Preparing the manufacturing workforce for Industry 4.0 technology implementation

Dr. Sheng-Jen Hsieh, Texas A&M University

Dr. Sheng-Jen ("Tony") Hsieh is a Professor in the Department of Engineering Technology and Industrial Distribution and a member of the Graduate Faculty at Texas A&M University. His research interests include automation, robotics, cyber-manufacturing and Industry 4.0; optical/infrared imaging and instrumentation; micro/nano manufacturing; and design of technology for engineering education. He is also the Director of the Rockwell Automation Laboratory at Texas A&M University, a state-of-the-art facility for education and research in the areas of automation, robotics, and Industry 4.0 systems. He was named Honorary International Chair Professor for National Taipei University of Technology in Taipei, Taiwan, for 2015-21. Dr. Hsieh received his Ph.D. in Industrial Engineering from Texas Tech University, Lubbock, TX.

Dr. Marilyn Barger, FLATE (Florida Advanced Technological Education Center of Excellence)

Dr. Marilyn Barger is the Senior Educational Advisor of FLATE, the Florida Advanced Technological Education Center, part of the FloridaMakes Network. FloridaMakes is the NIST Manufacturing Extension Partnership (MEP) Center in Florida, but previously FLATE was founded and funded by the National Science Foundations Advanced Technological Education (NSF-ATE) as a Regional Center of Excellence. FLATE's mission is to support manufacturing education in K-14 programs through outreach, professional development, curriculum reform and technician research. She earned a Ph.D. in Civil Engineering/Environmental from the University of South Florida and served on the Engineering faculty at Hofstra University and the FSU-FAMU College of Engineering. Dr. Barger has authored over 50 papers for presentations on engineering and technology education, serves on several national advisory boards for CTE and workforce education initiatives, and is a Fellow of the American Society of Engineering Education (ASEE) and the American Institute of Medical and Biological Engineering (AIMBE). Dr. Barger holds a licensed patent and is a licensed Professional Engineer in Florida.

Ms. Suzy Gorospes Marzano, Society of Manufacturing Engineers
Dr. Juan Song, Alamo Colleges District

Dr. Juan Song is Corporate Account Executive in Alamo College at San Antonio, TX. She oversees secondary and post-secondary training in manufacturing and liaison between Alamo College and manufacture partners.

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As information technology has become robust and mature, developed countries such as Germany have advanced the concept of the Fourth Industrial Revolution, often referred to as Industry 4.0 [1]. The intent is to integrate design, manufacturing, and consumer activities seamlessly to increase productivity, reliability and customer satisfaction. An Industry 4.0 manufacturing system—also called a cyber physical production system (CPPS)—integrates Internet of Things (IoT), Internet of Services (IoS, or also called Cloud Computing) and cyber-physical system (CPS) technologies [2]. These changes will profoundly impact manufacturing work and workers.

Industry 4.0 is projected to add $2.2 trillion to domestic GDP by 2025. The estimated maximum value of the operational transformation brought by Industry 4.0 to the global manufacturing industry is $3.7 trillion dollars per year. To remain competitive, manufacturers need to be able to rapidly adapt to changing markets, which requires having a well-prepared workforce. It has been reported that 27% of manufacturers are not able to expand their production due to lack of a properly skilled workforce. This challenge is exacerbated by a declining, experienced baby-boomer workforce, with an estimated 10,000 boomers retiring each day through 2029.

Industry 4.0 is projected to add $2.2 trillion to domestic GDP by 2025 and the estimated maximum value of the operational transformation brought by Industry 4.0 to the global manufacturing industry is $3.7T dollars per year [3]. To remain competitive, manufacturers need to be able to rapidly adapt to changing markets, which requires having a well-prepared workforce. It has been reported that 27% of manufacturers are not able to expand their production due to lack of a properly skilled workforce [4]. A survey by McKinsey reports that only 48% of 300 leading companies stated that they were prepared for Industry 4.0 advances [5]. This challenge is exacerbated by a declining, experienced baby-boomer workforce, with an estimated 10,000 boomers retiring each day through 2029 [6].

