The Fourth Industrial Revolution: Proceedings of a Workshop–in Brief

DETAILS

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Proceedings of a Workshop

IN BRIEF

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The Fourth Industrial Revolution

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On **October 25-26, 2016**, the Government-University-Industry Research Roundtable held a meeting to consider the Fourth Industrial Revolution and its implications for manufacturing, as well as its likely social and economic effects. The meeting also explored the cross-sector collaboration between government, universities, and industry needed to accommodate emerging developments in the key technologies of the Fourth Industrial Revolution, namely artificial intelligence, virtual and augmented reality, and the Internet of Things.

Thomas Philbeck, Global Leadership Fellow at the World Economic Forum (WEF), delivered the keynote address on October 25. The Forum made the Fourth Industrial Revolution the theme of a significant amount of its work for the past year (see Figure 1). The organization opened a Center for the Fourth Industrial Revolution in San Francisco in October 2016 that will host multi-stakeholder policy dialogues; work on issues related to technology, society, and values; and conduct applied research around these issues.

In explaining why the Forum labeled this era of change the Fourth Industrial Revolution, Philbeck provided an overview of the technological and social advances brought by previous industrial revolutions. The first revolution was powered by steam and led to the spinning jenny and the railroad. The second was driven by a better understanding of electromagnetism and chemistry, which led to telegraphy, telephony, the light bulb, photography, the automobile, and flight through propulsion. The third—the digital revolution—is still developing in terms of increasing sophistication through ongoing development and miniaturization of computing components.

Revolution	Year	Information
1	1784	Steam, water, mechanical production equipment
2	1870	Division of labour, electricity, mass production
3	1969	Electronics, IT, automated production
4	?	Cyber-physical systems

Figure 1 Navigating the Next Industrial Revolution; presentation by Thomas Philbeck to GUIRR, October 26, 2016.
Source: Thomas Philbeck, World Economic Forum.

"Building on the backbone of digital technologies and infrastructure, the emerging dynamics of the Fourth Industrial Revolution involve a convergence of technologies and disciplines, nonlinearity, and a re-emergence of digital into material and physical domains," Philbeck said. "These changes are having a multi-system impact. New technologies—such as 3-D printing, bioprinting, artificial intelligence, blockchain, virtual reality, and augmented reality—are creating pressures and raising questions about how these technologies should be used."

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The Forum's perspective on present and future technological and societal changes is captured in their 'Principled Framework for the Fourth Industrial Revolution.' Philbeck explained the four principles that characterize the Fourth Industrial Revolution.

- **Think systems, not technologies.** Individual technologies are interesting, but it is their systemic impact that matters. Emerging technologies challenge our societal values and norms, sometimes for good, but sometimes also in negative ways; the Fourth Industrial Revolution will have civilization-changing impact—on species, on the planet, on geopolitics, and on the global economy. Philbeck suggested that wealth creation and aggregation supported by this phase of technological innovation may challenge societal commitments to accessibility, inclusivity, and fairness and create the need for relentless worker re-education. As Philbeck stated, "The costs for greater productivity are often externalized to stakeholders who are not involved in a particular technology's development."
- **Empowering, not determining.** The Forum urges an approach to the Fourth Industrial Revolution that honors existing social principles. "We need to take a stance toward technology and technological systems that empowers society and acts counter to fatalistic and deterministic views, so that society and its agency is not nullified," said Philbeck. "Technologies are not forces; we have the ability to shape them and decide on how they are applied."
- **Future by design, and not by default.** Seeking a future by design requires active governance. There are many types of governance—by individuals, by governments, by civic society, and by companies. Philbeck argued that failure to pay attention to critical governance questions in consideration of the Fourth Industrial Revolution means societies are likely to allow undemocratic, random, and potentially malicious forces to shape the future of technological systems and their impact on people.
- **Values as a feature, not a bug.** The Forum considers three major values critical to a prosperous and equitable future in the context of the Fourth Industrial Revolution: preserving the common good, delivering multigenerational environmental stewardship, and holding the primacy of human dignity. "Values are embedded in technological systems," Philbeck noted. "They are embedded at points of decision making about what is worthwhile to pursue. They can be embedded in technological systems through organizational cultures and by prioritizing particular outcomes and rewarding behaviors. Values can be embedded in product design and encoded through power structures—through the military, the government, through labor unions."

