# Enabling Small and Medium Manufacturers to Adopt Smart Manufacturing

***Joy E. Pixley, Sabine Kunrath, Genoveva Paz, Richard Donovan, G. P. Li***
***University of California, Irvine***

**ABSTRACT**

Smart manufacturing is a framework for implementing smart technologies to optimize energy efficiency and productivity and to reduce waste, empowering workers and managers to improve decision-making. Research suggests that small and medium manufacturers (SMMs) face greater challenges to realize the potential of smart manufacturing than larger companies. However, little is known about how US SMMs view smart manufacturing and what their experiences have been with it, which is key to developing and implementing effective scaled-down solutions. The current paper presents survey findings for 54 owners and employees of US SMMs. Results show a limited level of readiness to adopt smart manufacturing, and that only 34% companies have begun implementing smart solutions and 26% would need to hire new employees. The top-most reported drivers of adoption were reducing costs (24%) and following a conscious strategy (15%), while the top-most barriers were the correlates: not having the time (26%) or money (22%) to invest. Although 20-30% reported already using smart solutions for specific tasks, even more felt smart solutions would help with those tasks, while a substantial minority were satisfied with how well low-tech solutions worked for certain tasks. The technologies the most subjects reported using are cybersecurity, big data and analytics, and tablets, but many others were currently used or considered by a smaller subset. Overall, variations in evaluations of certain solutions support the idea that SMMs can benefit from targeting their relatively limited resources on specific technologies for specific needs rather than embracing the full spectrum of smart manufacturing.

## Introduction

The manufacturing industry in the United States provides an invaluable basis for research, development, innovation, productivity, and job creation: it generates more economic activity than any other sector (Scott 2015) and has a large impact on the overall US economy (Manyika et al. 2021). Manufacturing is also highly energy intensive (Brueske et al. 2012). When accounting for both direct emissions from the manufacturing processes and indirect emissions from the associated electricity use, the industrial sector was the largest contributor of greenhouse gases of any sector, with almost 29% in 2018 (U.S. Environmental Protection Agency 2020). This makes the manufacturing sector a prime target to address unnecessary energy and process inefficiencies as they are impacting US manufacturers' productivity, with consequences for their economic health, competitiveness, and the environment (Brueske et al. 2012, Nimbalkar et al. 2017).

Emerging smart technologies can help to decrease production costs, enhance energy productivity, conserve finite energy resources, and reduce greenhouse gas emissions (Nimbalkar et al. 2017). Using smart technologies can facilitate more efficient use of materials by reducing production errors and subsequent losses and optimizing workflow overall (Intergovernmental Panel on Climate Change 2014).

Smart manufacturing is a framework for implementing smart technologies to optimize energy efficiency, productivity, and to reduce waste. The introduction of smart manufacturing has been equated with the Fourth Industrial Revolution and is commonly seen as a means for manufacturers to stay competitive in a global market (Manufacturing Policy Initiative 2019, Brune 2019, National Science & Technology Council 2018). The terms “smart manufacturing”, “Industrie/Industry 4.0”, and “Industrial Internet of Things" (IIoT) are often used interchangeably (Ezell et al. 2018). The American Council for an Energy-Efficient Economy states that smart manufacturing is defined by the integration of all aspects of manufacturing through Information and Communication Technologies (Rogers 2014). The goal is to optimize performance and data-driven, “smart” decision-making by providing actionable information (MEP National Network 2018, Nimbalkar et al. 2017, Gallaher et al. 2016). The definition presented to subjects in the current survey is the following: Smart manufacturing is the practice of using information about the manufacturing processes when and where it is needed, and in the form that it is needed, by people and machines (Davis et al. 2015, MEP National Network 2018).

Large manufacturing companies worldwide have been in the process of adopting this smart manufacturing approach and have reimagined their business models to capitalize on the benefits of executing this manufacturing framework; as a result, they have gained a competitive advantage in the globalized market by improving productivity, product quality, reducing costs and adding data-based services (Xu, Xu, and Li 2018, Erol, Schumacher, and Sihn 2016, Kagermann, Wahlster, and Helbig 2013). Those emerging smart technologies may also be able benefit small and medium manufacturers (SMMs) with a tailored approach (Xu, Xu, and Li 2018). However, there is a concern that SMMs are not able to leverage smart manufacturing technologies to the same extent as large companies (Sommer 2015): Smart manufacturing technologies are mostly made for large manufacturers by large corporations, making this technology less applicable and too expensive for SMMs (Radziwon et al. 2014). It is generally recognized that SMMs face specific financial, technical, and organizational constraints that may hinder innovation in general and specifically the adoption of smart manufacturing practices (Mittal et al. 2018). There is a concern not just about the implementation cost of IoT technologies (Rogers 2014), but also about the energy cost of operating these devices and networks (Dwyer and Bassa 2018), and even more so for SMMs. Most manufacturers in the US are small to medium enterprises, employing fewer than 500 people. In 2016, SMMs made up about 98.5% of the almost 250,000 manufacturing firms; of these, 58% employed more than five people (United States Census Bureau 2018).

Relatively little data is available about the perspectives of US SMMs on smart manufacturing. In the US, surveys have been conducted by consulting firms or interest groups, but these focus on larger and already engaged manufacturers (see for example Accenture 2016, Industry of Things World USA 2017, BSquare 2017, Lorenz et al. 2016); when they include smaller manufacturers, results are rarely presented stratified by enterprise size (see for example Advanced Manufacturing Media 2015, Sikich 2017, Morton et al. 2020). Only a few academic survey studies assessed the status of implementation and uptake of specific technologies and the perspective of SMMs regarding the drivers and barriers of smart manufacturing in the US. Wuest et al. (2017) surveyed 54 manufacturers, 70% of which were SMMs with up to 499 employees, to give an overview about smart manufacturing in West Virginia. The results showed that the surveyed manufacturers had little knowledge of smart manufacturing. While almost 60% said that they had heard the term, there was little understanding of smart manufacturing technologies and applications. From accompanying interviews, the authors concluded that smaller companies have less awareness about this topic and that those companies that are interested in the topic are in the early phases of transitioning to smart manufacturing. Most companies did not have dedicated financial and/or human resources to help with the transition, highlighting the needs for programs to support SMMs. The initial cost of these new technologies and a mind-set that does not embrace new technologies acted as a major barrier (Wuest et al. 2017). Bosman, Hartman, and Sutherland (2020) assessed how the size (less than 20 employees or 20 to 499 employees) and access to financial means (sales less than $10 million or equal or greater than $10 million) of 138 Indiana SMMs influence the investment decisions for smart manufacturing technologies. The survey found that smaller SMMs and/or SMMs with less available funds prioritize the enhancement of digital factory floor technologies whereas larger SMMs prioritize technologies that supports other operations, such as sales, accounting, and logistics.