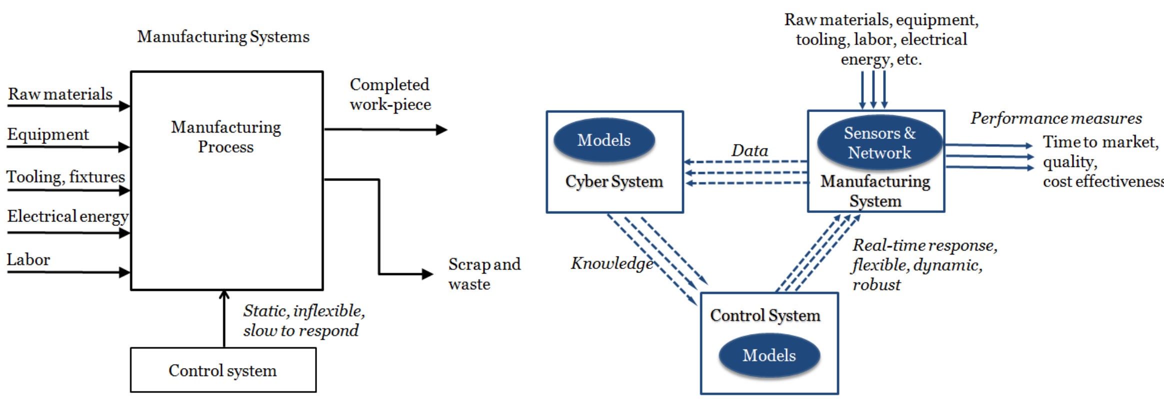
This paper reports findings from an industry survey and from a series of workshop discussions with industry professionals, academic researchers, and OEM manufacturers. The goals of the workshop were to discuss success stories, challenges, and opportunities related to workforce development and the implementation of Industry 4.0 within manufacturing enterprise settings. Having a better understanding of industry needs can help manufacturing educators better prepare their students for successful careers in the workforce of the future.

What is an Industry 4.0 Manufacturing System?

Advances in information and communication technology (ICT), computational modeling, and control algorithms have enabled the transformation of data into knowledge and control of machines and systems in real-time with high accuracy via smart sensory devices and wireless networks. Such systems are known as cyber-physical systems (CPS) [7-9].

In a conventional manufacturing system, inputs such as raw materials, equipment, tooling, fixtures, energy, and labor are fed into a manufacturing process. The manufacturing process transforms the inputs into a completed workpiece, along with scrap and waste, using the instructions programmed into its control system. Figure 2(a) illustrates the relationship of these components. For example, sheets of metal (input) fastened by fixtures (input), feed into a welding process, during which an industrial robot welds the sheets to form an automobile body frame based on the instructions from a control system. Outputs include completed auto body frames and scraps.

A cyber-physical system (CPS) is comprised of physical, cyber, and control systems. Figure 2(b) shows these concepts as applied to manufacturing. The physical system refers to the machine and the wireless sensors used to monitor and/or diagnose machine health. The cyber system refers to look-ahead analytic/simulation models designed to predict the state of machines. The control system includes the controller and control algorithms used to control the operation of machines. The connection between the physical and cyber systems is referred to as *communication*; sensory information is transmitted through a wireless network. The connection between the cyber and control systems is referred to as *computation*; the cyber system outputs knowledge, which becomes an input to the control system. Finally, the connection between the control and physical systems is referred to as *control* because an adaptive control algorithm is used to control the physical system.



(a) (b)

Figure 1. (a) Traditional and (b) Cyber-Physical System for Manufacturing Process Control

An Industry 4.0 manufacturing system combines CPS functionality with Internet of Things (IoT) and Internet of Services (IoS) to offer capabilities such as mobile device access and remote control and monitoring, as shown in Figure 2. This allows seamless integrated communication and data transfer among devices, machines, workers, and customers.

