%	29%
Awareness	13%	25%	12%	19%	19%	23%

Table 3: *Smart Manufacturing Technology Adoption (n=97)*

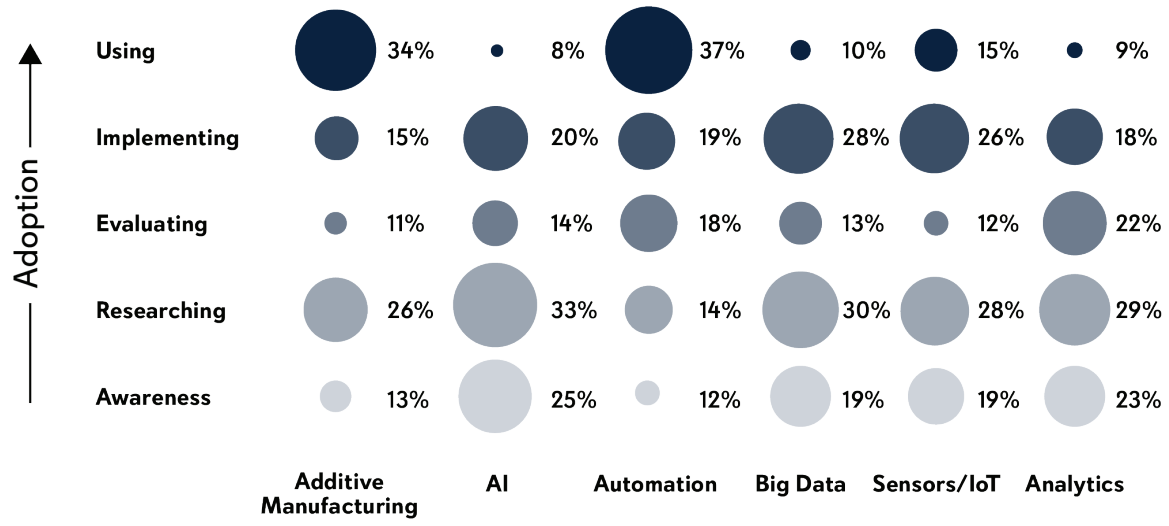


Figure 8: *Smart Manufacturing Technology Adoption (n=97)*

Adoption: Additive Manufacturing

Additive Manufacturing has seen significant changes year-over-year. In this past year alone, there has been a substantial movement from the awareness stage to the researching stage (13% of respondents). When this survey began in 2022, 43% of respondents were in the awareness stage, but now, only 13% are in the awareness stage. This drastic change indicates the growth and maturity of additive manufacturing over just a few short years. However, in contrast, there has been little change from 2023 to 2024 in the percentage of participants implementing and using additive manufacturing. (See Figure 9: Additive Manufacturing Adoption Year-Over-Year)

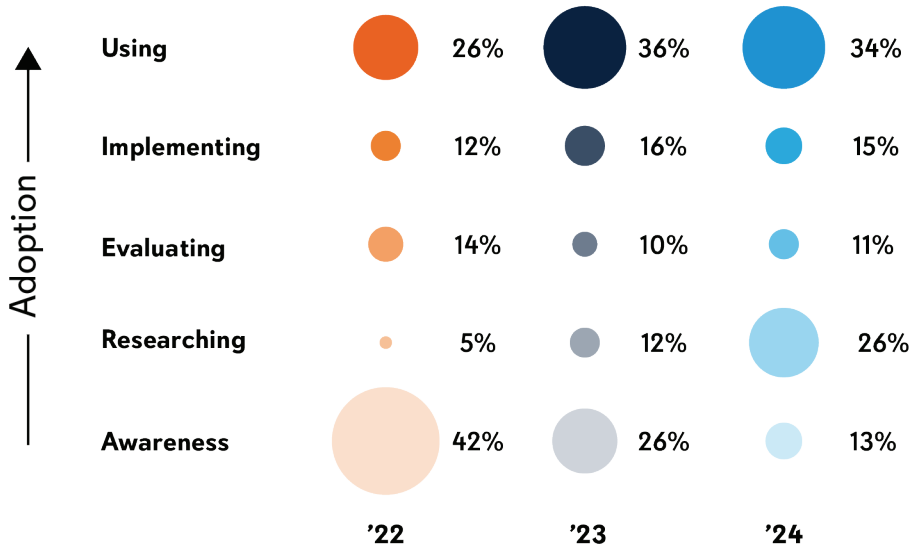


Figure 9: *Additive Manufacturing Adoption Year-Over-Year (n=97)*

Adoption: Artificial Intelligence

Artificial intelligence (AI) is still struggling to take hold in manufacturing, with only 8% of respondents using it (a two-percentage-point increase from last year). However, this will likely change in the coming years, as we have seen a 12 percentage-point increase in those implementing it. There has also been a 12 percentage-point decrease in those in the lowest stage of awareness, meaning that manufacturers are progressing in adopting AI. One of the most notable changes is the 22 percentage-point decrease in those in the awareness stage from 2022 to now (from 47% in 2022 to only 25% in 2024). (See Figure 10: Artificial Intelligence Adoption Year-Over-Year)

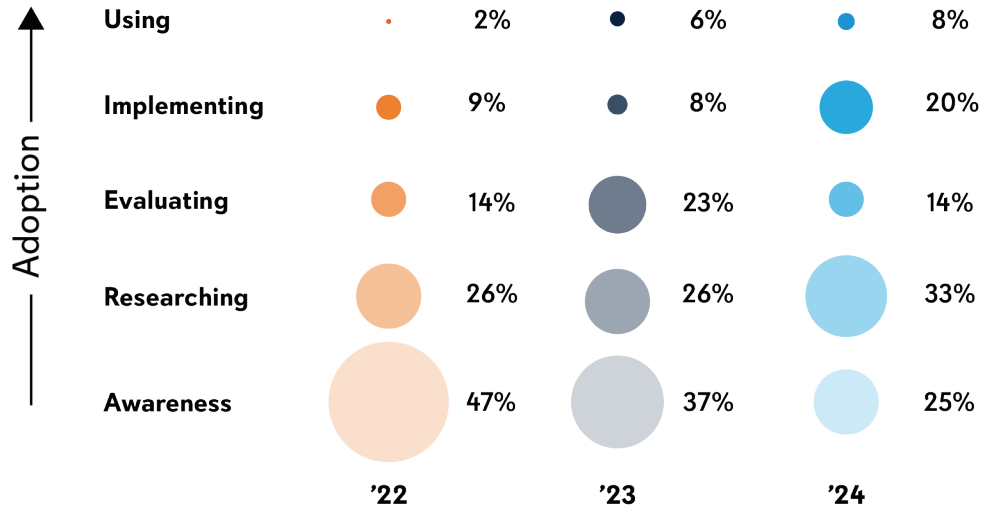


Figure 10: *Artificial Intelligence Adoption Year-Over-Year (n=97)*

Adoption: Automation

Of all the technologies analyzed by this survey, automation has seen the least change from 2022; this is likely because it has always been one of the most adopted technologies, with over half of the respondents being in the implementing or using stage over the past three years. There has been little movement between the stages over the past three years. The most significant change has been a seven percentage-point increase in automation users from 2022 to 2024. (See Figure 11: Automation Adoption Year-Over-Year)

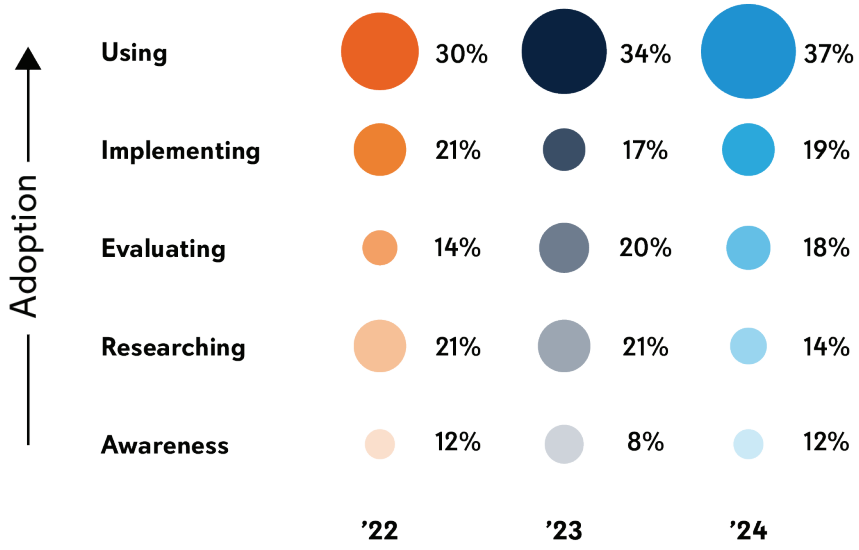


Figure 11: *Automation Adoption Year-Over-Year (n=97)*

Adoption: Big Data Processing

Like AI, big data processing has yet to become prominent in manufacturing, but its adoption is moving in the right direction. This year, 28% of respondents claimed to be in the implementation stage, a seven percentage-point increase from last year and a 12 percentage-point increase from two years ago. There has also been a significant movement out of the awareness stage (8 percentage-point decreases from 2022 to 2023 and from 2023 to 2024). This change is also evident in the increase of respondents researching big data processing (a 14 percentage-point increase from 2022). (See Figure 12: Big Data Processing Adoption Year-Over-Year)

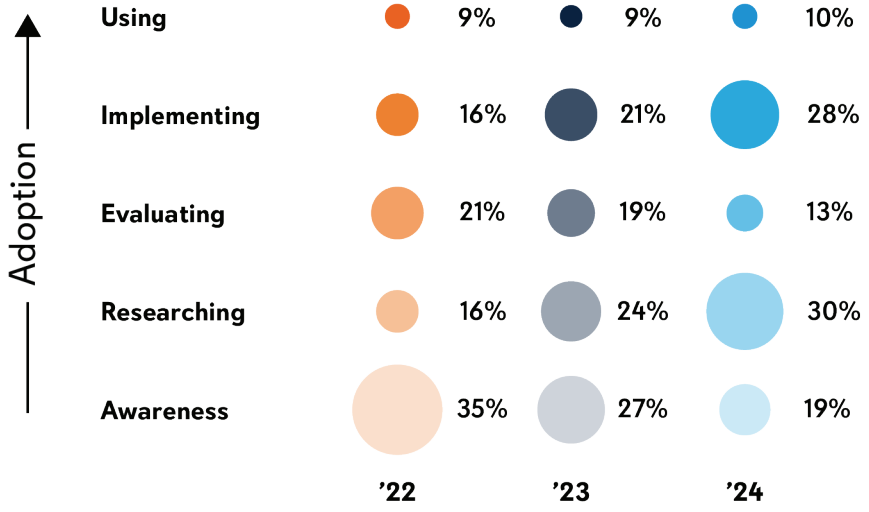


Figure 12: *Big Data Processing Adoption Year-Over-Year (n=97)*

Adoption: Sensors/IoT

Sensors/IoT is also struggling to mature, with nearly half of the respondents being in the awareness or researching stages (almost 47% of respondents). Two somewhat puzzling findings are the decrease in those who have reported using sensors/IoT (an 11 percentage-point decrease from last year) and the reduction in those evaluating sensors/IoT as a technology solution (a 15 percentage-point decrease from the previous year); many of the respondents have shifted back into the researching stage. (See Figure 13: Sensors/IoT Adoption Year-Over-Year)

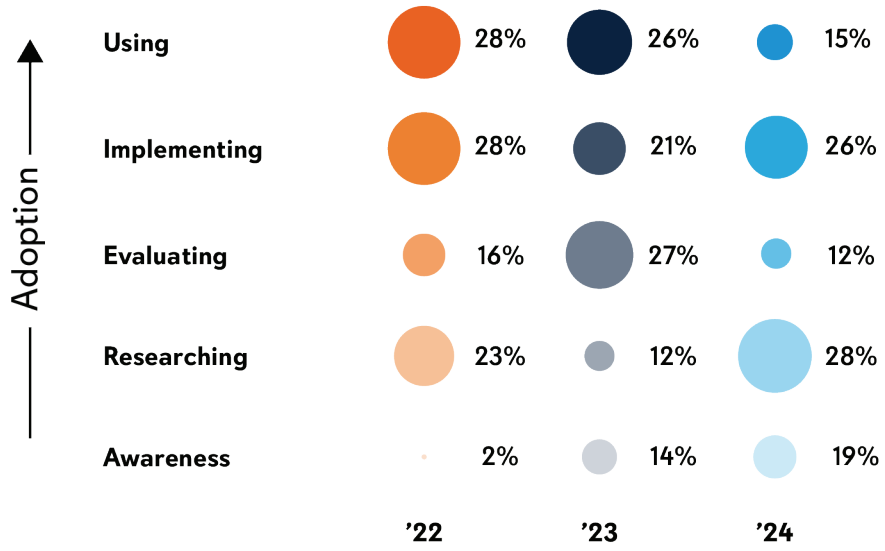


Figure 13: *Sensors/IoT Adoption Year-Over-Year (n=97)*

Adoption: Predictive Analytics

Predictive analytics is second to the least mature technology- AI, with 52% of respondents in the awareness or researching stage. Like automation, predictive analytics has seen very few changes year-over-year. However, this is likely due to the opposite reasoning; automation was already widely adopted, but predictive analytics was not. (See Figure 14: Predictive Analytics Adoption Year-Over-Year)