Other academic research about smart manufacturing implementation and barriers specifically in SMMs has been conducted in countries as diverse as Denmark (Stentoft et al. 2020), New Zealand (Hamzeh, Zhong, and Xu 2018), Peru (Huang, Talla Chicoma, and Huang 2019), Turkey (Sevinç, Gür, and Eren 2018), and Romania (Türkeș et al. 2019). Differences across countries in policy, law, and economics and the characteristics of SMMs necessarily limit the conclusions that can be drawn for SMMs in the US. The goal of this study was to assess systematically the state of smart manufacturing for SMMs across the US. Specifically, the survey looked at:

- how prepared SMMs are to adopt smart manufacturing technologies,
- which tasks could be improved with new technologies,
- which specific smart technologies and connected strategies are already being used,
- which specific benefits and barriers SMMs perceive for these technologies, and
- how have workers reacted to specific technologies.

This paper presents survey results for the individual owners and employees of small and medium manufacturers. The study is part of a larger CESMII project on smart manufacturing in SMMs funded by the US Department of Energy.

## Methods

To get a comprehensive picture of how US SMMs perceive the benefits and challenges of smart manufacturing, what the status of adoption is, and whether these SMMs are willing and feel ready to adopt these technologies, we first reviewed the questions and results of prior surveys to build upon.

We conducted a thorough review of national and international survey studies about smart manufacturing. We identified the studies through searches in literature databases. Additionally, we searched the reference lists of existing publications and the table of contents of special editions of journals and recent books. Last, we searched web pages of governmental organizations (e.g., the National Institute of Standards), industry and interest groups (e.g., Plataine) and consulting firms (e.g., Boston Consulting Group). We then designed a survey based on key questions from prior surveys that replicated exact wording whenever appropriate. In addition, we consulted with experts to construct a list of twenty specific smart manufacturing technologies, then designed questions to assess whether they have been considered, used, and/or discontinued in SMMs. One version of the question set was designed to capture the experiences and opinions of SMM owners and employees. A second version rephrased the questions to apply to consultants who work with multiple SMMs. All questions allow for “don’t know” and “prefer not to answer” responses to avoid forcing uninformed guesses. For the rare questions where more than a few subjects chose these responses, that is considered a finding and is discussed; otherwise they are omitted from analyses of that question.

Subjects were recruited via the national MEP network between November 2020 and March 2021. The recruitment plan involved sending recruitment materials to regional MEP Center leaders across the country who were asked to include them in regular email newsletters. However, monitoring revealed that few of these networks actually sent regular email newsletters, and few of those that did complied with requests to include recruitment announcements despite repeated requests from MEP representatives. As a result, sample size was substantially smaller than expected, and heavily skewed toward California subjects, as the California MEP director assisted with recruitment efforts. The survey was conducted online on the Qualtrics survey platform. As an incentive, subjects were offered the chance to win one of three randomly selected lottery prizes: Visa gift cards worth $500, $300, and $200. Subjects were deemed eligible if they were 18 or older and owned, worked for, or were a consultant for SMMs. Statistical analyses were conducted using SAS 9.4.

Current analyses focus on individual representatives of SMMs (owners or employees). To manage survey length, after the key questions were asked, subjects were thanks for completing the main survey and asked if they would be willing to answer some more questions. Surveys are considered complete for the 54 individual-level subjects who reached this branching question, although additional analyses are conducted on the 45 subjects who answered the supplementary questions.

## Results

### Subject Characteristics

The subjects are younger than a representative sample of adults, largely due to the presence of young production workers. Of the 54 subjects, 48% are 25 to 34 years old, compared to 11-15% each in the categories of 18-24, 35-44, 45-54, and 55-64. Subjects identified their current position in the company, which was collapsed into four categories to facilitate analyses. Management (n = 19, 35%) includes “owner”, “upper manager (president, CEO, VP)”, and “middle manager (supervise people and processes)”. Administrative (n = 7, 13%) includes “administrative worker (purchasing, marketing, clerical).” Expert (n = 14, 26%) includes “technical expert (engineer, scientist, IT, or R&D)” and “operations manager (manage facility, machines, operators).” Worker (n = 14, 25%) includes “production worker (operate machines, assemble product).” Given how few administrative workers were captured in the sample, they are not included in separate employment category analyses, although their answers are included in overall results. The rationale was to separate management, who would presumably know more about executive decisions, major investments, and costs, from production workers, who would presumably know more about what technology is actually used (or needed) on the factory floor. Technical experts and operations managers offer a useful midline view, presumably knowing more about the technology being employed across the range of workers and manufacturing processes than either management or workers. Finally, employees in administrative positions may range widely in knowledge of the company’s operations and products, but are unlikely to have either the big picture view of management or the technical understanding of the experts and workers. Of course, assumptions about knowledge areas and expertise may not apply equally to all members of these groups, particularly given the small and nonrepresentative sample. As explained in the methods section, almost half (48%) of subjects are from California. The other subjects are scattered across 21 other states, with only one or two subjects from each state.

Manufacturing companies were defined as being "small to medium" if they had fewer than 500 employees. Of the companies represented by this sample, 17% have 1 to 19 employees, 57% have 20 to 99, and 26% have 100 to 499. Industry type categories were drawn from the North American Industry Classification System (Office of Management and Budget 2017); subjects vary widely across these types. The largest groups are food manufacturing, with 10 subjects (19%), and textile and textile product mills (15%). Fifteen other categories include one to five subjects each, with the larger including apparel manufacturing, leather and allied products, wood products, fabricated metal products, and computer and electronic products.

**Readiness and Need to Implement**

One major question in this study, as with other studies of SMMs, is how prepared companies are to implement smart manufacturing solutions and the extent to which they have already adopted some measures. One measure of readiness uses seven items based on the Industry 4.0 Readiness Index (Stentoft et al. 2020) (see Table 1). The items were slightly modified to correspond to the rest of our survey. The question used a five-level Likert scale from strongly agree to strongly disagree (coded so that higher numbers indicate higher agreement). Results show a mean of 3.8 (s.d., 0.7), just below "somewhat agree." Average responses were similar across items. There were no differences in readiness score across employment categories. This level of perceived readiness is somewhat higher than the scale mean of 2.95 (s.d., 0.7) reported in the previous study (Stentoft et al. 2020). Additional readiness items are also shown in Table 1, and show similarly high perceptions of management's understanding of and willingness to implement smart manufacturing technology. There was somewhat lower agreement that the company was already using that technology, however.