Integrating design, manufacturing, and consumer activities allows companies to increase productivity, reliability and customer satisfaction. For example, customers will be able to order customized products over the web and the products will be manufactured to order. Engineers will be able to remotely monitor the performance of system and diagnose problems. A wide variety of data (including production, sales, system performance data, safety) will be available to aid decision-makers whenever and wherever the information is needed.

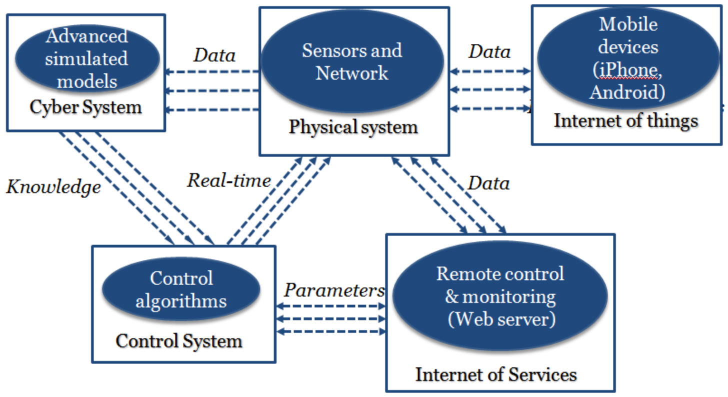


Figure 2. Industry 4.0 System

Industry 4.0 systems will also incorporate a myriad of new technologies such as artificial intelligence, augmented reality, advanced robotics, cyber-physical systems, and cognitive automation.

Challenges

Although Industry 4.0 manufacturing systems have many potential benefits, the transition from traditional manufacturing to Industry 4.0 can profoundly impact manufacturing work and workers. As the same time, the transition process is not straightforward. For one thing, companies are not able to completely stop work while their production systems and processes undergo transition—the show must go on. Second, transitioning to new technologies is expensive. Third, there is no one-size-fits-all Industry 4.0 solution. Different industries have different needs (such as different workforce skill sets), and even companies in the same industry may have different needs based on factors such as size and location. Therefore in practice, companies transitioning to Industry 4.0 technologies do so in an incremental manner, and different industries and companies have different transition paths. Roadmaps for technology adoption and implementation are lacking. Companies end up learning by doing, which can be costly and confusing to employees.

In addition, the new technologies associated with Industry 4.0—cloud computing, Internet of Things, big data, artificial intelligence, augmented reality, advanced robotics, cyber-physical systems, and cognitive automation—are still evolving and can be challenging to implement. For example, augmented reality is used by large companies for "pick by vision" applications such as warehouse operations and assembly. However, for smaller enterprises, AR is prohibitively expensive and technically challenging to implement [10-11]. Products and processes change faster than AR content can be developed to teach them. The lack of industry standards makes it challenging to maintain AR applications [12].

There are also human and societal challenges. New technologies require acquisition of new skills and in some cases could require jobs to change entirely. Workers have different strengths and skills that may impact their ability to adapt in both positive and negative ways. Companies need change management strategies to help workers respond to changes in the work environment. Workers may need to use cognitive or physical aids, such as smart glasses.

Addressing these diverse challenges effectively requires *convergence research*. According to the National Science Foundation (NSF), two primary characteristics of convergence research are that 1) it is driven by a specific and compelling problem; and 2) it shows deep integration across disciplines [13]. Solving Industry 4.0 manufacturing challenges requires experts from diverse fields—such as manufacturing engineering, computer science, human factors, human resource development, and sociology—to collaborate. In addition, input from industry—particularly from plant managers—is needed to help identify companies' greatest challenges and most needed solutions.

This paper reports preliminary findings from an industry survey and three workshop discussions involving industry professionals, academic researchers, and OEM manufacturers. The goals of the workshop were to discuss success stories, challenges, and opportunities related to workforce development and the implementation of Industry 4.0 within manufacturing enterprise settings. Findings from the survey and workshops will lay the groundwork for development of tools and technologies that can make the transition more straightforward and cost-effective for companies and augment worker performance and well-being. These could include, for example, road maps for transitioning from conventional manufacturing systems to Industry 4.0 systems; tools for ergonomic design of workstations and assembly lines; cognitive virtual assistants for workers; guidance for human interface design; and automated generation of knowledge and skill "crosswalks" to help companies identify existing skills that will still be needed and new skills that workers need to learn.