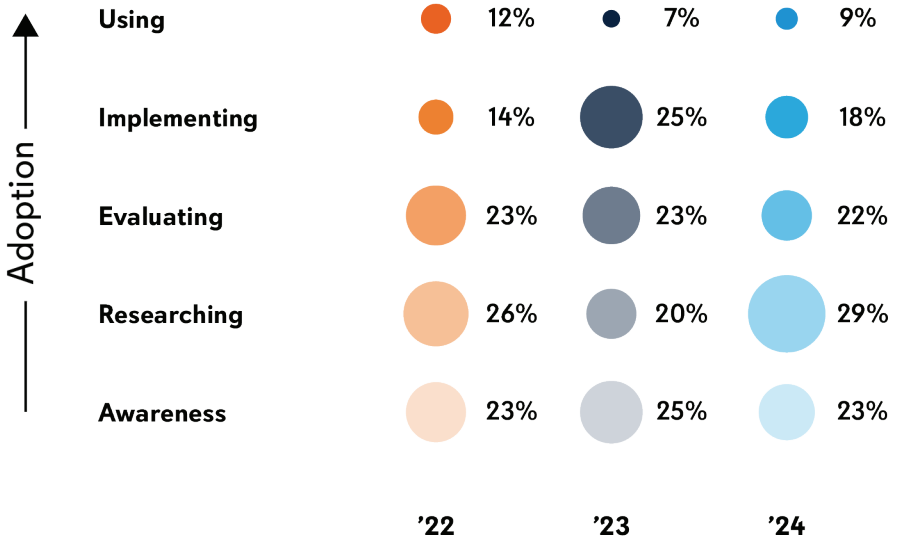


Figure 14: *Predictive Analytics Adoption Year-Over-Year (n=97)*

Smart Manufacturing Adoption Barriers

Respondents were then asked what the top three barriers are that prevent them from adopting the six technologies: lack of awareness, lack of business cases, lack of capital, high cost, lack of peer experience, lack of resources, lack of workforce, or lack of workforce skill set. Table 4: Adoption Barriers by Technology shows the results of a weighted average for each technology. More weight was given to the technologies ranked the highest by respondents. The impediments vary by technology, but the most prominent adoption barriers are a lack of workforce skill set and business cases. Both barriers must be addressed for manufacturers to progress in technology adoption.

	Lack of				Lack of				
2024	Awareness	Business Cases	Capital	High Cost	Peer Experience	Resources	Workforce	Workforce Skill Set	Number of Respondents
Additive Manufacturing	10%	19%	10%	18%	9%	8%	8%	17%	83
Artificial Intelligence	17%	21%	7%	8%	8%	6%	11%	21%	83
Automation	6%	11%	14%	21%	5%	11%	13%	20%	82
Big Data	16%	18%	6%	11%	11%	12%	7%	19%	81
Sensors/IoT	18%	16%	8%	8%	10%	7%	13%	20%	80
Predictive Analytics	18%	17%	6%	8%	10%	9%	13%	19%	79

Table 4: *Adoption Barriers by Technology*

Adoption Barriers: Additive Manufacturing

The most significant impediments to adopting additive manufacturing are a lack of business cases (19%), high cost (18%) and a lack of workforce skill set (17%). Most other impediments pale in comparison, being noted as a top three issue by 10% or less of respondents. The barriers have not changed significantly over the past year. The most considerable change was a lack of workforce as a barrier, which decreased by five percentage points, which is a change in the right direction. However, the lack of workforce skill set and resources continues to rise yearly, which goes along with the increase in respondents reporting they are using additive manufacturing, putting more pressure on the need for a skilled workforce. (See Figure 15: Adoption Barriers for Additive Manufacturing)

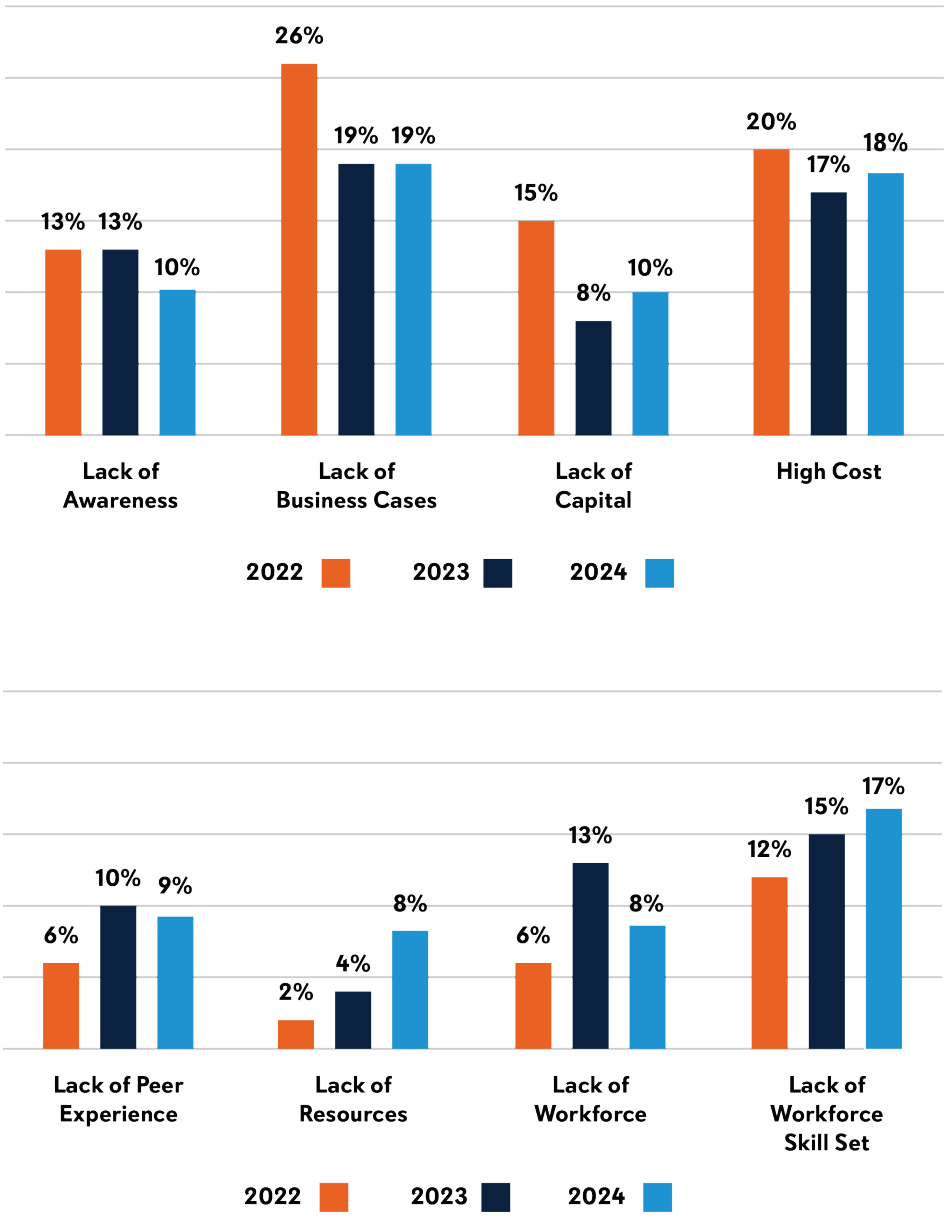


Figure 15: *Adoption Barriers for Additive Manufacturing (n=83)*

Adoption Barriers: Artificial Intelligence

The most significant barriers to adopting AI are a lack of business cases (21%), a lack of workforce skill set (21%), and a lack of awareness (17%). The lack of business cases and awareness is unsurprising, as these have been the top barriers over the past two years. However, the lack of workforce skill set has risen significantly (an increase of 8 percentage points since 2022). This means manufacturers are becoming more aware of AI and its benefits but are having trouble getting workers with the right skill sets to implement it. Manufacturers also wish to see business cases showcasing how other companies implement AI. (See Figure 16: Adoption Barriers for Artificial Intelligence)

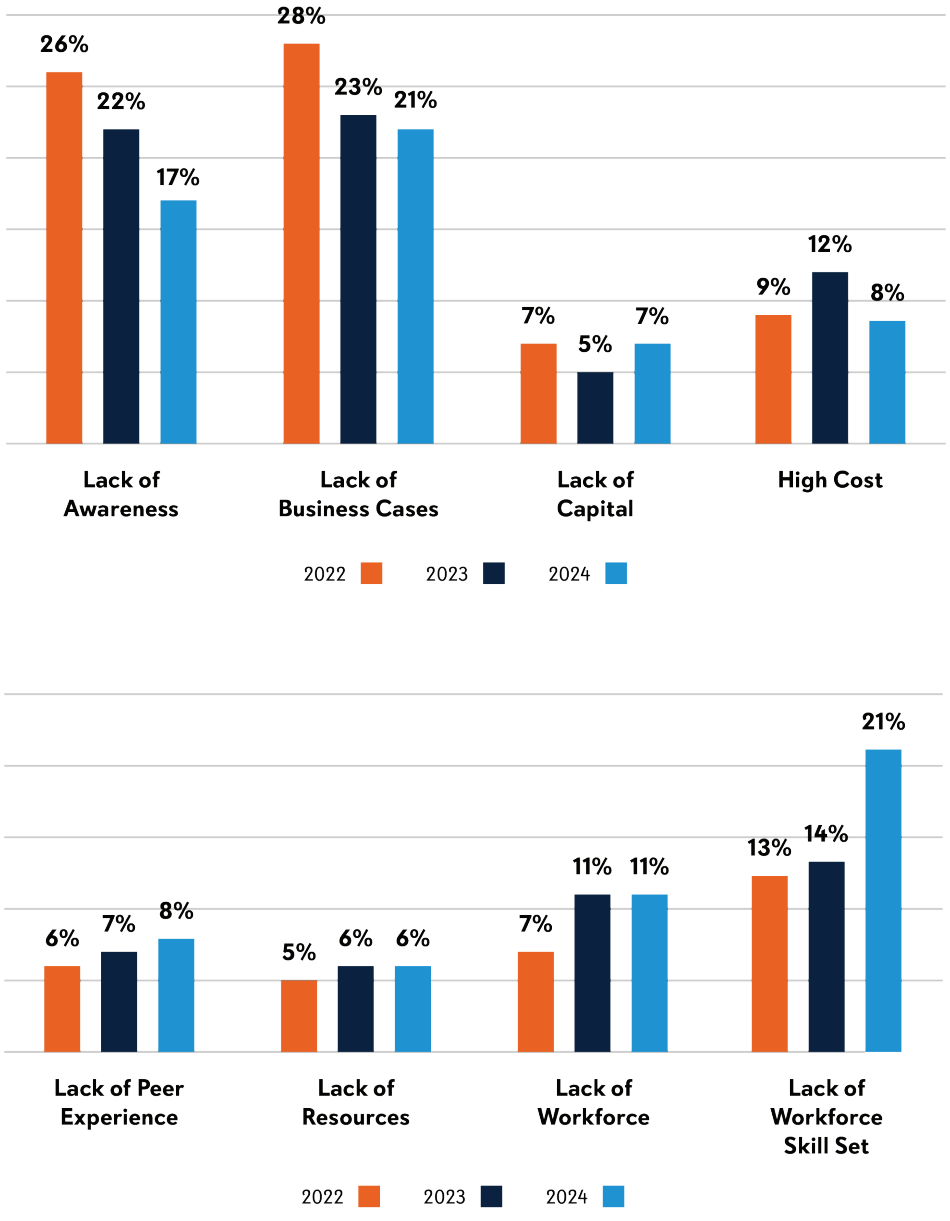


Figure 16: *Adoption Barriers for Artificial Intelligence (n=83)*

Adoption Barriers: Automation

The barriers to automation have changed minimally year over year. The top adoption barriers for automation remain the same as last year: high cost (21%) and lack of workforce skill set (20%). The only notable change from 2022 to now is capital lessening as a barrier (a six percentage-point decrease). Therefore, capital is not as prevalent an issue as it used to be; the focus now should be on finding cost-effective solutions and the skills to implement automation. (See Figure 17: Adoption Barriers for Automation)