Table 1. Mean for Readiness Index and Individual Measures

| | Mean | s.d. |
|---|---|---|
| Readiness Index | 3.82 | 0.77 |
| Management pressured to work with SM | 3.70 | 1.01 |
| Management willing to take risks to experiment | 3.87 | 1.03 |
| Management has necessary knowledge about SM | 3.91 | 1.10 |
| Company has support from top management | 3.98 | 1.08 |
| Employees have right competencies | 3.79 | 1.12 |
| Employees have right motivation | 3.74 | 1.01 |
| Company has economic freedom | 3.72 | 1.13 |
| Management has clear concept of technology | 3.81 | 0.98 |
| Management has clear concept of potential | 4.00 | 0.84 |
| Management willing to implement near future | 3.98 | 0.91 |
| Company already using SM | 3.61 | 1.19 |
| N | 53 | |

Two other measures of readiness level include a question on how prepared the company is to introduce new technologies, and whether the existing employees have sufficient skills (see Table 2). Subjects report a wide range of preparation levels for their companies. About one in three (33%) say the company has a clear business case, with another third reporting that their companies are more prepared than this, about one in four reporting their companies are less prepared. A relatively large minority (compared to other questions) say they don't know or choose not to answer, which is especially surprising among the manager category. The variation across employment categories is not statistically significant. A study of larger US and German manufacturers (annual revenue of more than 50 million) by the Boston Consulting Group (Lorenz et al. 2016) showed that about 5 years ago, only 3% of the sampled US manufacturers had the full Industry 4.0 concept in implementation and 41% identified their company as not yet prepared. The largest share (29%) had developed first concepts.

A frequent worry is that the skillset needed for smart manufacturing cannot be met with the existing workforce. As shown in Table 2, few subjects believe their company's existing employees have the skills needed to adapt to smart manufacturing technology. The majority (63%) believe that their workers could adapt if given a little training, but one in four believe the company would need to hire new workers. These perceptions are quite similar across employment categories.

Table 2. Preparation Level Measures

| Questions and answer choices | All | Manager | Expert | Worker |
|---|---|---|---|---|
| *How prepared is your company to introduce new technologies for smart manufacturing?* | | | | |
| Full concept in implementation | 15% | 21% | 7% | 7% |
| Implemented first measures | 19% | 5% | 29% | 36% |
| Developed clear business case | 33% | 26% | 29% | 36% |
| Developed first concepts | 15% | 11% | 29% | 14% |
| Not prepared | 11% | 21% | 7% | 0% |
| Don't know | 6% | 11% | 0% | 7% |
| Prefer not to answer | 2% | 5% | 0% | 0% |
| | | | | |
| *What best describes the skill level of the workers in your company?* | | | | |
| Existing employees have enough skills to adapt to new technology | 11% | 11% | 7% | 14% |
| Existing employees could adapt to new technology with a little training | 63% | 63% | 57% | 64% |
| Existing employees would find it significantly difficult to adapt to new technology, so there would be a need to hire new people | 26% | 26% | 36% | 21% |
| N | 54* | 19 | 14 | 14 |

* Total includes administrative category.

Another aspect of readiness is the extent to which the company is already using digital processes. This question was asked in the supplementary section. The results suggest that while few see their companies as still paper intensive, managers believe their companies are less digitalized than experts and workers, although these differences are not statistically significant. Morton et al. (2020) report the results for this question from a 2018 and 2020 survey conducted with a mix of small, medium, and large manufacturers. In 2018, 21% of the surveyed manufacturers called themselves paper intensive, while in the 2020 sample the share had decreased to 16% (note that this was not a longitudinal study and thus the proportions are not directly comparable). The proportion claiming to be fully digital did not increase greatly from 2018 to 2020 (from 2% to 6%) but the proportion who said they were mostly digital increased from 24% to 35%. In our sample, only 11% called themselves paper intensive and 36% describe themselves as fully digital and automated, which may indicate that the respondents answering this question represent a group of SMMs that are rather engaged in smart manufacturing.

Table 3. Digitalization Level of Company

| Level | All | Manager | Expert | Worker |
|---|---|---|---|---|
| Paper intensive | 11% | 13% | 17% | 8% |
| Moving toward digitization | 33% | 47% | 25% | 25% |
| Mostly digital | 16% | 13% | 8% | 8% |
| Fully digital and automated | 36% | 20% | 50% | 58% |
| Don't know | 4% | 7% | 0% | 0% |
| N | 45* | 15 | 12 | 12 |

* Total includes administrative category.

A related question is the extent to which companies have sufficient incentive to upgrade to smart technologies for any specific tasks or processes. Lower-tech approaches can be effective, especially at the smaller scale of SMMs. If companies are not experiencing productivity problems that would be noticeably improved by new technology, the investment of time and money would not be worth it.

Subjects were asked directly whether they thought smart technology would help with specific tasks or whether they thought that traditional, lower-tech solutions, such as paperwork on clipboards, would work equally fine. The tasks are listed in Figure 1, sorted by the percent of subjects who said that the task would benefit from new technology. For two of these tasks—assigning jobs or tasks and communicating with third parties—more subjects reported that the existing low-tech solutions worked fine than reported that newer technology would be beneficial. About one-third of subjects also said that internal communication worked fine using low-tech methods. Also notable is that about one-third said that they were already using smart technology for completing timesheets, accessing data (such as temperature readings), and inputting information into job or task-related forms. However, smart solutions were more often seen as beneficial (and less often used) for analyzing data (e.g., about machines, process, or personnel), accessing job or task-related information, and managing stock.