Review of Related Surveys

A review of the literature was conducted to gain a sense of the types of Industry 4.0 technologies that are being implemented, the level of technology implementation, implementation challenges, and areas in which more specific information would be especially helpful. As one of the main project tasks is to develop an industry survey, we looked especially closely at available industry surveys. Several surveys have been conducted by consulting firms such as Deloitte [14-16], PwC [17-18], and McKinsey [19-20]. We also reviewed 2019 research by Frank, Dalenogare, & Ayala that utilized a survey to investigate Industry 4.0 implementation patterns in manufacturing companies in Brazil [21]. Finally, to further inform our survey design, we reviewed previous research that used surveys to investigate industry implementation of manufacturing technologies that were new at the time, such as group technology and cellular manufacturing [22-23].

Most of the surveys targeted leaders of companies from a variety of industries around the globe. For example, one of the Deloitte surveys was administered to approximately 2000 CXO-level (i.e., CEO, CIO, COO, etc.) executives in over 19 countries [16]. The 2020 PwC survey collected responses from almost 1600 CEOs [17]. The 2018 McKinsey Global Expert Survey had over 700 respondents, but provides little detail about their role in their companies [20]. The survey by Frank et al. targeted Chief Executive Officers or Operations Directors of companies in the Brazilian Machinery and Equipment Builders' Association (ABIMAQSul) [21]. There appears to be relatively little investigation of issues from the perspective of technical managers at the plant/factory level.

The focus of the surveys varies. The Deloitte surveys primarily focused on CEOs' perceptions of their companies' Industry 4.0 technology readiness, investment priorities, and social responsibilities. The PwC surveys focused on CEO insights about issues such as company growth, technology regulation, upskilling, climate change. The McKinsey surveys focused on gathering experts' perspectives on the status of digital manufacturing (their term for Industry 4.0) implementation at their companies, their perceptions of their position relative to their competitors, and barriers to implementation. Frank et al. focused on the types of technologies that are being implemented and the stage of implementation, with a view toward discerning patterns in Industry 4.0 adoption. The Frank et al. study provides more detail about methodology and a more rigorous analysis than the reports by the consulting firms. Also, it presents a theoretical framework of Industry 4.0 technologies that is useful for organizing the types of technologies available.

A common theme in the surveys is the importance of finding or cultivating talent. The PwC 2020 report notes that companies with more advanced upskilling programs for their employees are more effective at employee engagement, workforce productivity and innovation, and acquiring and retaining talent [17]. The 2019 Deloitte reports note that only 20% of respondents agreed their companies are completely ready skill-wise and 60% have invested significantly to understand what skills are needed [14-15].

Many companies have begun to implement Industry 4.0 technology in a limited fashion, but relatively few projects have reached the point of company-wide adoption. The 2018 McKinsey report [20] notes that roughly 2/3 of digital manufacturing adopters are still in the pilot phase; technologically more advanced areas (such as industrial automation) tend to be more advanced. The 2019 Deloitte reports note that making effective Industry 4.0 technology investments is a relatively low organizational priority; their respondents were interested in Industry 4.0 primarily as means to maximize profit and reduce costs. Uncertainty about issues such as cybersecurity, uncertain economic growth, and trade conflicts also inhibit growth [14-15].

Most companies have not yet leveraged big data capabilities A 2019 Deloitte report [14] notes that companies are mostly still using tools such as spreadsheets (88%) and ERP software analytics (85%) to access, analyze, and leverage data; sensorization (26%) and physical robotics (24%) is relatively uncommon. Frank et al. noted that usage of big data and analytics was low in their sample and were used mostly by advanced adopters of Industry 4.0 technology [21].