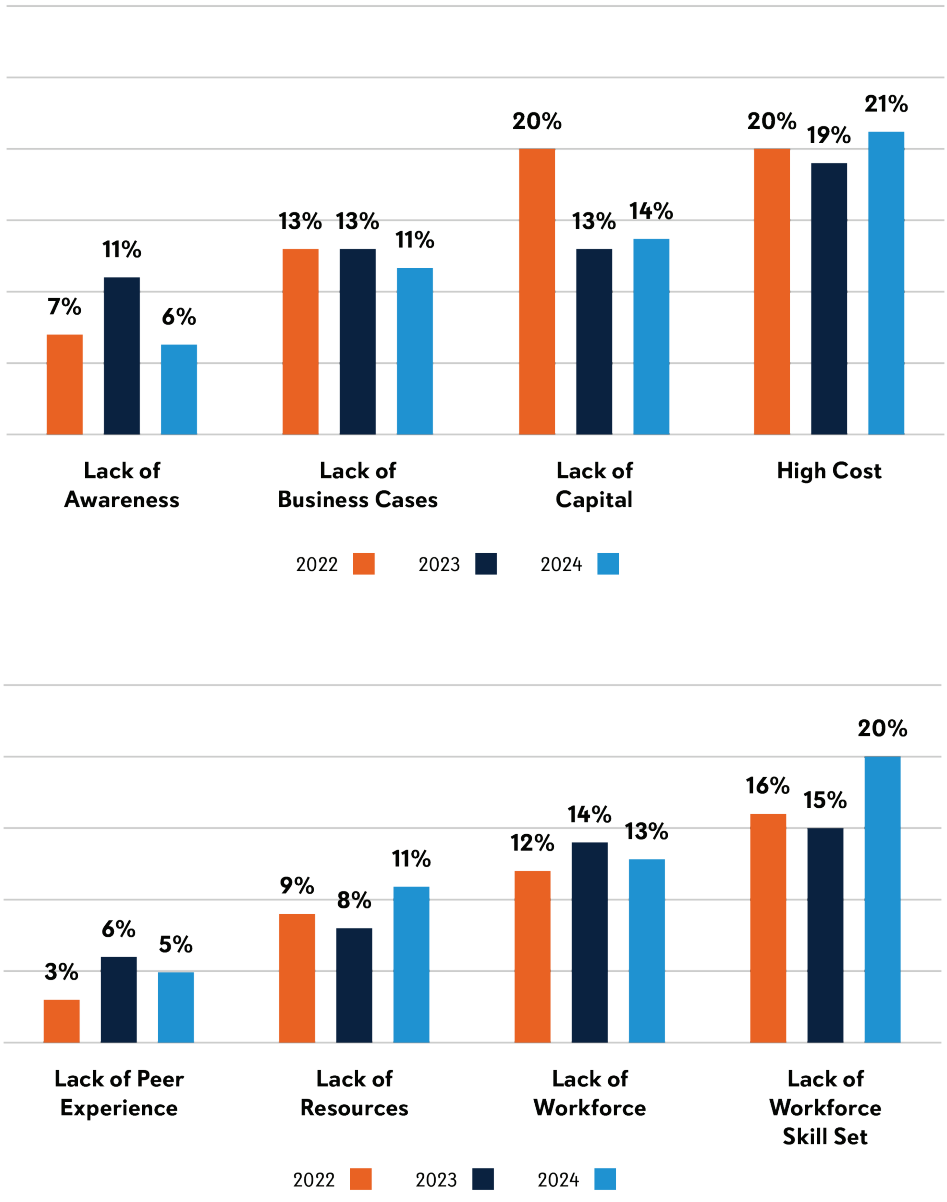


Figure 17: *Adoption Barriers for Automation (n=82)*

Adoption Barriers: Big Data Processing

This year, the top three barriers to big data processing were workforce skill set (19%), lack of business cases (18%), and lack of awareness (16%). This is only a slight change from the past two years, in which a lack of awareness and a lack of business cases took the leading spots. As with most technologies analyzed by this survey, big data processing is not immune to workforce skill set issues. (See Figure 18: Adoption Barriers for Big Data Processing)

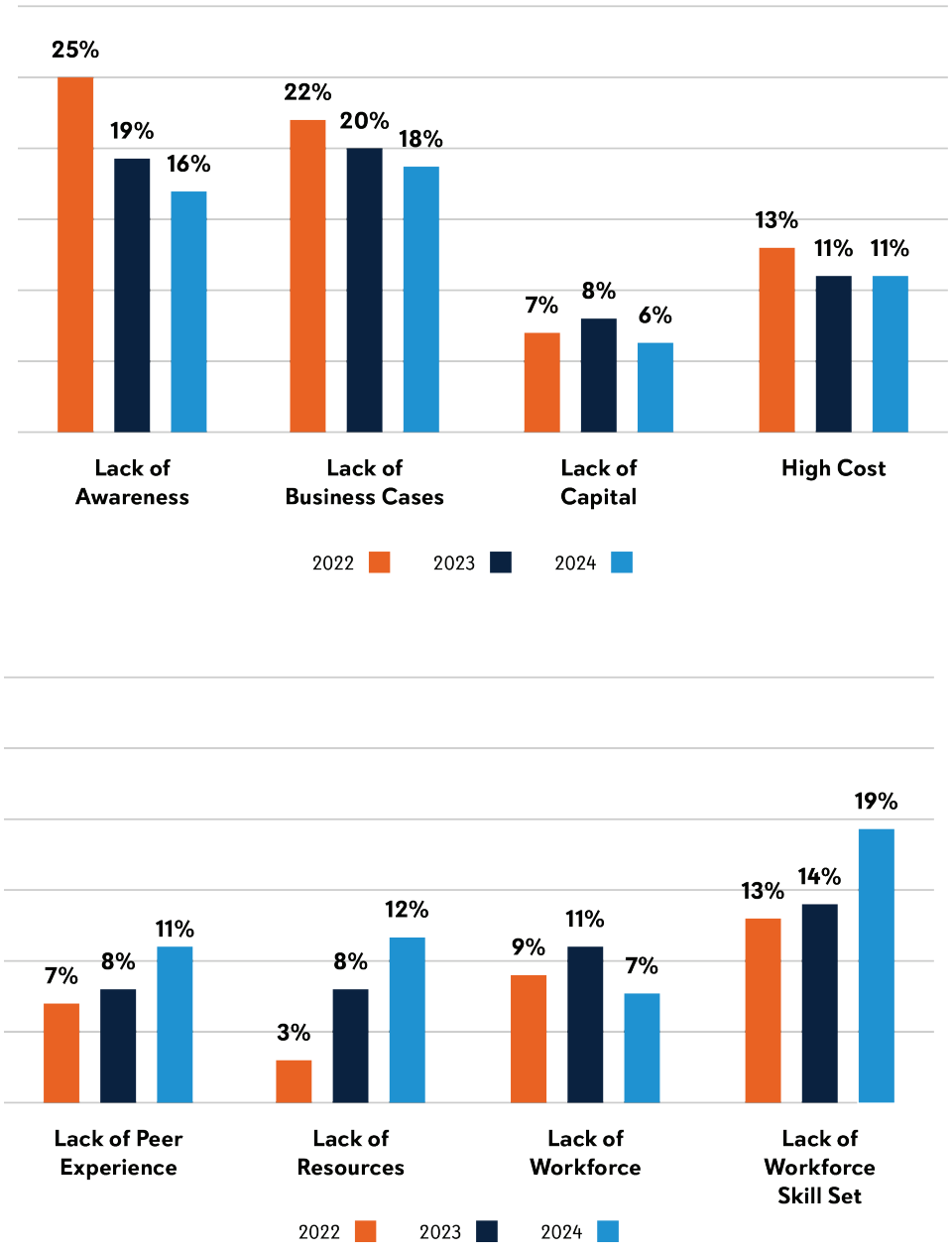


Figure 18: *Adoption Barriers for Big Data Processing (n=81)*

Adoption Barriers: Sensors/IoT

A lack of workforce skill set (20%), lack of awareness (18%), and lack of business cases (16%) are the top three adoption barriers for Sensors/IoT. Over the past few years, capital and cost have lessened as issues, and peer experience has grown as an issue (an increase of 7 percentage points since 2022). (See Figure 19: Adoption Barriers for Sensors/IoT)

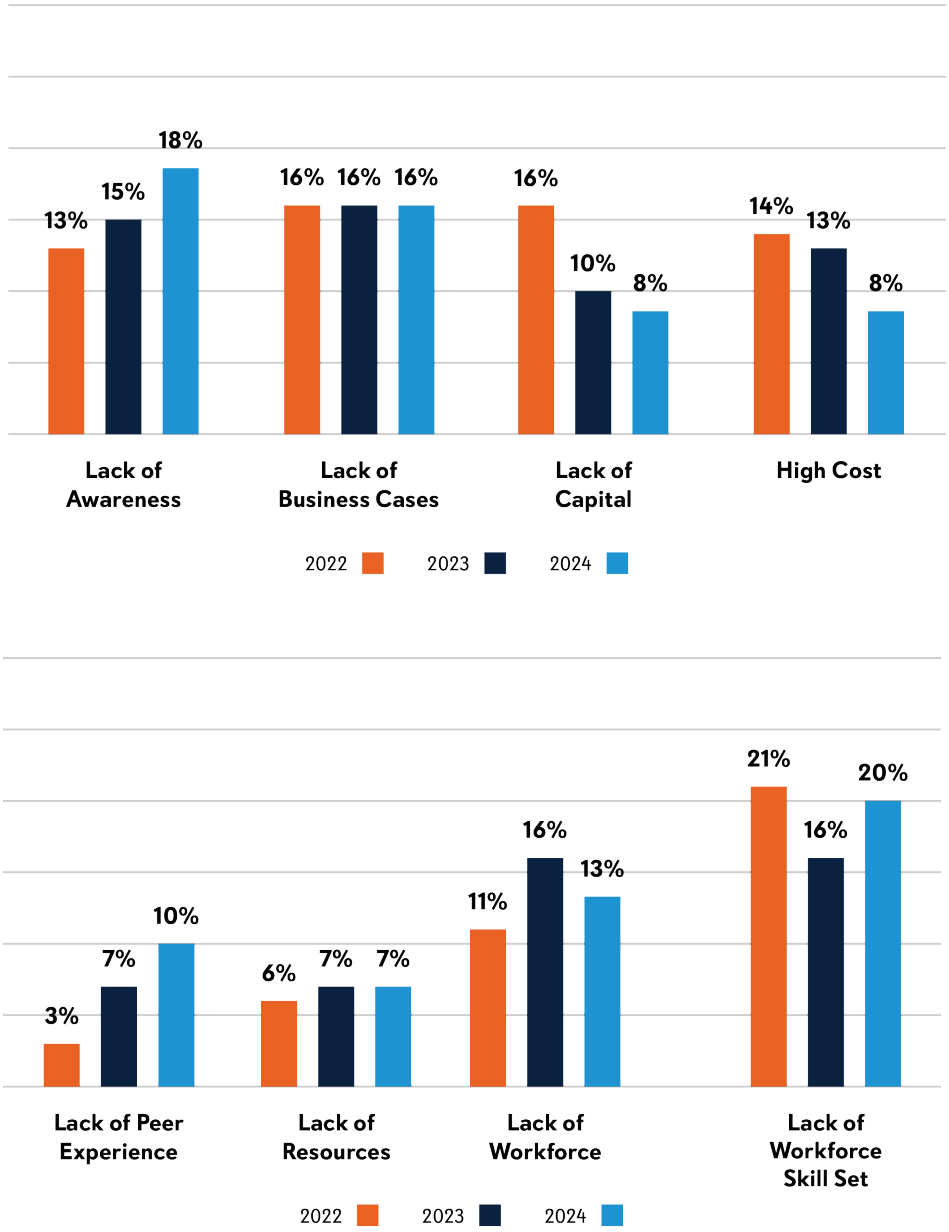


Figure 19: *Adoption Barriers for Sensors/IoT (n=80)*

Adoption Barriers: Predictive Analytics

In terms of barriers, predictive analytics has seen the most change. Lack of awareness (a decrease of nearly 9 percentage points) and business cases (a reduction of 11 percentage points) have shrunk. Lack of peer experience (an increase of 5 percentage points), resources (a rise of 6 percentage points), workforce (an increase of 6 percentage points), and workforce skill set (an increase of 5 percentage points) continue to rise as barriers. Though many changes have occurred, the top three barriers remain the same since 2022: lack of awareness, business cases, and workforce skill set. In 2024, the most significant barrier was workforce skill set at 19%, followed by lack of awareness at 18%, and lack of business cases at 17%. (See Figure 20: Adoption Barriers for Predictive Analytics (n=79))