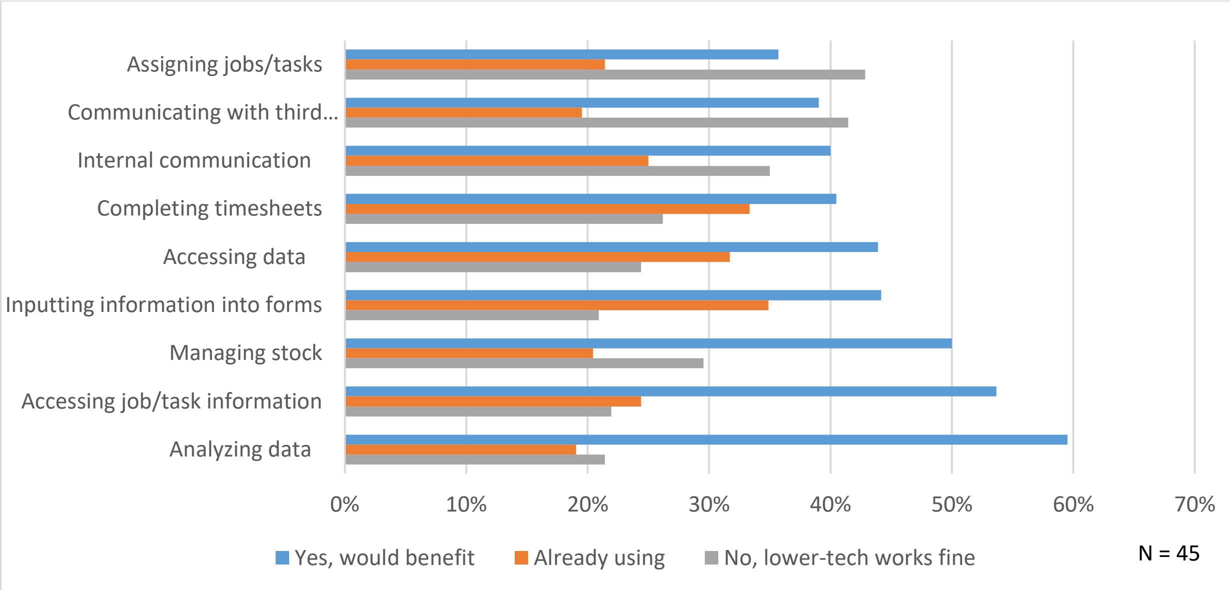


Figure 1. Tasks that Could Benefit from Smart Manufacturing Solutions

The productivity problems that a company faces provide a key incentive to adopting new solutions for those tasks or issues. One way of looking at productivity problems that might be solved with new technology is to assess where inefficient outcomes are observed in the production process. Based on the productivity ("waste") problems identified in lean management (Caldera, Desha, and Dawes 2019), subjects were asked which waste stream issues have the strongest negative impact on productivity for their company. They were allowed to select up to three. Nine percent said they didn't know or chose to give no answer. Of those who gave valid answers, one said "none", 37% marked one issue, 10% marked two, and 51% marked the maximum of three. Lack of training (e.g., delays while waiting for skilled worker) was cited most frequently (37%), followed by 26% for not utilizing talent (e.g., trained workers doing less-skilled tasks), 22% for delays while waiting for earlier processes to complete, 20% for losing batches due to defects. Storing too much inventory, overproduction, and transportation problems such as slow arrival of goods were all mentioned by at least 1 in 6 subjects.

Subjects were also asked in the supplementary part of the survey how often the company faced "significant productivity issues" due to a list of problems with how tasks are done, such as sharing information or using tools (see Figure 2). Response options were always, often, sometimes, rarely, and never, These tasks were at least sometimes a problem for 49% to 78% percent of subjects, and often or always a problem for 18% to 36%. Having to do tasks manually (e.g., on paper) and having to wait for information needed for the job or task were reported most frequently as problematic.

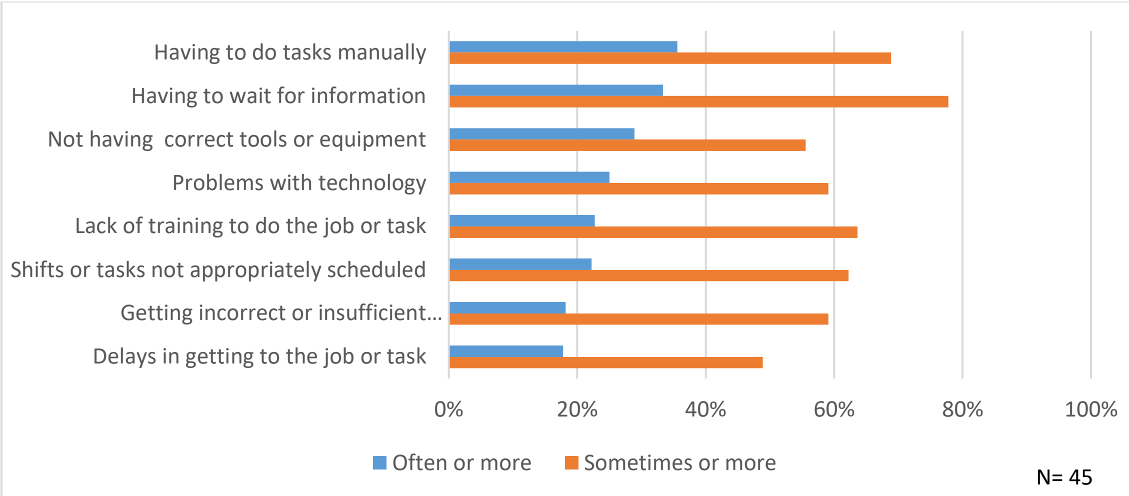


Figure 2. Productivity Problems (n=44)

## Perceived Drivers and Barriers

One driver for adopting smart manufacturing is the perceived benefits. Subjects were offered ten potential drivers (see Figure 3) and asked what they saw as the most critical factors driving their company to implement smart technologies. They were allowed to select up to three, and to write their own answers into an "other" category. The 72% of subjects who chose more than one driver were then asked to narrow down the top-most factor. The most frequently cited of these drivers was to reduce costs, followed by having a conscious strategy on smart manufacturing. Lowering costs emerges consistently as the top driver in numerous other survey studies (Hamzeh, Zhong, and Xu 2018, Morton et al. 2020, Stentoft et al. 2020, Türkeș et al. 2019). The relative importance of other drivers varies and may be influenced by the choices presented to the respondents. In two European studies that used mostly the same categories as the authors, the desire to improve time-to-market (Stentoft et al. 2020, Türkeș et al. 2019), and having a conscious strategy on smart manufacturing (Stentoft et al. 2020) were the top drivers.

As with drivers, barriers are influenced by perceptions of anticipated problems, such as the difficulty or costs of the solution. Subjects were offered eleven potential barriers (see Figure 4) and asked what they saw as the most critical barriers to implementing smart manufacturing for their company; they were allowed to select up to three options and to write their own answers into an "other" category. The 80% of subjects who chose more than one barrier were then asked to narrow down the top-most critical barrier.