The 2019 Deloitte report [15] notes that digital transformation is most mature in supply chain, product design, and marketing in the U.S. Supply chain applications are the top priority for future investment, followed by planning and product design.

Based on this review, we developed our survey as follows:

- The existing surveys primarily targeted CXOs. Our survey targeted plant technical managers. As the focus of our project is on Industry 4.0 tools and technologies, we anticipate that we can learn more about what is happening on the plant floor if we gather data where "the rubber meets the road."
- In surveying managers about the technologies they are using, we followed Frank et al's conceptual framework, which provides a useful taxonomy of Industry 4.0 technologies. However, Frank et al.'s sample consisted of Brazilian companies in construction and machinery which may be more traditional and less high-tech than U.S. companies. For

our study, we focused on U.S. manufacturers and anticipated that our sample would include a wider variety of manufacturing sectors.

- The existing surveys did not explore the needs of the workforce other than noting the need for upskilling, finding, and retaining talent. Our survey will focus more on investigating how workers are impacted by the implementation of Industry 4.0 technology and identifying specific training needs.
- Questions of interest for us included:
  - What Industry 4.0 tools and technologies are being used in the U.S. manufacturing industry and what is the level of adoption?
  - What challenges are companies facing in implementing Industry 4.0?
  - What tools would be helpful to industries seeking to implement Industry 4.0?
  - What worker needs are associated with specific Industry 4.0 technology areas?

Survey Development

An industry survey was developed to collect specific information about needs and challenges related to Industry 4.0 implementation in manufacturing. The goal of this survey is to help us learn more about (1) the state of Industry 4.0 implementation in various industry types; (2) challenges and opportunities; (3) activities that enable successful implementation, and (4) hardware and software used in the process (including internally developed tools), if any.

To make sure the questions are easy-to-understand, the survey length is acceptable, and we are getting the desired information in the responses, we had two iterations of evaluation--version 0.5 (for industry expert review) and version 1.0 (for pilot-testing). Version 0.5 consisted of open-ended questions on the themes of the research. The industry expert's suggestions included: 1) make the survey more responsive to different job roles; 2) wording changes to use industry-standard terminology; 3) modify certain questions to use closed-ended formats.

The survey was subsequently revised to address these suggestions and to include more closed-ended questions (version 1.0). This version was structured based on the framework proposed by Frank, Dalenogareb, & Ayala [21]. In addition, to address participants' potential hesitance to disclose specific information about implementation of technology at their companies, we developed a separate "Agreement to Participate" survey. This survey allows respondents to identify themselves so that we can keep track of who has participated and notify winners of the prize drawing. The Agreement to Participate survey is not linked to the Industry 4.0 survey in any way.

The Agreement to Participate, the revised Industry 4.0 survey, and the text of the cover letter, were reviewed by an external evaluator. The evaluator noted that the surveys were well-designed and comprehensive and suggested only minor edits to wording.

Survey Implementation

The survey was sent to about 75 companies but getting useful information was challenging. For example, 21 people were willing to participate, but 10 were screened out because either they were not in the targeted group (plant-level technical managers responsible for production, engineering, scheduling, or product design) or their areas were not in the process of planning or implementing Industry 4.0 technologies. Possible reasons include the length of the survey and reservations about discussing sensitive information about company plans and processes with strangers.

To obtain richer data, we began collaborating with entities that work closely with companies to co-sponsor half-day workshops for industry. Our thinking is that if workshop participants have something in common—such as a mutual connection or similar interests—they will speak more freely. In addition, participants are offered a stipend for attending the workshop and the agenda includes time at the end to complete the survey. The survey length was reduced to 14 questions, which most participants were able to complete in 10-15 minutes.

As of August 2022, we held workshops in collaboration with the Alamo Colleges District Workforce Training Network in San Antonio, Texas, and the Florida ATE Center (FLATE) in Orlando, Florida. We also collaborated with SME to co-sponsor a workshop at SME's RAPID + TCT 2022 conference in Detroit. The goal of the workshops is to bring industry professionals, academic researchers, and OEM manufacturers to share current and planned activities related to Industry 4.0, exchange ideas, and lay groundwork for future collaborations on research and education to enable smart working in the 21st century. Each workshop includes a presentation from a guest speaker currently involved with implementing Industry 4.0 technology, a group discussion during which participants describe their I4.0-related endeavors and challenges, and time to complete the survey.