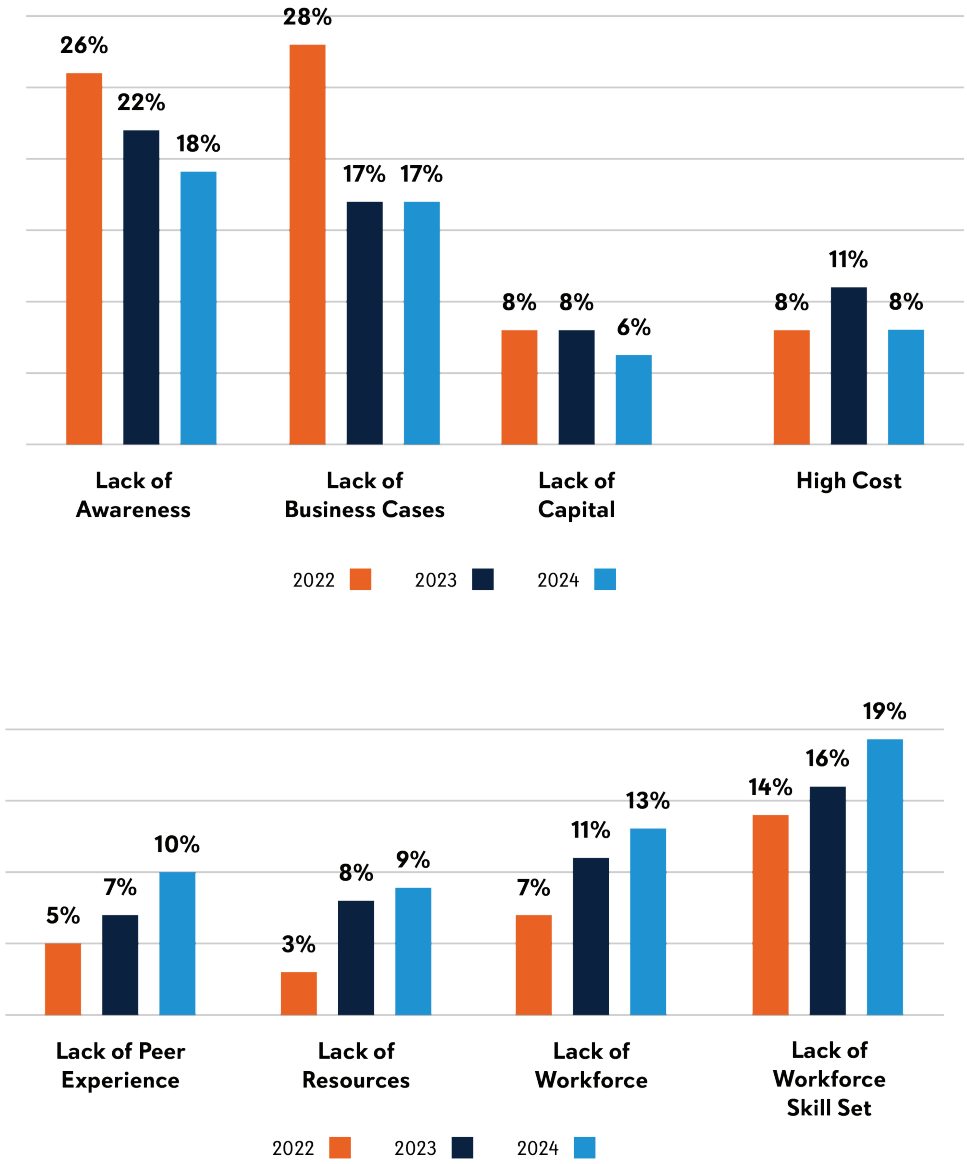


Figure 20: *Adoption Barriers for Predictive Analytics (n=79)*

Resources to Learn, Decide, and Implement

Survey respondents were asked what resources they use when learning about, deciding on, and implementing new smart technologies: academic papers, business articles, case studies, consultants, peers, vendors, or other. The responses call out the importance of peer-to-peer collaboration and case studies. Vendors also have a prominent impact, but more so in the implementation phase than in the learning and deciding phases. (See Table 5: Resources to Learn, Decide, and Implement)

2024	Academic Papers	Business Articles	Case Studies	Consultants	Peer Experience	Vendors	Other
Learn	8%	15%	21%	12%	22%	20%	2%
Decide	6%	15%	22%	13%	25%	18%	1%
Implement	5%	9%	16%	20%	24%	25%	1%

Table 5: *Resources to Learn, Decide, and Implement (n=83)*

Resources to Learn

How manufacturers learn about new technologies continues to evolve. In 2024, manufacturers preferred peer experience (22%), case studies (21%), and vendors (20%). In 2023, business articles were more prevalent, being the most preferred learning method at 23%. The most substantial changes from last year are a decrease in learning from business articles (a reduction of approximately seven percentage points) and an increase in learning from vendors (a rise of 6 percentage points). It is important to note that manufacturers report that they rarely utilize academic papers and consultants when learning about smart technologies. (See Figure 21: Resources to Learn)

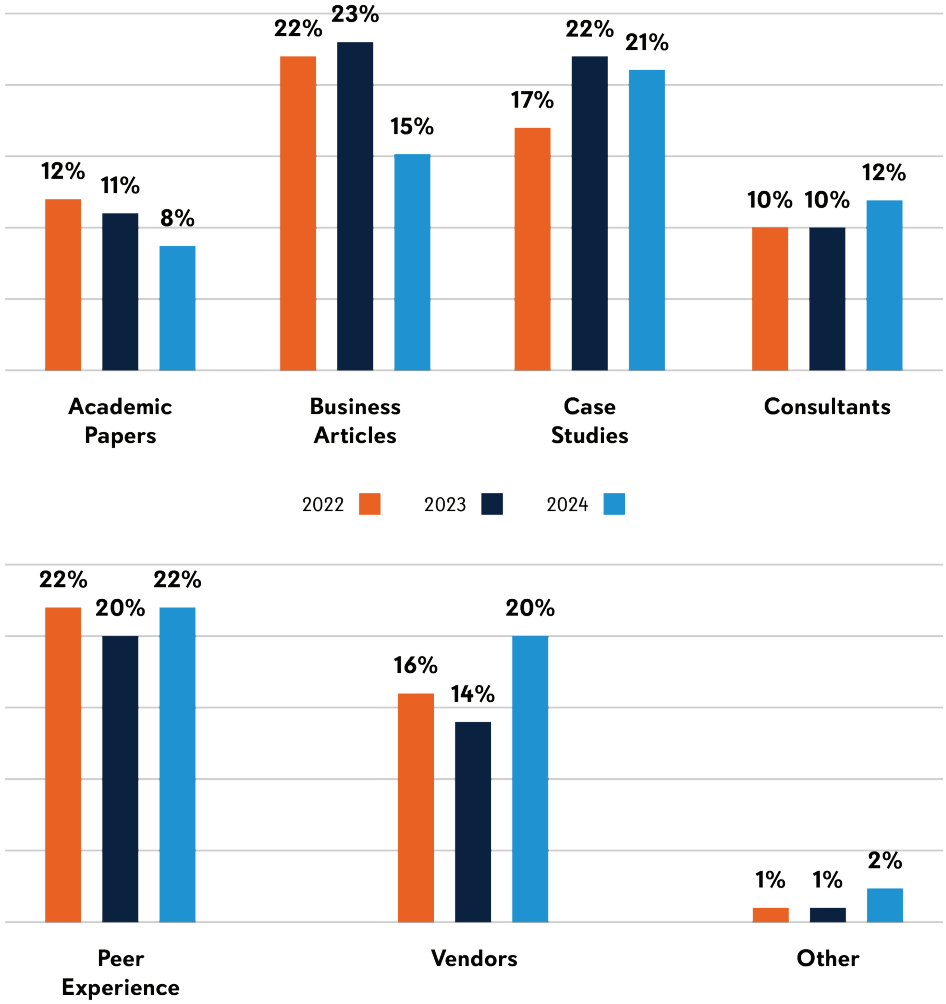


Figure 21: *Resources to Learn (n=83)*

Resources to Decide

Manufacturers are highly consistent in how they decide on smart technologies. Peer experience and case studies have flipped back and forth as the top method since 2022. This year, peer experience was the most preferred method by 25% of respondents, followed by case studies at 22% and vendors at 18%. Academic papers are the least preferred method when deciding on smart technologies, meaning increased effort should be placed on case studies because they are more influential for manufacturers. (See Figure 22: Resources to Decide)

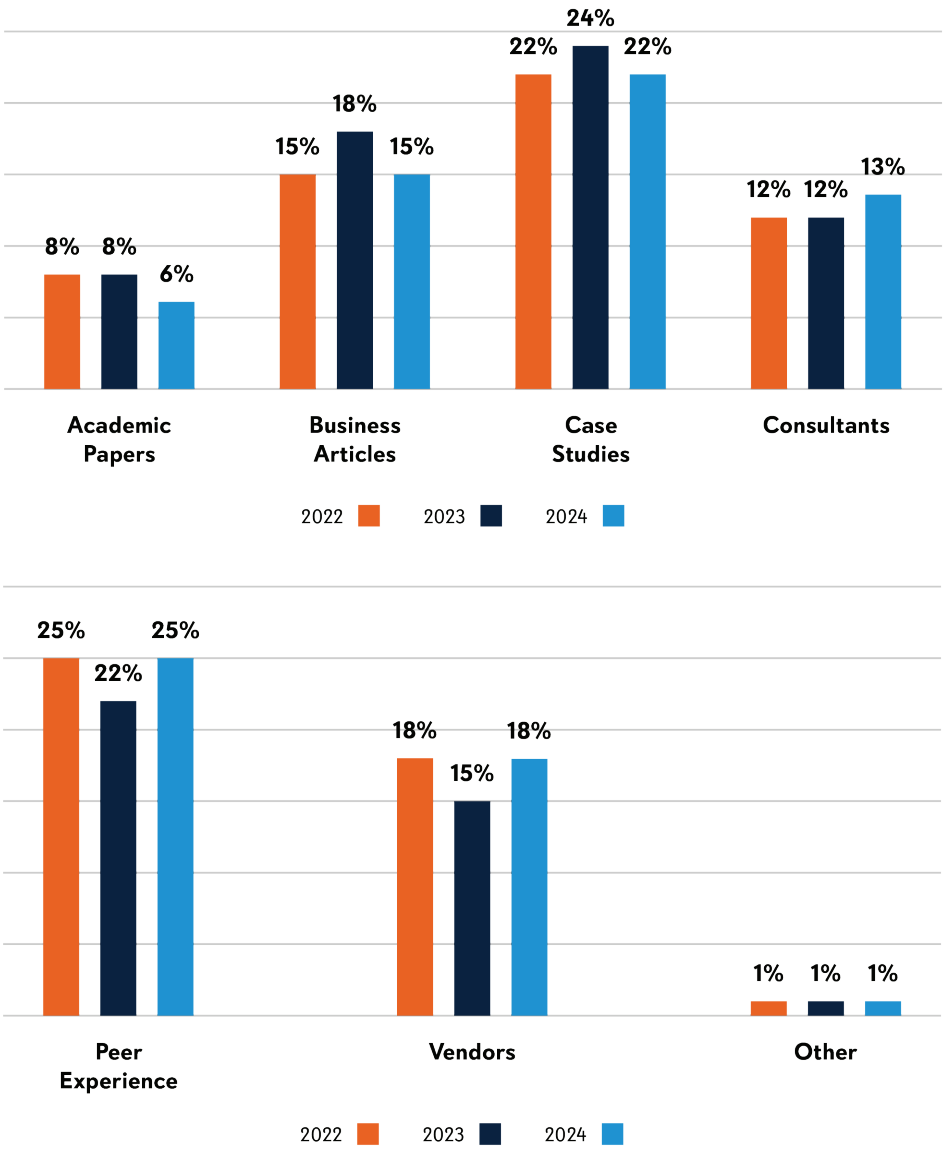


Figure 22: *Resources to Decide (n=83)*

Resources to Implement

Manufacturers predominantly reach out to vendors (25%) and peers (24%) when needing help with technology implementation. Unsurprisingly, this has changed very little over the past few years. It is common for manufacturers to seek help from vendors responsible for implementation or contact peers who have implemented a similar technology. Manufacturers place significant trust in people they know and share problems with. (See Figure 23: Resources to Implement)