The most frequently cited of these barriers was investment of time, marked by 26% of subjects as the most critical barrier and by another 4% as in their top three. Costs, or investment of funds, was identified as the most critical barrier by slightly fewer subjects (22%) but mentioned by another 19% as among their top three. Only uncertainty about what the effect would be on company profits came close to costs in terms of being mentioned in the top three (39% v. 43%), but few subjects chose it as the most critical barrier. Several other reasons show a similar pattern, with as many as one in four subjects choosing them as one of the top three, but fewer than half that many selecting it as the top barrier. The ratio for the item "lack of qualified employees" is especially high, and telling: a fairly large proportion of subjects believe this is a problem (enough to include it as second or third most important), but almost none believe it is the single most important problem. Overall, technical concerns (e.g., equipment availability, connectivity standards, or network bandwidth) seem to play an inferior role compared to financial and organizational concerns. Hamzeh, Zhong, and Xu (2018) report similar results for their sample of 43 New Zealand SMMs: 66% report that the additional investment of funds and/or securing the funding poses a challenge, followed by the challenge of the additional time needed (41%) and the lack of access to people with the right skills (38%). By comparison, only seventeen percent mentioned the availability of the right equipment or software as challenge.

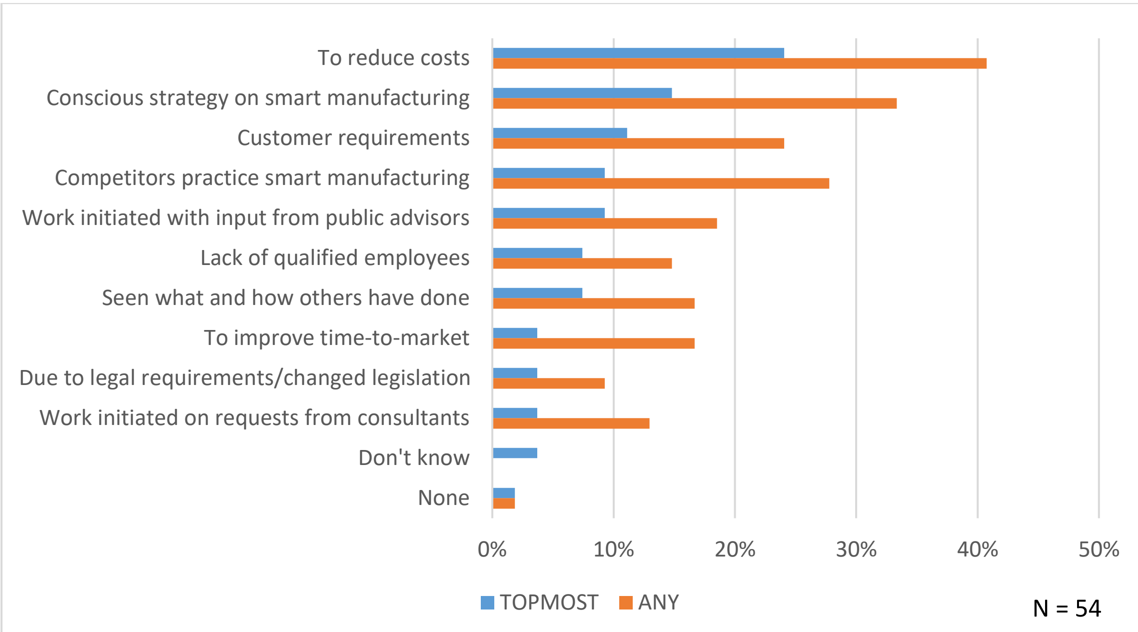


Figure 3. Perceived Drivers for Subject's Company to Adopt Smart Manufacturing

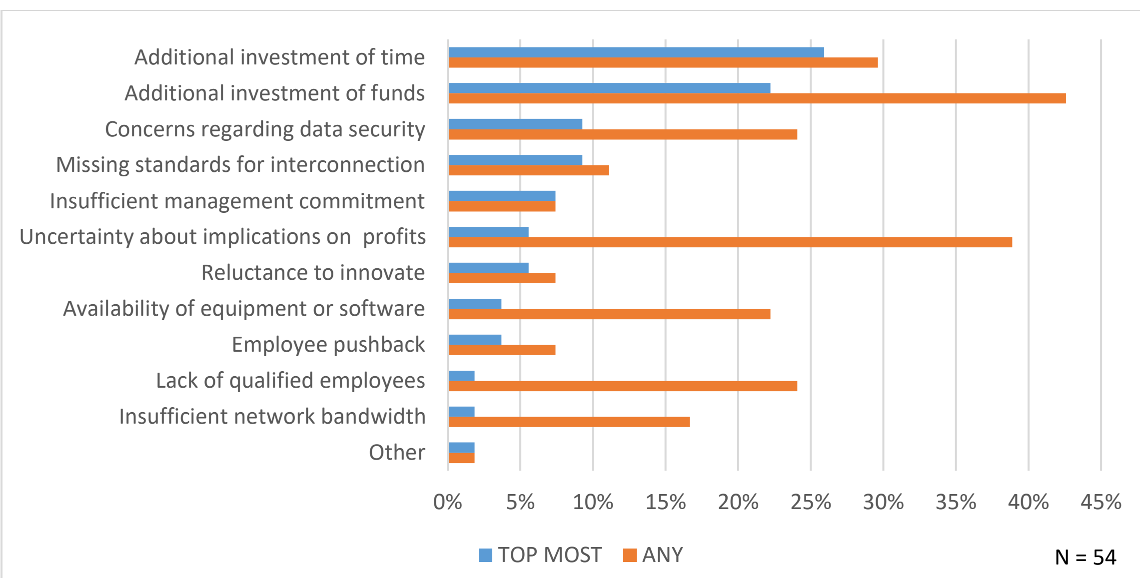


Figure 4. Perceived Barriers to Subject's Company Adopting Smart Manufacturing

### Experience with Specific Smart Manufacturing Technologies

One of the main purposes of this study was to determine which specific smart manufacturing solutions SMMs already had deployed, as well as which ones they had tried or considered and decided against. The survey offered a choice of twenty technologies and asked if they were being used in subjects' companies "as part of a smart manufacturing solution." Subjects who reported that a given technology type was not currently used in their companies were asked whether that technology had ever been implemented but was later discontinued due to problems with it, or if the company had seriously considered implementing the technology but decided against it based on expected problems. The combined results of these two questions are shown in Figure 5.