So far, we have had 23 workshop participants representing 19 companies and four universities. It is still challenging to recruit participants, but the discussions have been informative, and we have been able to collect additional survey responses.

Survey Findings

As of August 2022, we received 35 surveys of which 25 were usable. Of the 25 usable responses, 11 were from the long version of the survey developed in spring 2021. After revising and shortening the survey and administering it in conjunction with the workshops, we received 14 responses. Selected data from the surveys are summarized below. In cases where the same question appeared on both versions, the data have been combined.

Which of the following types of I4.0 technologies are you using, planning to use, or not planning to use? (n=14)

Type of technology (n=14)	No plans to use	Planning to use	Using
Analytics	1	4	9
Machine-to-machine communication (M2M)	1	5	8
Technologies for identification and traceability of final products	1	5	8
Cloud computing	2	4	8
Vertical integration	2	4	8
Industrial robots, autonomous guided vehicles, or other advanced robot technologies	3	3	8

Type of technology (n=14)	**No plans to use**	**Planning to use**	**Using**
Automatic identification of nonconformities in production	3	3	8
Internet of Things (IoT)	1	6	7
Process simulation (digital manufacturing, digital twin)	1	6	7
Remote monitoring of production	1	6	7
Additive manufacturing	2	5	7
Flexible and autonomous lines	1	7	6
Big data	2	6	6
Technologies for identification and traceability of raw materials	2	6	6
Digital platforms with customers	4	4	6
Digital platforms with other internal company units	4	4	6
Digital platforms with suppliers	5	4	5
Collaborative robots	5	4	5
Product connectivity	5	5	4
Energy efficiency improvement systems	7	3	4
Remote operation of production	6	5	3
Augmented reality for maintenance	7	4	3
Energy efficiency monitoring systems	8	3	3
Artificial Intelligence for planning of production	3	9	2
Augmented and virtual reality for product development	9	3	2
Artificial Intelligence for predictive maintenance	6	7	1
Virtual reality for worker training	7	7	0

Summary. The most commonly used technology was analytics (9/14). Also, more than 50% of respondents (8/14) reported using machine-to-machine communication, technologies for identification and traceability of final products, cloud computing, vertical integration, industrial robots, and automatic identification of nonconformities in production.

The least used technology was virtual reality for worker training (0/14), and 50% of respondents (7/14) have no plans to use it. Also, although two of 14 respondents are using augmented and virtual reality for product development, 64% (9/14) have no plans to use it.

How have Smart manufacturing/I4.0 technologies changed the nature of work at your factory/company? (Select all that apply.) Which change has been the biggest? (n=14)

How SM/I4.0 technologies have changed the nature of work	# of times selected	# of times selected as biggest change	% selected as biggest change
Workers need to use computers more	10	4	40%
Training needs to be more individualized/personalized	8	2	25%
Workers need new technological tools (e.g., smart glasses)	6	2	33%
Workers need to collaborate more with other workers	5	0	0%
Training needed more frequently	5	2	40%
Workers need to think more (e.g., make more decisions)	3	3	100%
Reduced need to perform physical tasks (e.g., walking, lifting)	3	0	0%
Other (please specify): embracing semi-automation/raw materials	1	1	
Not applicable (we are not using any I4.0 technologies)	0	0	

Summary. 71% of respondents noted that the need for workers to use computers more has changed the nature of work at their company. 57% noted that the need for training to be more individualized/personalized and changed the nature of work.

Relatively few respondents (21%, 3/14) noted that workers needing to think more has changed the nature of work, but all of the respondents who made this observation believed it to be the biggest change.