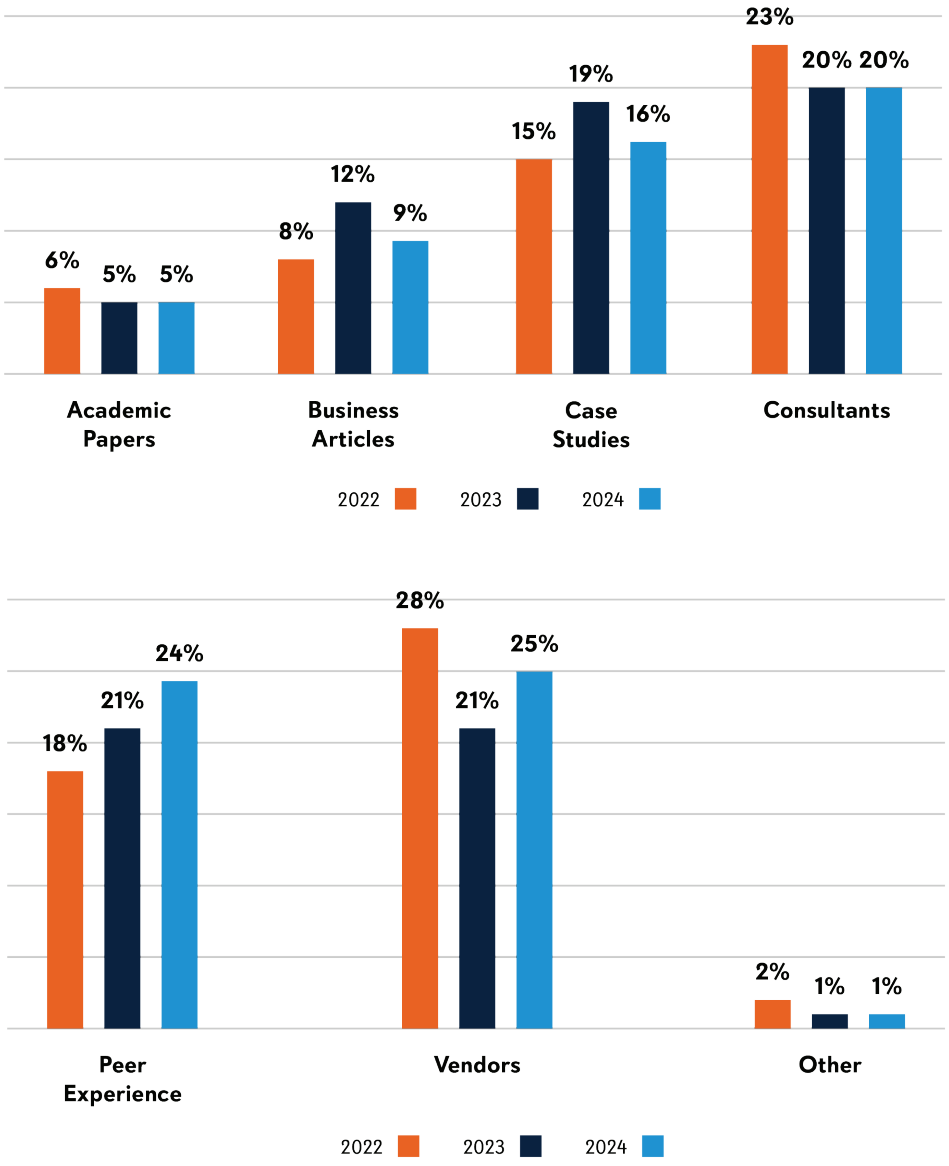


Figure 23: Resources to Implement (n=83)

Differences Between LV/HM and HV/LM Responses

At the beginning of the survey, manufacturers were asked to select their order mix: low volume, high mix (LV/HM), high volume, low mix (HV/LM), or both (LV/HM & HV/LM). Most respondents were LV/HM (54%) or both LV/HM & HV/LM (37%). When reading these results, it is essential to remember that a small subset of the respondents was HV/LM (only 9%). Separating and comparing the results by order mix allows us to see if order mix impacts business challenges, technology value perception, and barriers. (See Figure 24: Mix of Orders)

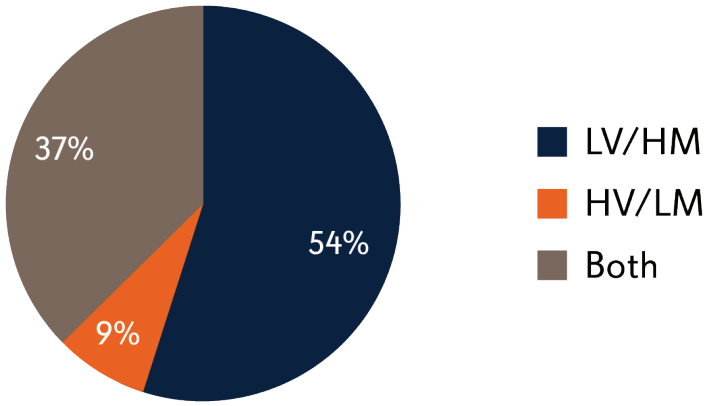


Figure 24: *Mix of Orders (n=103)*

The **top challenges** varied somewhat according to the order mix. The following percentages are the percentage of respondents in each category that ranked the challenge as a top-three issue:

- **Low volume, high mix (LV/HM):** workforce- operations (60%), workforce- engineering (43%), and operational efficiency (42%)
- **High volume, low mix (HV/LM):** workforce- operations (100%) and operational efficiency (88%)
- **Both (LV/HM & HV/LM):** operational efficiency (57%), workforce- operations (54%), and capital improvements (49%)

For LV/HM respondents, workforce- operations and operational efficiency were ranked as the #1 business challenges by 19% of the respondents, meaning these challenges are likely the most pressing and top-of-mind. Interestingly, revenue/profits was ranked as the #2 business challenge by 21% of respondents, meaning it should not be overlooked. However, few respondents ranked it their #1 or #3 business challenge, so revenue/profits did not make our list of top challenges for LV/HM respondents.

For respondents that indicated they have both types of order mix (LV/HM & HV/LM), capital improvements was most concerning, with 24% of respondents ranking it as their #1 business challenge; operational efficiency followed close behind at 22%. The challenge ranked by the most participants in the #2 slot was workforce- operations at 24%.

All types of order mixes struggle with workforce- operations and operational efficiency. Workforce- engineering was a more substantial challenge for LV/HM participants than other mix types, and capital improvements was more prominent for combined mix types (LV/HM & HV/LM).

Differences by Company Size

The responses were parsed by company size to analyze gaps in technology adoption between small and medium-sized manufacturers and larger companies. Demographic data from the respondents was used to conduct this analysis. Company size was separated into four categories (recall Figure 3).

- Less than 50 employees (35%)
- 50-250 employees (41%)
- 250-500 employees (10%)
- More than 500 employees (15%)

The **top challenges** vary somewhat varied by business size. The following percentages are the percentage of respondents in each category that ranked the challenge as a top-three issue:

- **Less than 50 employees:** workforce- operations (65%), revenue/profits (43%), and capital improvements & workforce- engineering (39%)
- **50-250 employees:** workforce- operations (70%), workforce- engineering (50%), and competitive pressure (40%)
- **250-500 employees:** workforce- operations (82%), operational efficiency (64%), and capital improvements & workforce- engineering (36%)
- **More than 500 employees:** operational efficiency (66%), workforce- operations (50%), and capital improvements (39%)

Workforce- operations is a prominent challenge for companies of all sizes; it is overwhelmingly the largest challenge for companies of all sizes except those with more than 500 employees. For companies with more than 500 employees, operational efficiency was ranked as a top-three business challenge by nearly 66% of respondents. There has been little change in the top challenges based on company size year-over-year. Last year, workforce- operations was also a top challenge for companies of all sizes.

Few conclusions can be drawn when analyzing how companies of varying sizes perceive the value of technologies. There is no upward or downward trend in value perception by company size. For example, additive manufacturing is not necessarily valued more or less by smaller manufacturers than by large manufacturers. However, manufacturers of all sizes see the value in automation. (See Figure 25: Perceived Value of Technologies by Company Size - Note that scoring for these categories combined the top two vote percentages.)

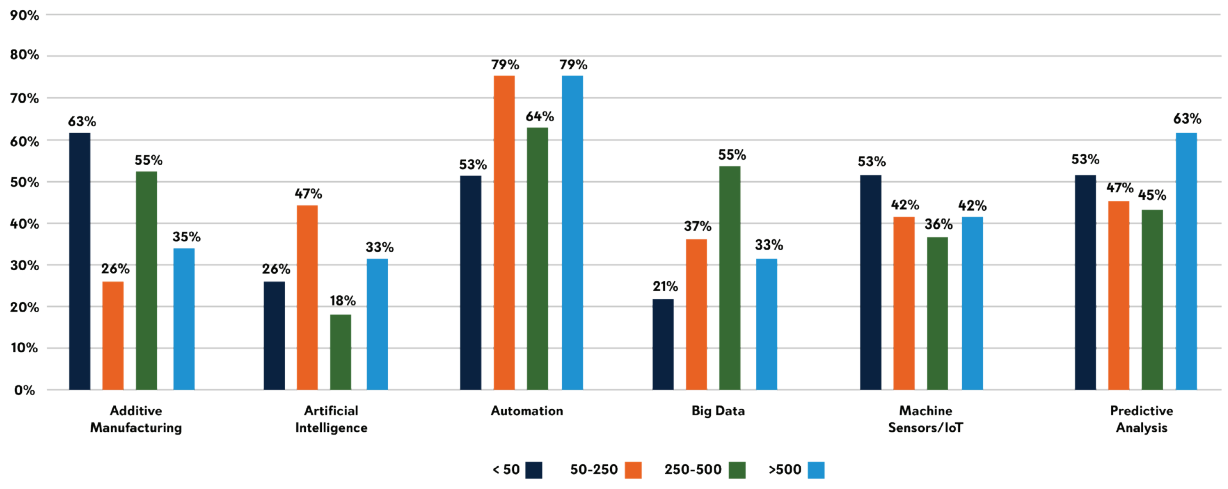


Figure 25: *Perceived Value of Technologies by Company Size*

See APPENDIX B – Adoption Comparison by Company Size, which compares technology adoption stages by company size (grouped by technology). As anticipated, for most technologies, adoption stages are further along the larger the company is.

See APPENDIX C – Adoption Comparison by Technology, which compares technology adoption stages by technology (grouped by company size). Manufacturing companies can use these charts to compare their technology adoption stage to their peers of similar company size.

Top Adoption Barriers by Company Size

Table 6: Top Adoption Barriers by Company Size, lists the top two adoption barriers for each technology by company size. This table can be used to identify and address technology adoption barriers for companies of various sizes.

	Additive Manufacturing (n=83)	AI (n=83)	Automation (n=82)
<50	Lack of Workforce Skill Set (22%) Lack of Business Cases & High Cost (15%)	Lack of Workforce Skill Set (27%) Lack of Business Cases (17%)	Lack of Workforce Skill Set (24%) Lack of Business Cases & High Cost (17%)
50-250	Lack of Workforce Skill Set (22%) Lack of Business Cases & Lack of Resources (18%)	Lack of Workforce Skill Set (25%) Lack of Awareness (19%)	Lack of Workforce Skill Set (27%) High Cost, Lack of Resources, & Lack of Workforce (17%)
250-500	Lack of Workforce Skill Set & Lack of Business Cases (21%)	Lack of Business Cases (33%) Lack of Awareness (26%)	Lack of Capital & High Cost (19%)
>500	Lack of Awareness (36%) Lack of Business Cases & Lack of Workforce Skill Set (15%)	Lack of Awareness (50%) Lack of Business Cases (23%)	Lack of Capital & High Cost (19%)

	Big Data (n=81)	Sensors/IoT (n=80)	Predictive Analytics (n=79)
<50	Lack of Workforce Skill Set (22%) Lack of Business Cases (19%)	Lack of Business Cases (22%) Lack of Workforce Skill Set (19%)	Lack of Business Cases (19%) Lack of Awareness (17%)
50-250	Lack of Awareness, Lack of Resources, & Lack of Workforce Skill Set (19%)	Lack of Workforce Skill Set (29%) Lack of Awareness, Lack of Resources, Lack of Workforce (14%)	Lack of Awareness & Lack of Workforce Skill Set (22%)
250-500	Lack of Peer Experience (22%) Lack of Workforce Skill Set (19%)	Lack of Business Cases (23%) Lack of Awareness (17%)	Lack of Workforce Skill Set (25%) Lack of Peer Experience (17%)
>500	Lack of Awareness (39%) Lack of Peer Experience (16%)	Lack of Awareness (47%) Lack of Business Cases, Lack of Peer Experience, & Lack of Workforce Skill Set (14%)	Lack of Awareness (46%) Lack of Workforce Skill Set (15%)

Table 6: *Top Adoption Barriers by Company Size*

Resources Used to Learn, Decide, and Implement Smart Technologies by Company Size

Table 7: Resources Used to Learn, Decide, and Implement Smart Technologies by Company Size, lists the top two resources used to learn, decide, and implement smart manufacturing technologies by company size. This table can be used by government, industry, and academia to increase the availability of the resources that manufacturers of varying company sizes use.

	Learn	Decide	Implement
<50	Peer Experience & Vendors (20%)	Vendors (24%) Peer Experience (21%)	Peer Experience (26%) Vendors (25%)
50-250	Peer Experience (22%) Business Articles & Vendors (20%)	Peer Experience (26%) Business Articles & Case Studies (17%)	Vendors (27%) Consultants (24%)
250-500	Case Studies & Vendors (23%)	Peer Experience (30%) Case Studies (22%)	Peer Experience (25%) Case Studies & Vendors (21%)
>500	Case Studies (23%) Peer Experience (21%)	Case Studies (25%) Peer Experience (21%)	Vendors (25%) Case Studies (21%)

Table 7: *Resources Used to Learn, Decide, and Implement Smart Technologies by Company Size (n=83)*

SMART MANUFACTURING ADOPTION SUCCESS IN SOUTH KOREA

The ICAMS team visited South Korea in July 2024 to learn more about the country's success in accelerating the adoption of smart manufacturing.