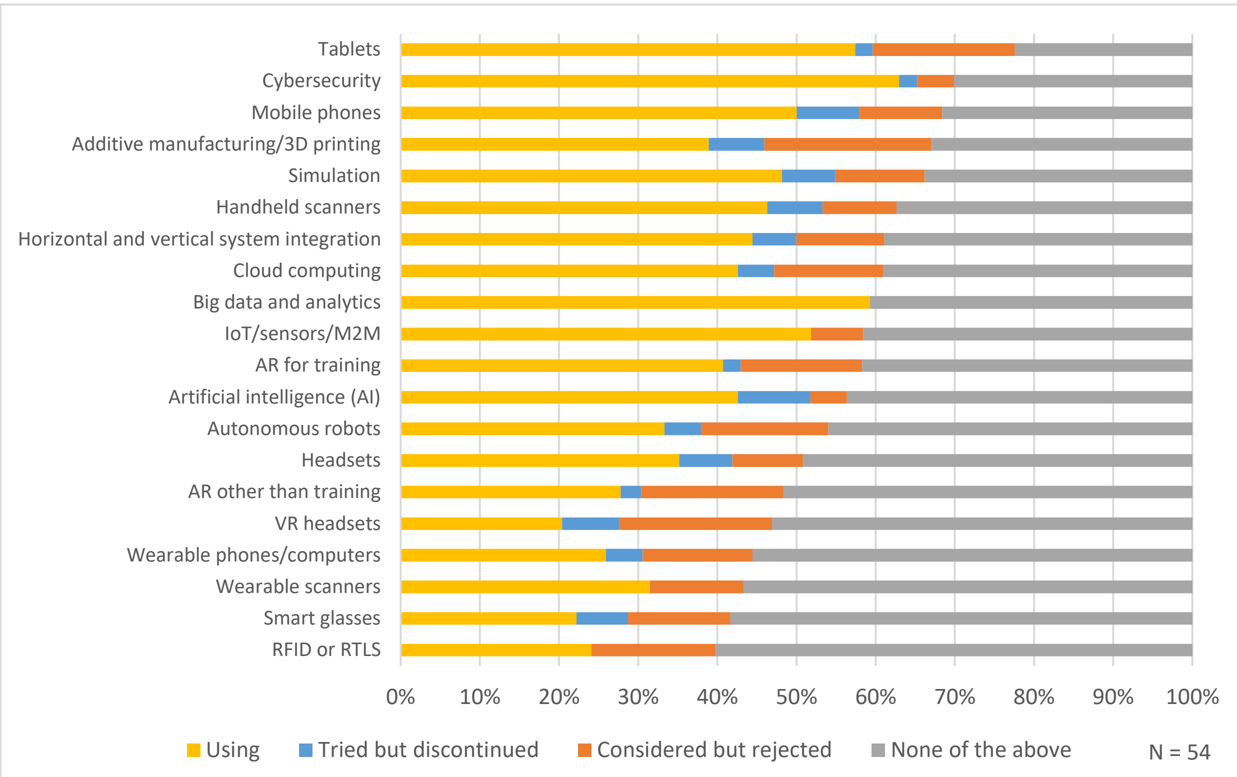


Figure 5. Current and Past Use of Technology Types

The primary take-away is which technologies are most commonly used, with cyber-security, big data and analytics, and tablets not surprisingly in the lead, and IoT sensors (and machine-to-machine communications) and mobile phones close behind. The results do not indicate a clear group of popular solutions and a clear group of less-used solutions, but rather a gradual decline all the way from almost two-thirds in use to only about one in five for the lowest ranked, including VR headsets, smart glasses, and radio-frequency identification (RFID) and/or real-time locating system (RTLS) technologies. Cybersecurity also emerged as the most-applied technology in other survey studies (Sarı, Güleş, and Yiğitol 2020, Stentoft et al. 2020, Yu and Schweisfurth 2020); for other technologies the order differed, which may indicate the sampling of different industries or geographical differences.

Several technologies had been discontinued by more than 5% of the companies represented, led by artificial intelligence and mobile phones (used specifically for smart manufacturing solutions). The technology most often considered for use in smart manufacturing but later rejected was additive manufacturing/3D printing (21%), with tablets, AR and VR types, autonomous robots, and RFID close behind. In total, 33% of subjects reported their companies discontinued at least one smart manufacturing solution (with half of these reporting at least two) and 59% reported seriously considering but rejecting at least one solution (with half of these reporting at least three). No significant differences were observed by employment category.

### Pros and Cons of Specific Technologies

For each smart manufacturing technology type subjects reported using in their company, they were asked for the most significant "pro" and "con" of that technology, based on their experience with it. The response options are shown in Figure 6 for pros and Figure 7 for cons. In both figures, the technology types are sorted by how many subjects reported using them in their companies (see Figure 5), from lowest to highest. Note that the subsample answering for each technology is limited to those who reported that their company uses the technology.