In closing, Philbeck noted that deliberate leadership is needed to maintain values, support responsible governance, and develop resilient economic, industrial, and education systems to uphold these principles.

MAKING VALUE FOR AMERICA

National Academy of Engineering (NAE) Senior Program Officer **Kenan Jarboe** moderated the first panel on October 26th with the purpose of examining opportunities for value creation within the context of emerging digital and distributed tools for manufacturing. Kate Whitefoot of Carnegie Mellon University offered the first presentation, an overview of the NAE-commissioned report *Making Value for America: Embracing the Future of Manufacturing, Technology, and Work*. The study was prompted by concerns among Academies members about historic job losses in the manufacturing sector, in combination with the rise of novel technologies in manufacturing. The study was undertaken to envision a path forward for U.S. manufacturing.

Whitefoot explained that the committee decided that manufacturing could not be comprehensively studied without considering the full value chain—including R&D, design, and software and services provided throughout a product's lifetime. The report describes how manufacturing value chains are being transformed by technologies such as additive manufacturing, collaborative robotics, and digital platforms. These technologies are changing the way manufacturers develop, produce, and deliver products and services to customers. According to Whitefoot, "Emerging technologies are creating opportunities for U.S. businesses and the workforce, but there were serious concerns that many Americans are being left behind by these changes—particularly the middle skills workforce."

The *Making Value for America* report includes many recommendations for government, academia, and businesses, which can be summarized as three points: (1) educate—build partnerships to provide the U.S. workforce with the skills that will be in high demand in light of changes caused by the Fourth Industrial Revolution; (2) collaborate—best practices should be spread across organizations. Data show a significant gap between top-performing businesses and lagging ones. Efforts to address this gap in performance distribution will generate economic growth and job creation; and (3) be inclusive—in many cases, innovation benefits from diversity and diverse teams.[1]

[1] National Academy of Engineering. 2015. *Making Value for America: Embracing the Future of Manufacturing, Technology, and Work*. Washington, DC: The National Academies Press.

Whitefoot closed by noting examples of how new technologies are changing how work can be done in manufacturing value chains. At Carnegie Mellon's NextManufacturing Center, for example, she and her colleagues are developing new ways of designing and producing metal additive manufacturing parts and are moving toward optimizing the topology of parts down to the microstructure in order to improve their performance.

The next presentation by **Theresa Kotanchek** of Evolved Analytics LLC, and a member of the NAE Committee on Foundational Best Practices for Making Value for America, covered current trends in digital data and its use. "Not only is data expanding exponentially, its generation is becoming more global and is shifting toward emerging markets," she said. "However, not all data is useful. To be actionable, it needs to be tagged with metadata for us to discern its relevance in space and time and its relationship to other objects. At this point in time, only about 25 percent of data is tagged, and only 5 percent of data is target rich—easy to access and potentially transformative for a value chain. Data embedded in the Internet of Things (IoT) accounts for only 3-4 percent of data."

Kotanchek continued, "Seventy percent of data is created by individuals, but enterprises ultimately have responsibility and liability for about 85 percent of that individually created data. While 40 percent of data requires protection, only about 20 percent is protected in a meaningful way."

"The world is shifting from recognizing atoms first, to bytes first," explained Kotanchek. "The companies that embrace first using computational methods to identify new targets and then using that knowledge to design and deliver solutions are going to win; those that do not will not survive. To make strategic decisions about how to meet goals, we need to address the recognized four V's of data—volume, velocity, variety, and veracity—in order to make effective decisions about what we're trying to accomplish and create."

Kotanchek referenced Whitefoot's point about transforming workforce needs, suggesting that this growing supply and reliance on data requires policymakers, employers, and educators to think about how the next generation of employees—not just computer scientists, but all employees—will acquire and use computational capabilities going forward. "Enterprises need to establish training programs that prepare workers to continually emphasize skills development, throughout all parts of society." Kotanchek noted the importance of partnerships among colleges, businesses, and local school districts in helping students graduate and pursue higher education, and access ongoing education throughout their careers.