At the heart of the South Korean government's success is a highly focused and coordinated program that helps its manufacturing industries generate 26% of the country's Gross Domestic Product (GDP) [7]. The Ministry of SMEs (small and medium-sized enterprises) and Startups [8] is a cabinet-level organization responsible for industry policies and funding. In 2019, the organization created the Korea Smart Manufacturing Office (KOSMO), a department solely focused on manufacturing and responsible for achieving outstanding results.

KOSMO established and defined four "smart manufacturing" levels and set an objective of getting 30,000 of the country's manufacturers to at least a basic level by 2025. Executing this $414 million program, KOSMO surpassed that objective two years early. The program has now advanced to become the Manufacturing Innovation and Digital Transformation (DX) Acceleration Strategy, "MIDAS 2027", where they plan to have 25,000 manufacturers advance to a higher level of digital manufacturing and bring in 5,000 more manufacturers. This effort was bolstered by **establishing 19 demonstration centers where manufacturers can see smart technologies in operation** to better understand how they may help.

Additionally, **two fully outfitted Smart Manufacturing Innovation Centers (SMIC) were created,** providing modern tools and connectivity to serve as development and test beds for industry engagement. The availability of 600 manufacturing mentors, with another 400 being recruited, further strengthens this effort.

South Korea has a well-coordinated and robust effort to address workforce needs, beginning in high school and continuing through advanced degrees. A key requirement is that all those teaching manufacturing must come from manufacturing.

The findings from the ICAMS visit clearly show how South Korea's policies, practices, and investments have quantitatively raised the level of the country's manufacturing.

ANALYSIS

Finding #1: Artificial intelligence is gaining traction.

At a time when AI dominates news across all media, industry seems to be recognizing its value for manufacturing. While the perceived value of AI has changed little from the previous year, there is significant growth in various adoption stages of AI.

Over the past year, adoption at the awareness stage dropped from 37% to 25% this year, likely indicating that many respondents have moved on to the next phase. That would explain the growth in the research stage from 26% to 33%. Likewise, there was a drop from 23% to 14% in the evaluation stage, but there was a considerable jump in implementation from 8% to 20% this year.

The adoption barriers for AI have also changed over the past year. Lack of awareness saw a significant year-over-year drop of 5%, indicating that manufacturers are gaining a better understanding of what AI is. The lack of relevant business cases remains a significant barrier that may prevent manufacturing executives from understanding how AI might help their business. The most notable change in the barriers to AI adoption is the jump in the lack of workforce skill set from 14% to 21% this year. Even though manufacturers are gaining a better understanding of AI and the perceived demand is increasing, they cannot find employees who can implement it.

When examining the adoption of AI by company size, firms with 50-250 employees place a higher value on AI than the other size categories, and they have the greatest number of companies actively researching AI. Firms with 250-500 people are very active in the adoption process, with 36% at a lack of awareness, 27% actively researching, and 27% evaluating. Large firms with more than 500 people are the furthest along in AI adoption, with 23% implementing it and 14% using it.

Finding #2: Automation continues to lead in perceived value and level of adoption.

Automation still has the highest perceived value among this survey's six smart manufacturing technologies. Of all the respondents, 38% chose it as their #1 technology solution, and 72% chose it as one of their top three. No other technology comes close; predictive analytics is the nearest technology, with only 55% of respondents ranking it in their top three solutions. At a time when the manufacturing industry has nearly half a million unfilled jobs [9], there is a tremendous emphasis on reshoring additional manufacturing, and automation is seen as a solution to help overcome workforce challenges and remain globally competitive.

Automation is the most widely used smart manufacturing technology, with 37% of the survey respondents using it and most others in the later stages of adoption. The number of manufacturers using automation has grown steadily, with 30% in the first year, 34% in the second, and 37% in this most recent survey.

Barriers to automation adoption remain about the same, with the most significant barrier increase being over four percentage points for lack of workforce skill set, followed by a lack of resources, which increased from 8% to 11%. The only barriers that decreased were a lack of business cases and awareness, which dropped by two and five percentage points, respectively.

Automation adoption is relatively consistent across manufacturers of all sizes, with companies having 250-500 employees reporting the highest use at 55%. Small firms with less than 50 people report the lowest use at just 27%, although 32% report that they are evaluating automation.

Finding #3: South Korea excels at smart manufacturing adoption, providing key lessons and opportunities for the U.S.

South Korea boasts a program that is one of the best in the world at accelerating the adoption of smart manufacturing. The resulting quantitative success in reducing manufacturing costs and time while improving quality is leveraged for economic development. This program is a key factor in helping the manufacturing industries generate over 26% of the country's gross domestic product [7].

One of the key drivers of this success is the Ministry of SMEs (small and medium-sized enterprises) and Startups [8], a cabinet-level organization responsible for industry policies and funding. In 2019, it created the Korea Smart Manufacturing Office (KOSMO) [10], a department solely focused on manufacturing. It is responsible for the country's original goal of having 30,000 companies achieve a level one or two smart manufacturing rating. Easily surpassing that goal in 2022,

KOSMO launched the MIDAS 2027 policy, which aims to bring 25,000 factories to level 2 and 5,000 more to the digital manufacturing program.

A highly planned and coordinated workforce development program supports the focus on smart manufacturing. South Korea has established smart manufacturing paths for high school students, supported by universities. Many universities have opened departments dedicated to smart manufacturing. The country's equivalent of U.S. community colleges is heavily involved in manufacturing workforce development. One unique characteristic is that all professors teaching manufacturing must come from a manufacturing organization.

To address upskilling the existing workforce, KOSMO had more than 1,000 mentors with extensive manufacturing experience to help grow workforce skills and capabilities. South Korean companies are very focused on improving worker skills for new technologies.

South Korea is expanding its efforts through partnerships with countries like Germany to promote innovation and interoperability of Industrie 4.0 solutions [11]. With collaborations like this and an annual budget greater than $400 million, KOSMO has significantly increased the global competitiveness of its manufacturing industry. A full report from the ICAMS team on South Korea's efforts can be found here [12].

RECOMMENDATIONS

Recommendations for Government

The U.S. Department of Commerce, Department of Defense (DoD), and the National Institute of Standards and Technology (NIST) should immediately establish a collaborative partnership with South Korea's Ministry of SMEs and Startups. Doing so will help U.S. manufacturers understand and keep pace with South Korea's smart manufacturing advancements. The insights gained will also help inform U.S. decisions on policy, programs, and funding.

The U.S. government should provide financial assistance to help fund the implementation of automation. In addition to being an important solution to address workforce shortages, automation is a key enabler for the defense industrial base to handle an unexpected demand surge. In support of that effort, the government should launch a major education effort to upskill the existing manufacturing workforce in automation and AI.

Recommendations for Industry

The lack of business cases continues to be a stumbling block for adopting AI. While using AI is often considered a competitive advantage, large manufacturers should more openly share AI success with their supply chain. The use of AI by small and medium-sized manufacturers will help large companies realize even greater returns.

The ICAMS team again calls on industry associations to aggregate and disseminate relevant information. Industry associations are uniquely positioned as trusted third parties to aggregate, anonymize, and publish information that can help smaller manufacturers accelerate smart manufacturing adoption.

Industry associations should also do more to promote workforce opportunities, highlighting advanced working conditions and desirable career paths. Such programs should also tout the financial benefits of professional trades, which allow people to earn an income quickly without incurring significant debt.

Recommendations for Academia

The workforce challenges continue to hamper U.S. manufacturing. While the industry wrestles with attracting more individuals to enter the workforce, academia can considerably impact upskilling the existing workforce. The lack of workforce skills was a leading barrier to adopting each of the six smart manufacturing technologies. Academia should develop curricula for stackable and transferable credentials in each area. Such programs must be readily accessible by a regional workforce, which may require evening and weekend classes that will not interfere with work.

ACKNOWLEDGMENTS

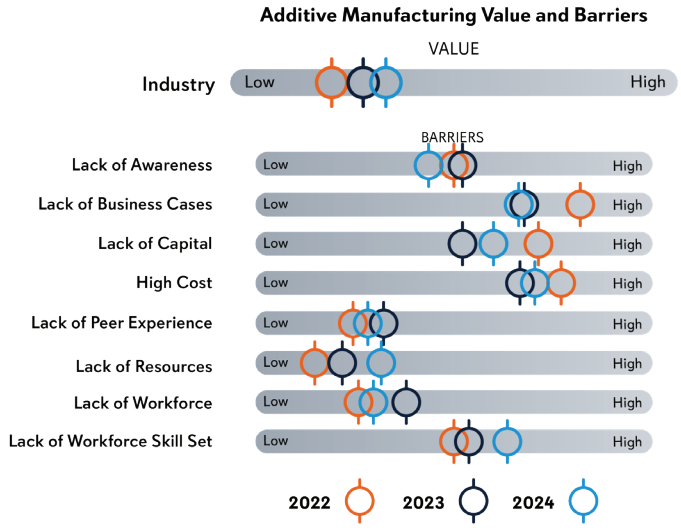
We would like to acknowledge the support and participation of the following in the execution of this research:

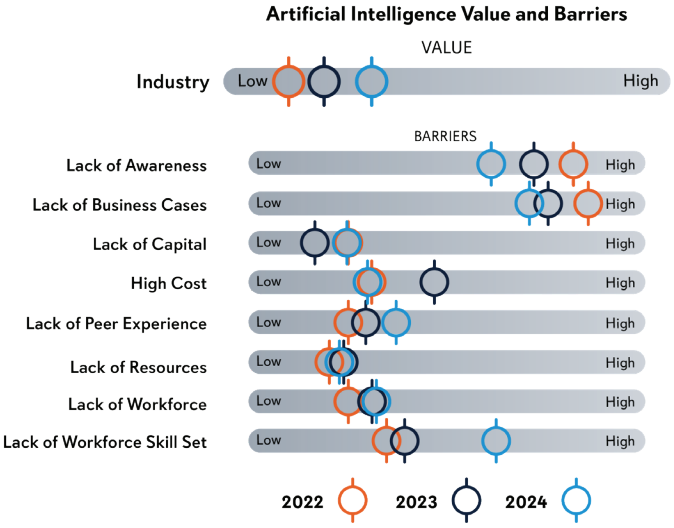
- America Makes
- Economic Development Partnership of Alabama (EDPA)
- Global Electronics Association (Formerly IPC)
- National Center for Defense Manufacturing and Machining (NCDMM)
- North Alabama Works Manufacturing Cluster
- Society of Manufacturing Engineers (SME)
- Steel Founders Society

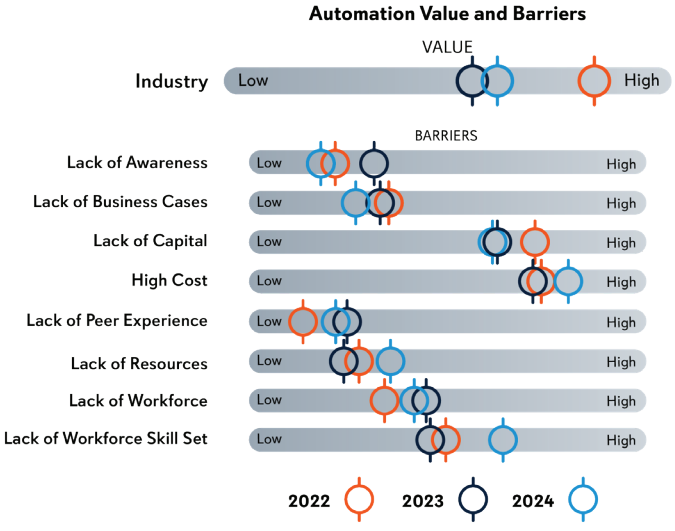
APPENDICES

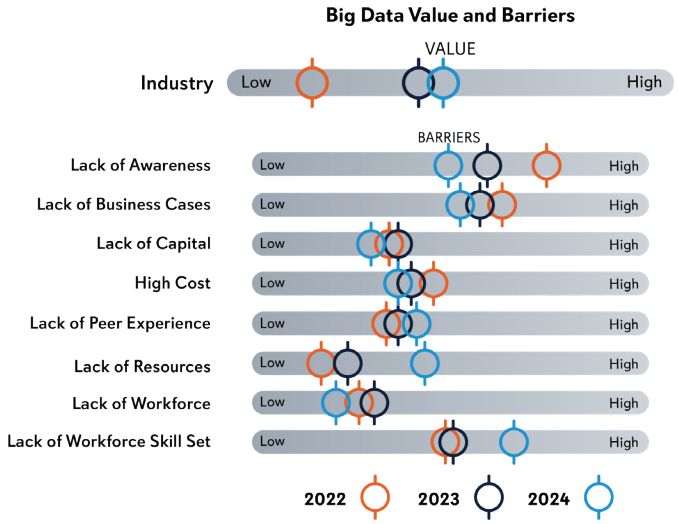
APPENDIX A – Technology Adoption Value and Barriers

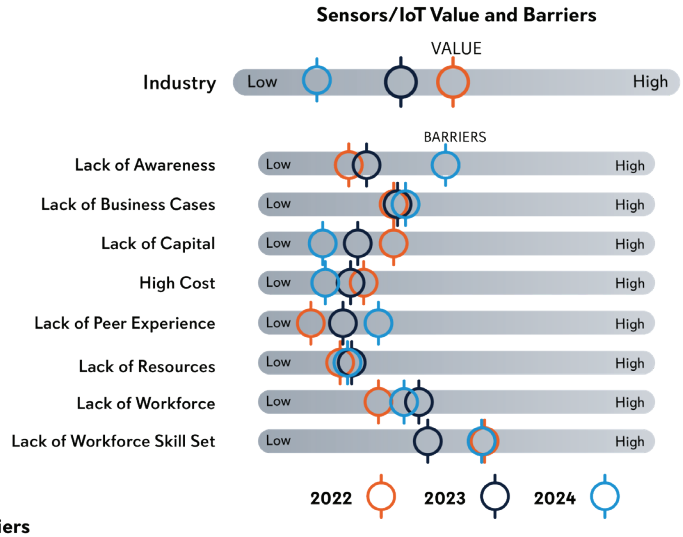
The following graphs compare the perceived value of a technology with its adoption barriers.
If the perception of value is high, respondents ranked the technology favorably as a technology that can help solve their business challenges. It is desirable for each barrier to be on the lower end.