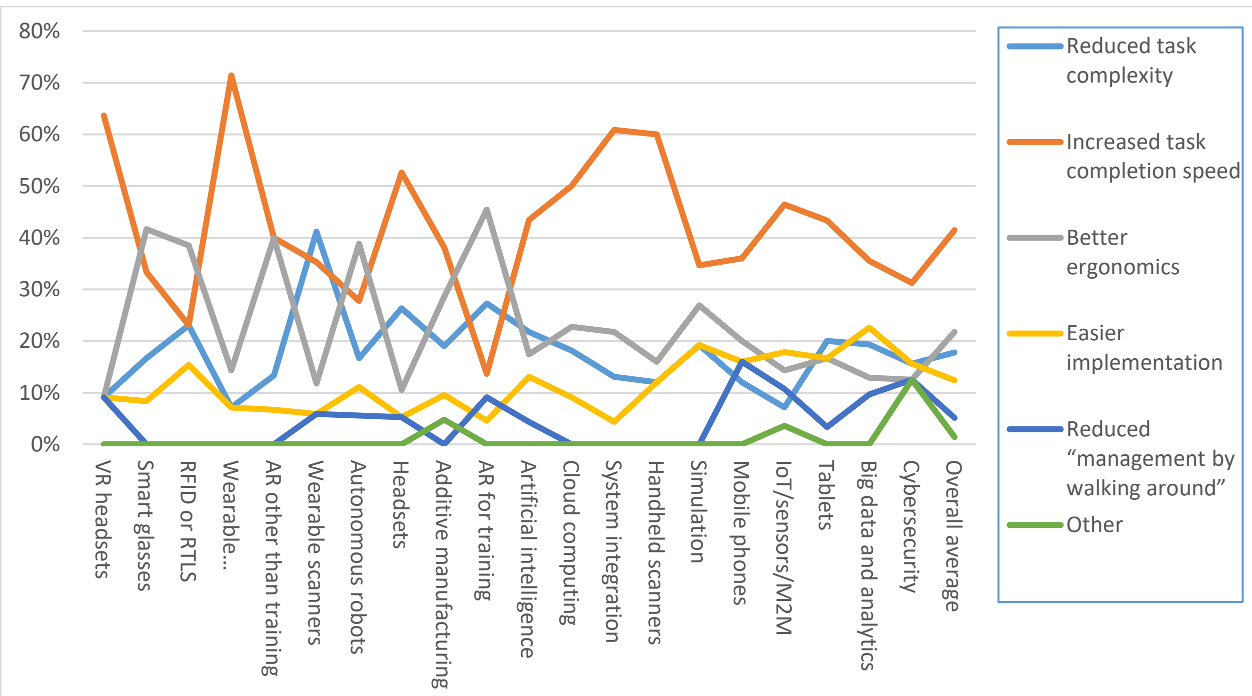


Figure 6. Perceived Pros of Specific Technology Types

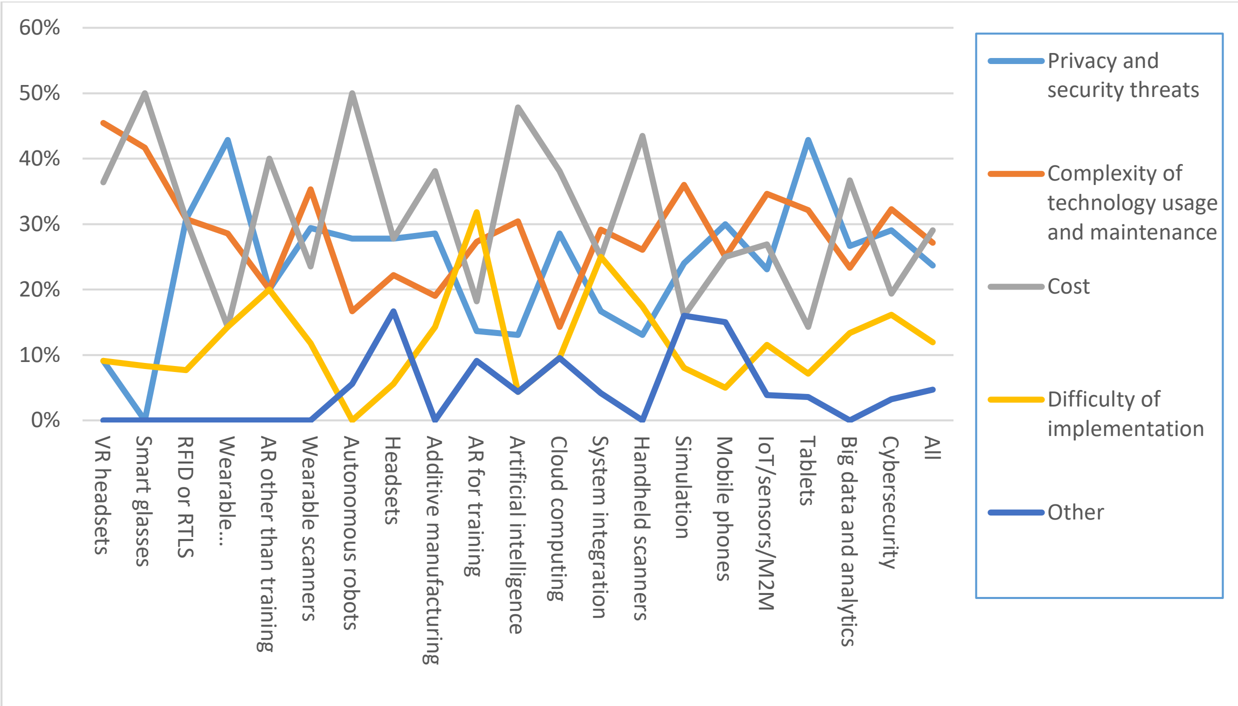


Figure 7. Perceived Cons of Specific Technology Types

Looking first at the pros of each technology, increased task completion speed is endorsed by more subjects than other options for most of the technologies, including all of the most-often used ones (to the right of the figure). Improved ergonomics also does well for several technologies, including smart glasses, AR, and autonomous robots. It does less well for VR headsets and wearable mobile phones/computers, although this doesn't mean they don't also provide better ergonomics, only that task completion speed is more important. Reduced task complexity was the most often mentioned pro for wearable scanners, and second-most for headsets, AR for training, and tablets. Easier implementation was selected as the main pro by a small minority of subjects for every technology type, although both were mentioned somewhat more often for the most used technologies, such as cybersecurity, tablets, big data and analysis. Reducing 'management by walking around' was cited as the primary pro only 5% of the time on average.

### Worker Reactions

Subjects who reported that their companies had implemented specific new technologies were asked how most workers reacted, overall. Almost nobody reported strongly negative reactions to technology, with the exception of autonomous robots. However, many types of technology received somewhat negative or mixed or neutral reactions and the only technologies that reached 50% strong positive support were mobile phones, tablets, smart glasses, and cyber-security. This is potentially problematic, given the importance of enthusiastic worker cooperation to the success of implementing smart manufacturing solutions. Moreover, problems in the human–machine interaction can result in work-related stress (Körner et al. 2019).

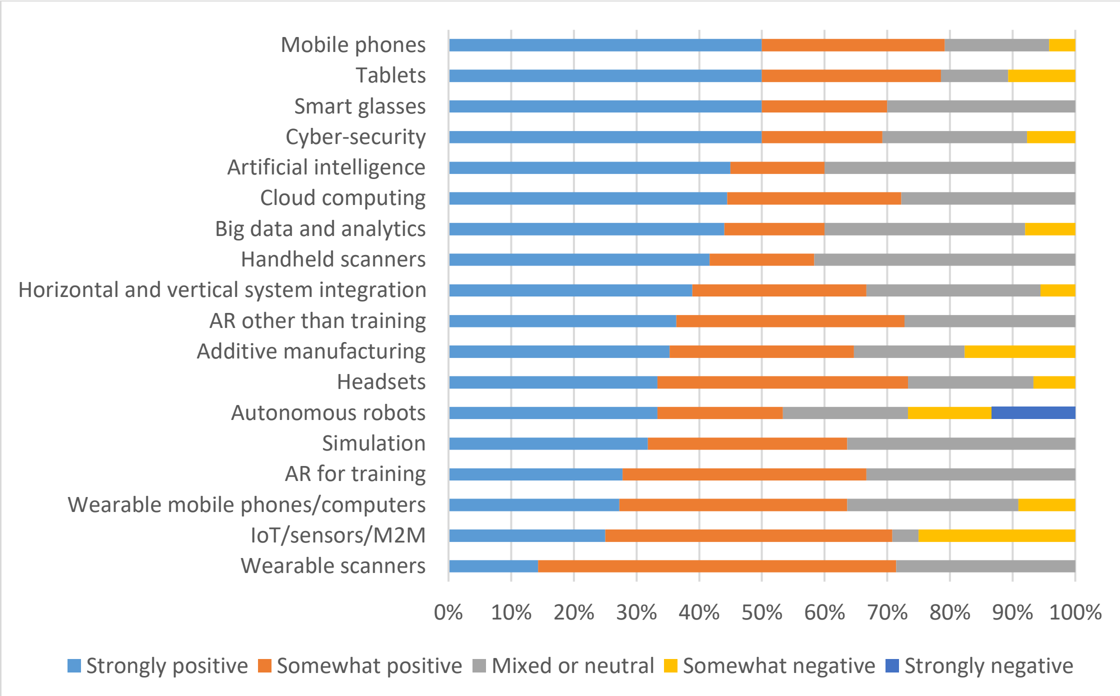


Figure 8. Perceived Workers' Reaction when Smart Manufacturing Technology was Implemented