What types of jobs have been (or would be) affected by implementation of these technologies? How will they be affected? (n=14)

- Production workers/operators - learning digital skill sets
- Labor and Technical
- Employees that do more of the hands-on production e.g. welders, painters. Developing higher level skill set. Many of these people do not do well in higher level training settings.
- More IT, higher productivity but more skilled workforce
- Engineering, machine operating, and maintenance
- CNC equipment to better utilize time, efficiencies, assembly area to improve out put and communicate weaknesses and ways to improve output
- Mechanical engineering - faster design iteration with internal digital twin initiatives

- Biggest impact will be on factories and manufacturing facilities, esp. the leaders. They will need to successfully transition their organizations to Industry 4.0, keep themselves up to date and also maintain their employee expectations.
- Usually shop floor personnel. Training requirements, adoption resistance.

Summary. This was an open-response question and responses were quite varied, ranging from hands-on production workers to engineers to managers. As we collect more data, we will cross-tab these responses by industry.

Which types of skills would you say workers need for SM/I4.0? (n=14)

Skills needed (n=14)	Number of times selected	Number times selected as most needed	% selected as most needed
Technical skills (programming and adapting to new technologies)	10	5	50%
Process skills (critical thinking and deductive reasoning)	9	3	33%
Content skills (understanding ICT, active learning)	7	2	29%
Cognitive skills (data analysis, abstract thinking)	6	2	33%
Resource management skills (managing time and resources efficiently)	5	0	0%
Social skills (negotiations, collaboration)	3	0	0%
Personal/mental abilities (decision making under pressure, persistence)	3	0	0%
Intercultural skills (working across culture and geographics)	3	0	0%
System skills (integrated decision making, entrepreneurial skills)	2	1	50%
Other (please specify): N/A	1	1	

Summary. The top two worker skills selected by respondents were technical skills (10/14) and process skills (9/14). These were also most often selected as being the most needed skills.

Which of the following challenges/obstacles to implementing Industry 4.0 technologies have you faced? (Check all that apply.) Of your selected challenges/obstacles, which have been the most challenging?

Challenges/Obstacles Faced	Number of times selected (n=25)	Number of times selected as most challenging (n=25)
Redesigning production systems and processes	13	8
Cost of new technology	13	7

Challenges/Obstacles Faced	Number of times selected (n=25)	Number of times selected as most challenging (n=25)
Can't stop work while production systems and processes undergo transition	9	7
Cost of training	9	1
Worker resistance	7	2
Not knowing how to start	6	3
Other: *See below*	6	3

Other: Management acceptance (1); lack of skilled workers (3); change of tooling and customer demands (1); Incomplete awareness of technologies and their ROI (1)

Other (Most challenging): Lack of skilled workers (1); change of tooling and customer demands (1); Incomplete awareness of technologies and their ROI (1)

Summary. The two most common challenges/obstacles to implementing Industry 4.0 faced by respondents (13/14, 93%) were "redesigning production systems and processes" and "cost of new technology." In addition, "Can't stop work while production systems and processes undergo transition" and "Cost of training" were faced by a majority of respondents (9/14, 64%).

What advice (do and don't) would you give to other companies/plants who are planning to implement Smart Manufacturing/I4.0 technologies? (n=14)

- Find low hanging fruit opportunities
- Evaluate their process, develop good training
- Find someone in your industry that has already started the process.
- Invest in more inhouse training
- Caution - I may be at 4.0 but if my suppliers or customers are not, can have huge impact on me!
- Don't take on too much at one time
- In the implementation process, I think investing in training for current employees to become your companies' SMEs, helps with employees adopting the technology and recognizing the opportunity for growth as the company evolves.
- Do not underestimate the need to have dedicated staff who are invested in the success of the implementation. No implementation is smooth and requires a dedicated push by someone responsible for making it a success.
- I think to continue to improve your place of business we have to learn to adapt to the new technologies to stay up with our ever-changing world. By doing so we will also help our businesses to grow and become that much better overall.
- Prepare employees with proper tools
- Attend technical conferences to see the bigger picture or what others are doing
- Take a hybrid approach to implementation. Do not stick to a top-down approach.
- Use pilot programs. Involve all staff involved in the areas being affected. Get buy-in at the highest levels in advance.