Big Data Value and Barriers
VALUE
Industry
Low
High
BARRIERS
Lack of Awareness
Lack of Business Cases
Lack of Capital
High Cost
Lack of Peer Experience
Lack of Resources
Lack of Workforce
Lack of Workforce Skill Set
2022
2023
2024


Sensors/IoT Value and Barriers
VALUE
Industry
Low
High
BARRIERS
Lack of Awareness
Lack of Business Cases
Lack of Capital
High Cost
Lack of Peer Experience
Lack of Resources
Lack of Workforce
Lack of Workforce Skill Set
2022
2023
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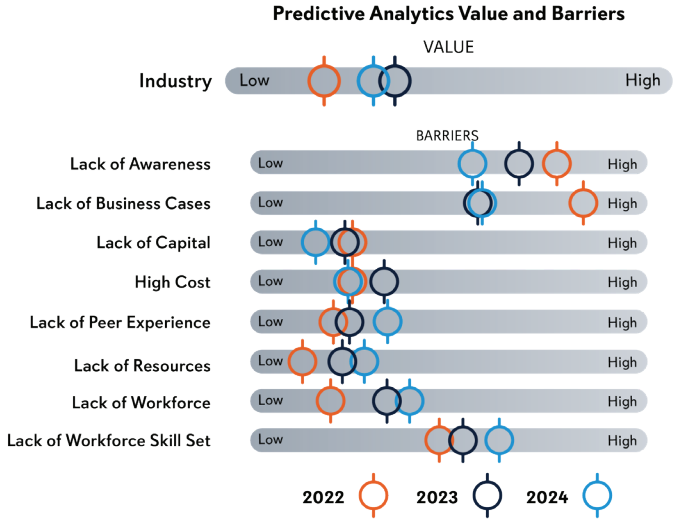
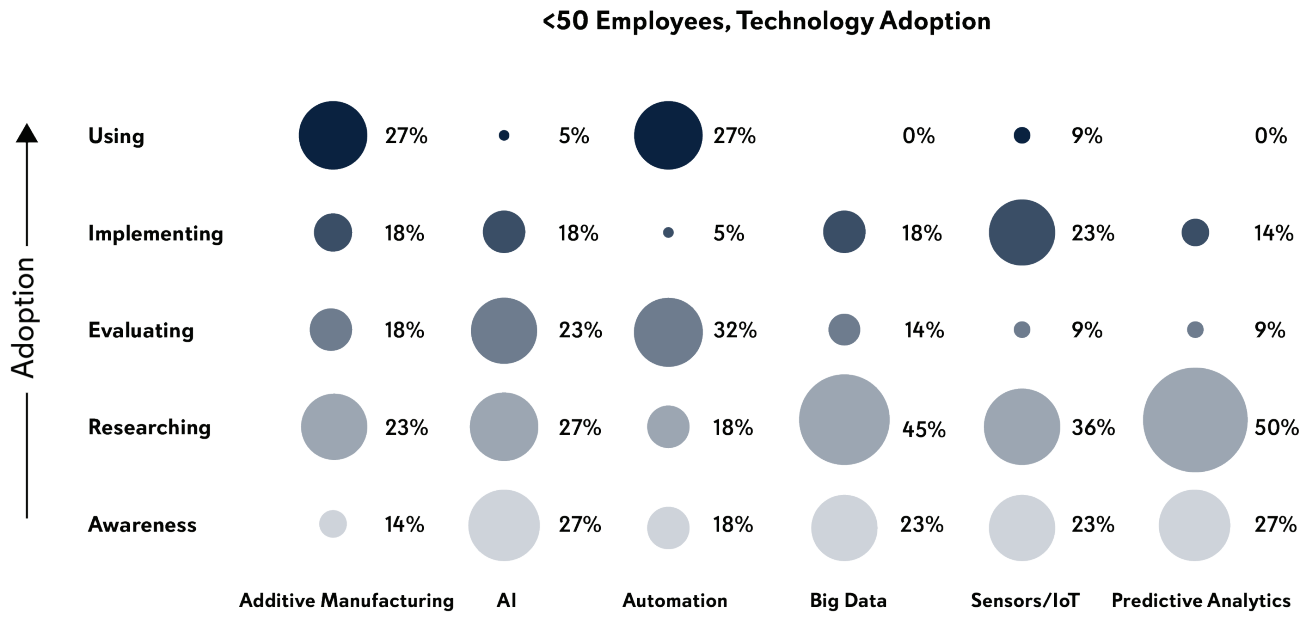
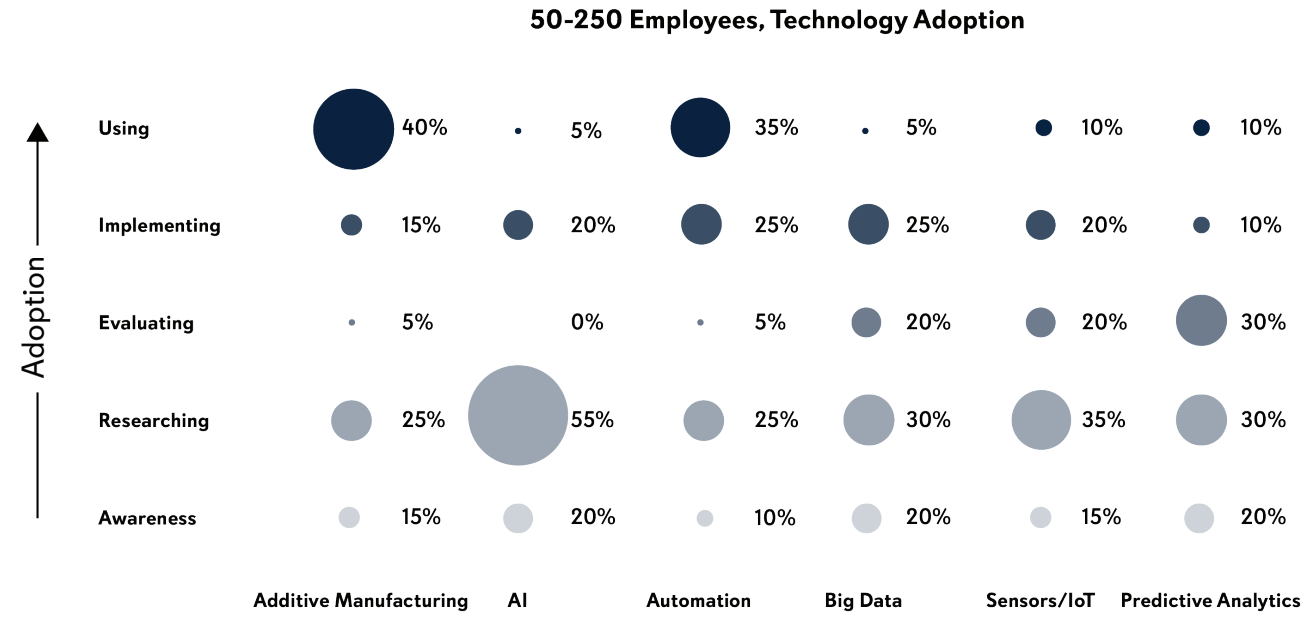
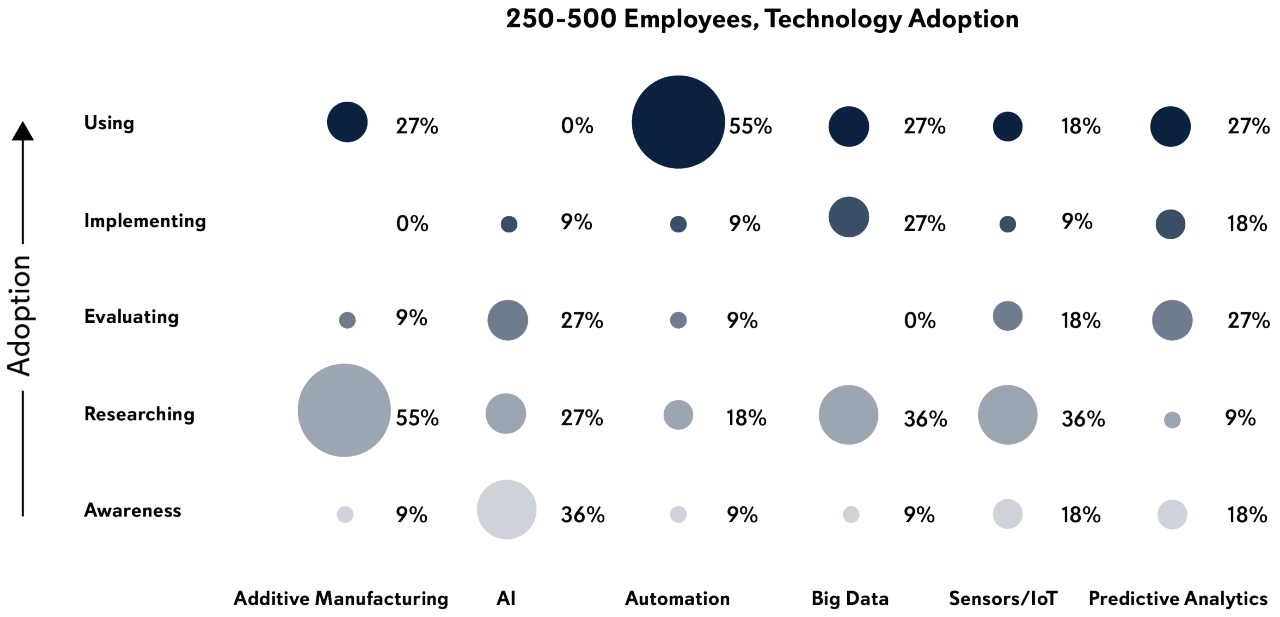

Predictive Analytics Value and Barriers
VALUE
Industry
Low
High
BARRIERS
Lack of Awareness
Lack of Business Cases
Lack of Capital
High Cost
Lack of Peer Experience
Lack of Resources
Lack of Workforce
Lack of Workforce Skill Set
2022
2023
2024

APPENDIX B – Adoption Comparison by Company Size

The following graphs are grouped by company size. The charts compare the adoption stages of the six smart manufacturing technologies by company size. Manufacturers can determine their adoption level of each technology and then use these graphs to compare their adoption progress with companies of similar size.