## Conclusion

These results replicate key findings of other studies as well as add new findings. Although the sample size is not large, it is still one of the largest quantitative surveys of small and medium manufacturers (SMMs) in the United States. It thus helps to quantify previously generalized knowledge and also give insights into how small and medium American companies compare to prior studies of large American manufacturers and smaller European manufacturers. Results confirm that few SMMs have fully implemented smart manufacturing (15%) and most have not even implemented first measures (66%). However, it is promising that many companies consider themselves either fully or mostly digitalized, with only 11% described as still paper intensive and 33% as moving toward digitalization. By comparison, the West Virginia study showed that only 14% of the respondents were working to adopt smart manufacturing practices in their operations (Wuest et al. 2017). Likewise, the current subjects feel their companies are, on average, more ready than the companies in a similar study to embrace smart manufacturing technologies (Stentoft et al. 2020). Still, most subjects expect that current employees would need additional training to be able to adapt to smart technology (63%) and one in four subjects anticipate having to hire new, more skilled workers (26%).

For these overall measures, the current study indicates a higher level of readiness to adopt smart manufacturing technologies than was found in earlier studies of SMMs. This could suggest recent advances in awareness about smart manufacturing, and that SMMs have taken more steps towards implementation. However, it could also be due to varying ideas of what counts as smart manufacturing, digitalization, and related terms. Another possibility is that the sample is biased toward SMMs that are more advanced than others, possibly due to being recruited through the NIST Manufacturing Extension Partnership (MEP) centers, which may indicate a higher level of engagement with new initiatives on the manufacturers' part. However, smart manufacturing is not yet a major initiative of the MEP network, which was a major impetus for conducting the current study. Also, it is worth noting that although about half the sample is from California, and California is known for technology leadership, subjects from California did not display significantly higher readiness scores than others.

This study goes beyond general readiness level measures and gives insight into specific applications for smart manufacturing. Between 20% and 30% of subjects reported their companies as already using smart manufacturing solutions for specific tasks such as assigning jobs or tasks, internal communication, timesheets, inputting information into forms, managing stock, and accessing task information. For all the tasks asked about, more subjects felt that smart manufacturing would help than reported already using such technology. A substantial minority of subjects reported being satisfied with how well low-tech solutions worked, particularly for assigning jobs or tasks, communicating with third parties, internal communication, and managing stock. It is important to remember that not all solutions should be sought simply because they are smart: SMMs need to concentrate their relatively limited resources on adopting only those solutions that solve their specific needs.

To help determine those special needs, the survey asked about productivity problems. The three types of tasks with the most subjects saying they faced significant productivity issues "often" (or more) were: having to do tasks manually, having to wait for information, and not having the correct tools or equipment. Lack of training caused productivity issues for over half the sample at least "sometimes" and in another question, lack of training was mentioned most often (37%) as a waste stream issue having the strongest negative impact on productivity. Non-utilized talent (trained workers doing less skilled work) was the second most mentioned waste stream issue. Both were much higher than production line problems such as overproduction, transportation, and inventory problems, highlighting the importance of coordinating human resources in any smart manufacturing solution.

The topmost perceived driver for adopting smart manufacturing was to reduce costs (24%), followed by being driven by a conscious internal strategy that supported smart manufacturing (15%). The corollary is that the topmost perceived barriers to adopting smart manufacturing were the additional investment of time (26%) and money (22%). Since constructing a conscious internal strategy takes time and labor that most SMMs can't spare, these two findings illustrate the essential challenge faced by SMMs: they don't have the time and money they'd need to invest in order to make better use of their time and save more money.

The study also makes a unique contribution by addressing experiences with and attitudes toward twenty major smart manufacturing technology types that SMMs might use. The technologies the most subjects reported using are cybersecurity, big data and analytics, and tablets, but many other technology types are used by at least a third of the subjects' companies.

For technology types not currently being used in the subjects' companies, 33% reported trying and discontinuing at least one of them, while 59% reported that their company seriously considered adopting at least one smart technology but decided against it because of anticipated problems. Many of the technologies considered and rejected were the same ones currently being used by many other subjects' companies, such as tablets, reflecting their ubiquity rather than their likelihood of rejection. More concerning are the technologies that companies tried and rejected, nine of which were reported by more than 5% of subjects (ranging from 6%-9%): mobile phones, additive manufacturing/3D printing, simulation, handhold scanners, system integration, artificial intelligence, headsets, VR headsets, and smart glasses. This is another important insight, that technologies that may work well for some companies (especially larger ones) may not work for SMMs.

Subjects were also asked about the pros and cons they experienced with the technology types currently being used in their companies. By far the most commonly mentioned main pro, especially for the technologies used by the most companies, was increased task speed. Reduced complexity and improved ergonomics were also highly rated for certain technologies. There was more variation in the main cons of these technologies, with no single problem dominating across all types: cost, complexity of use and maintenance, and privacy and security threats were all high for certain technologies and lower for others.

Another challenge for adopting new technology is engaging workers. For technologies used by subjects' companies, they were asked how negative or positive workers' reaction were, overall. Only one technology type received a strongly negative reaction from more than 10% of workers: autonomous robots. On average, subjects reported that half or even two-thirds of workers were at least somewhat positive for most technologies. However, given the importance of enthusiastic worker buy-in, the low levels of strongly positive reactions for many of these technologies and the substantial minorities of mixed or somewhat negative reactions raises concerns. These findings reinforce the importance of bringing workers to the table in discussions of technology development, both to educate and learn from them, and of considering how new solutions will affect employees at all levels.

SMMs potentially benefit from smart technologies, but they face serious challenges when adopting this digital transition. Overall, these results support the idea that SMMs, probably even more so than larger companies with more flexible resources, should focus their decision-making on specific technologies for specific needs rather than embracing the full spectrum of smart manufacturing at once. More research is needed to gain a better understanding of where US SMMS are in their transition to smart manufacturing and what problems they have that specific new technology can address. This study further adds to this research by asking about companies' experiences with specific technologies. These results will inform the development of technological solutions that are affordable and easily adaptable for SMMs.

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