Which, if any, of the following human resources-related tools would be (or would have been) helpful as you transition to I4.0? Select all that apply. -

Human resources-related tools	Number of times selected (n=25)
Strategies/tools/training to help employees to successfully transition to new technologies/processes	17
Tools to identify training crosswalks to identify existing skills that will still be needed and new skills that workers need to learn	12
Tools to help workers be involved in the process	11
Tools to understand how to maximize productivity.	9
Tools to assess impact of change on workforce	5
Other (please specify): *cost/benefit analysis; N/A*	2

Summary. 68% (17/25) of respondents indicated that "Strategies/tools/training to help employees to successfully transition to new technologies/processes" would be a helpful human resources-related tool.

Which, if any, of the following planning tools would be (or would have been) helpful as you transition to I4.0? Select all that apply.

Planning-related tool	Number of times selected (n=25)
Road map of the process for transforming a traditional manufacturing system into a cyber-physical system with the least amount of disruption to production and to the workforce	14
Methods for calculating the trade-offs between the additional resources that will be needed in smart factories and the potential generated savings	14
Tools to help you decide which I4.0 technologies to implement	10
Tools to help managers develop plans for managing complex products and manufacturing systems	8
Other (please specify) - *N/A*	1

Summary: A majority of respondents (14/25, 56%) indicated that the following planning tools would be helpful: "Road map of the process for transforming a traditional manufacturing system into a cyber-physical system with the least amount of disruption to production and to the workforce" and "Methods for calculating the trade-offs between the additional resources that will be needed in smart factories and the potential generated savings."

Which, if any, of the following technology implementation tools would be (or would have been) helpful as you transition to I4.0? Select all that apply.

Implementation tool	Number of times selected (n=25)
Strategies for determining appropriate visualizations to provide needed information to different audiences—such as operators, maintainers, and control system engineers	16
Strategies for achieving real-time visualization of materials, product, machine, and production status, quality and related resources	10
Safety and security tools to ensure that production facilities and products do not pose a danger to people or to the environment, and to protect data against misuse and unauthorized access	9
Other (please specify): *Cost-benefit analysis; N/A; blank*	3

Summary. 64% of respondents noted that "Strategies for determining appropriate visualizations to provide needed information to different audiences—such as operators, maintainers, and control system engineers" would be helpful for technology implementation.

Conclusion and Future Plans

A skilled workforce is essential to any successful transition. Most needed are technical skills (programming and adapting to new technologies) and process skills (critical thinking and deductive reasoning).

It is difficult for small businesses to find workers who already have needed technical skills. Often they spend 1-2 years training new hires only to have them leave shortly afterwards to take better-paying jobs at bigger companies.

When redesigning a process, it's important to help workers to not only do the job, but also understand the process. For example, one company that implemented an augmented reality system to guide an assembly process noted that new workers were completely reliant on the system to the point of not knowing how to perform the task if the AR was not working. Workers need to understand processes well enough to be able to spot problems or suggest improvements.

Companies can't stop production while new technology is being implemented. Before new technology can be implemented, management needs to know the cost and how soon will it generate income. Companies need to be able to reduce/mitigate disruptions to cash flow.

Sometimes business requirements can limit implementation of I4.0 technologies. For example, when doing business with DOD, use of cloud-based technologies is limited due to enhanced security requirements.

Future plans include: 1) Conduct additional workshops in collaboration with Southwest Research Institute (SwRI) Ross Consortium, The University of Texas at Arlington Research Institute (UTARI), Rockwell Automation Fair 2022, NSF ATE Centers, and SME. The workshops will focus on specific industry sectors (e.g., aerospace, semiconductor industry) or operations (e.g., smart assembly or machining). 2) Collect additional survey data. 3) Cross-tabulate and analyze by factors such as industry sector and company size. 4) Form research community and develop research agenda. 5) Pursue external funding for research agenda.

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