250-500 Employees, Technology Adoption
Adoption
Using
Implementing
Evaluating
Researching
Awareness
27%
0%
55%
27%
18%
27%
0%
9%
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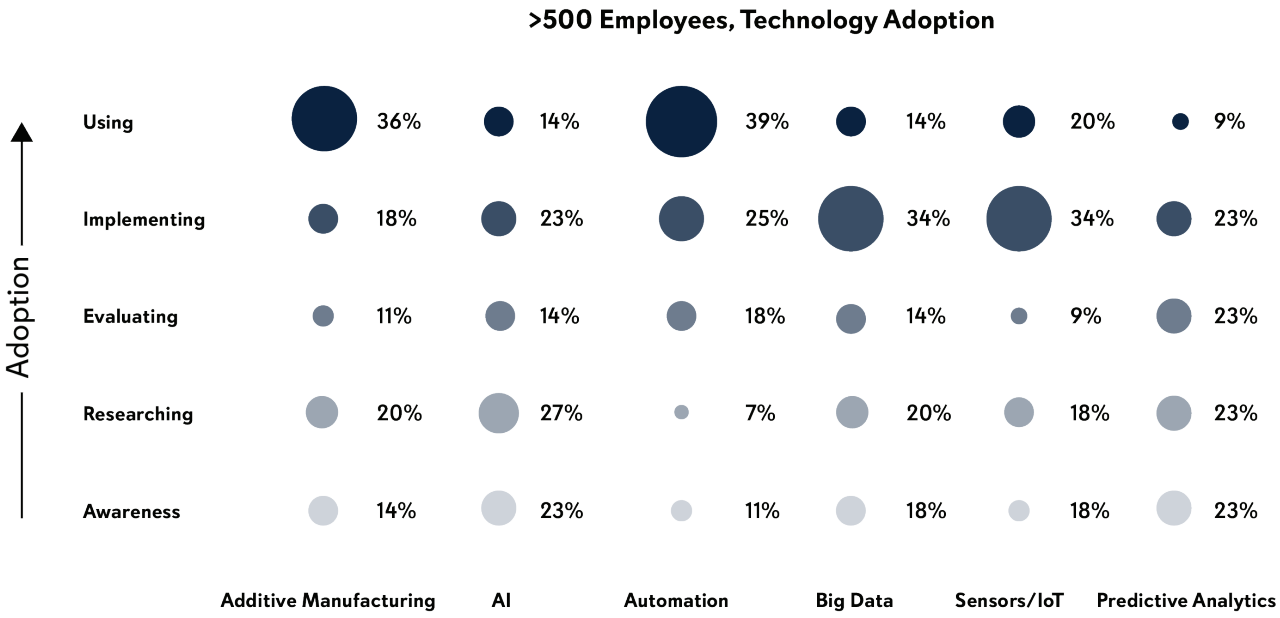
Additive Manufacturing
AI
Automation
Big Data
Sensors/IoT
Predictive Analytics


>500 Employees, Technology Adoption
Adoption
Using
Implementing
Evaluating
Researching
Awareness
36%
14%
39%
14%
20%
9%
18%
23%
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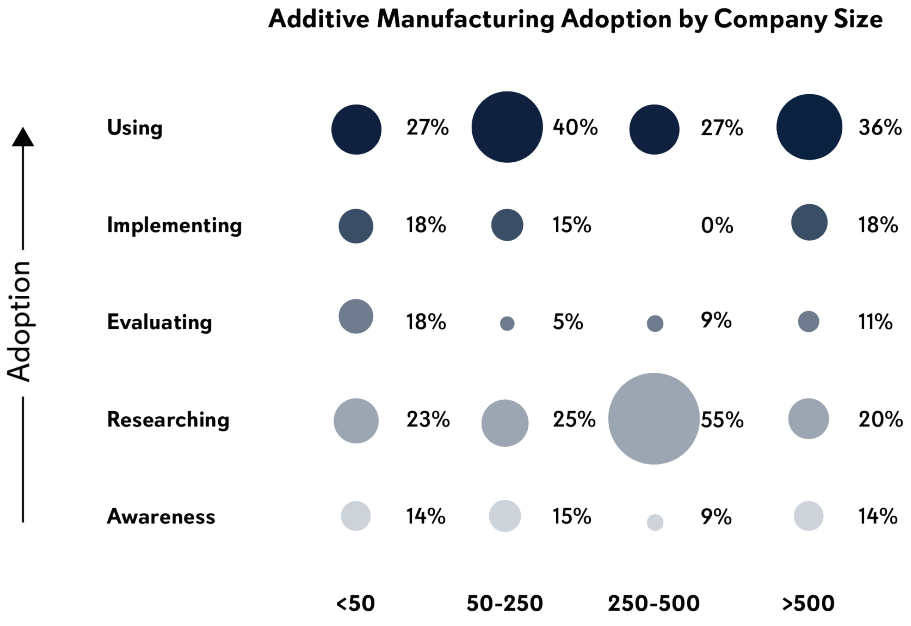
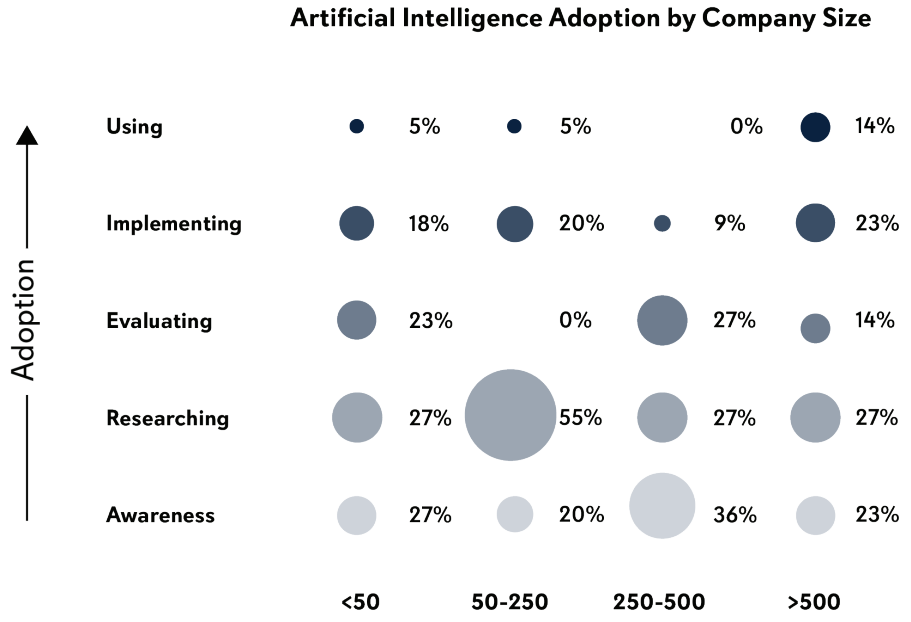
18%
23%
14%
23%
11%
18%
18%
23%
Additive Manufacturing
AI
Automation
Big Data
Sensors/IoT
Predictive Analytics

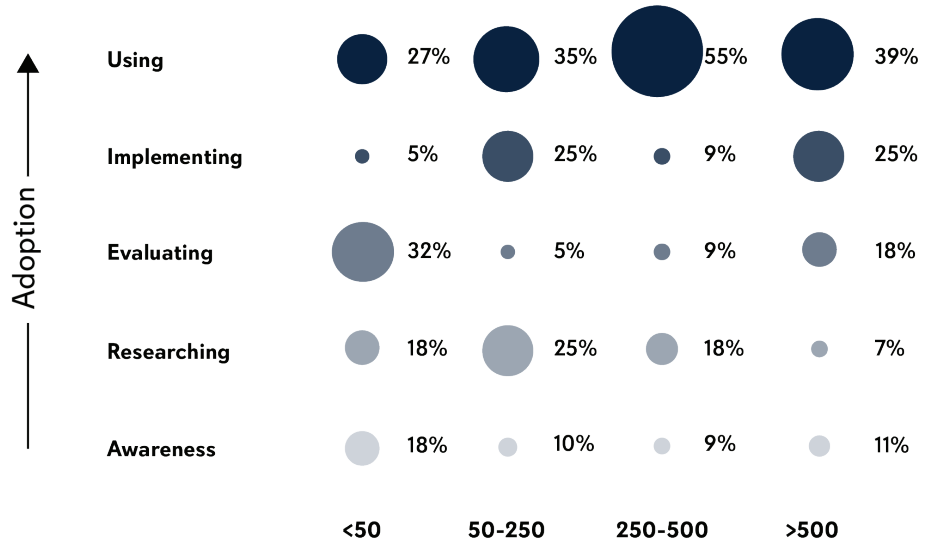
APPENDIX C – Adoption Comparison by Technology

The following graphs are grouped by technology. The charts compare the adoption stages of the six smart manufacturing technologies by each technology. This allows us to discern whether small and medium-sized manufacturers are behind in their technology adoption compared to companies of larger size

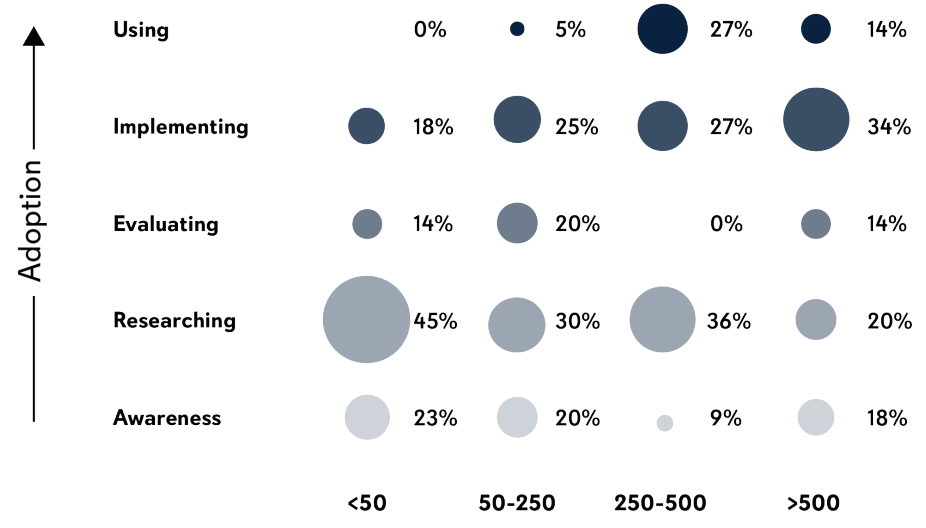




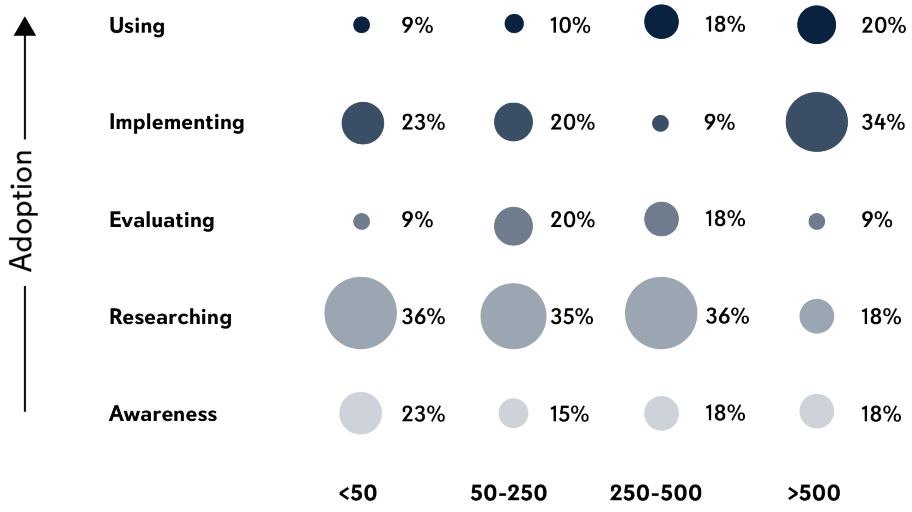
Automation Adoption by Company Size



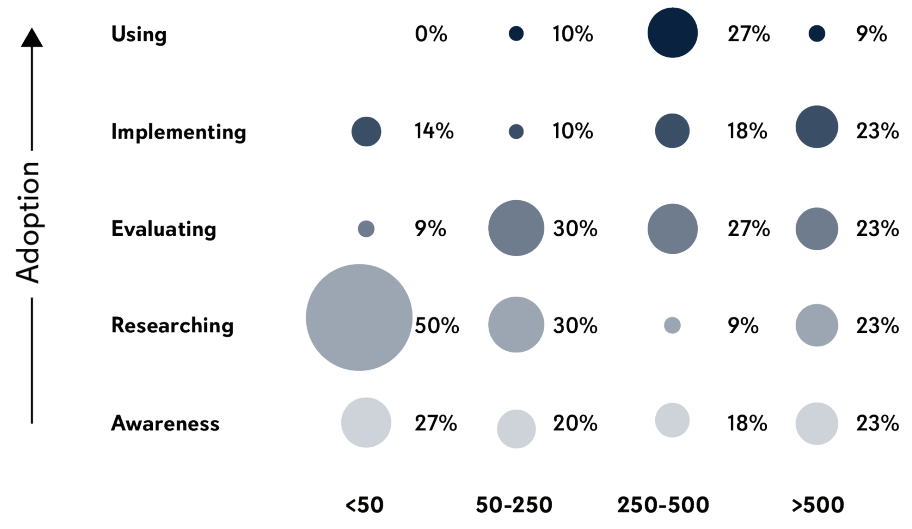
Big Data Adoption by Company Size



Sensors/IoT Adoption by Company Size



Predictive Analytics Adoption by Company Size



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