INDUSTRIAL INTERNET OF THINGS AND ADVANCED ANALYTICS

The next panel, moderated by **Jack Hu** of the University of Michigan, explored the industrial Internet of Things (IIoT) and advanced analytics and opened with a presentation by **Rob Ivester** from the Advanced Manufacturing Office at the Department of Energy (DOE). Ivester considers measuring energy productivity as equal in importance to measuring energy consumption in manufacturing, as enabling increases in U.S. industrial productivity from an energy standpoint writ large increases global competitiveness. The DOE issues a Quadrennial Technology Review that identifies core technologies expected to contribute to meeting the nation's energy needs, and in that review is a chapter dedicated to manufacturing.

According to Ivester, the progression of technologies within manufacturing is highly interconnected and complicated. The overriding goal of the Advanced Manufacturing Office (AMO), an applied research office within DOE, is enabling a series of innovations so that energy products like solar cells and wind turbines, as well as non-energy products like those used in the transportation sector and by industry in general, can be made in the United States on a competitive basis. The AMO uses three strategies to support domestic manufacturing: (1) technical assistance, which is primarily focused on disseminating information to help drive adoption of new technologies and to help small- and medium-sized manufacturers make decisions; (2) R&D project investment; and (3) R&D facilities, which focus on consortia between public and private entities to address common problems.

The AMO has a significant presence within a series of institutes called Manufacturing USA, formally known as the National Network of Manufacturing Innovation (NNMI). To support a transition towards advanced manufacturing, the institutes depend on and are driven by the IIoT—technologies that are creating new lanes of opportunity. For example, PowerAmerica, headquartered at North Carolina State University in Raleigh, focuses on developing cost-competitive, wide bandgap semiconductors for power electronics, which use materials that operate at higher temperatures and voltages to replace silicon to halve power losses. Another, the Clean Energy Smart Manufacturing Institute, aims to enable the adoption of smart manufacturing technologies, including advanced sensors, controls, platforms, and modeling tools, to improve energy productivity by 50 percent, to reduce installation costs for smart manufacturing hardware and software by 50 percent, and to achieve an overall 15 percent improvement in energy efficiency at a systems level.

The next presentation was offered by **Humera Malik** of Dat-uh, an IIoT analytics platform focused on automating data science—taking huge datasets from the operational side, putting them through the platform, automating the building of predictive models, and enabling the models' constant learning. Dat-uh works with large manufacturers around the globe, many of them in Europe.

"In North America, big manufacturers have spent almost $7 trillion retrofitting old equipment with sensors that allow systems to talk to each other, but that investment only helps them use about 1 percent of their operational data in making business decisions. How can they start to take the lead in using the other 99 percent of data, which is a huge opportunity?"

"The European market is leading the way in digital and automated manufacturing," Malik said. "They have adopted standards and developed a strategy for digitizing all of their assets over the next 5, 10, and 20 years—allowing them to monetize that 99 percent data opportunity. CEOs in manufacturing in the United States are looking to predictive analytics and smart factories to solve their problems, but when they examine their systems they realize they are not ready for it and will not be ready for 5 years."

"Implementing advanced analytics works best when adoption can save businesses costs, usually in two key areas," Malik explained. "The first is when manufacturers are looking to optimize their assets—Dat-uh can help them increase the lifespan and reduce their maintenance costs by 50 percent. The second is through process optimization, by leveraging predictive analytics to reduce process costs by up to 30 percent."

Malik noted that small- and medium-sized manufacturers often do not feel ready to adopt these technologies because of a fear of sharing data. She is seeing successful adoption by some progressive North American manufacturers—usually larger ones, who are embracing the technologies and understand the concept and benefits of building connected industrial ecosystems.

Dimitry Gorinevsky of Stanford University offered the next presentation. "The internet revolution so far has been focused on connecting people to one another, and what is new is connecting machines to machines," he said. "Connecting people is presumably 10-15 percent of the economy, and connecting machines makes up much of the rest. So the coming phase of the Fourth Industrial Revolution can potentially have a much larger economic impact than the internet revolution has so far."

Regarding machine to machine interaction, Gorinevsky explained, "There is not just one level of analytics application, but rather an analytics stack," (see Figure 2). "In the bottom layer of the stack are embedded controls and optimization. The computer systems that are running industrial plants are called operational technology (OT), and these are very secure networks. On the top of the OT there is Information Technology (IT), which includes things like desktop computers, cloud computing, and software, that have a lower level of criticality. The earlier internet revolution has been happening on the IT side. But now, data from the OT side is actually getting collected, and that is where the IIoT action is happening."

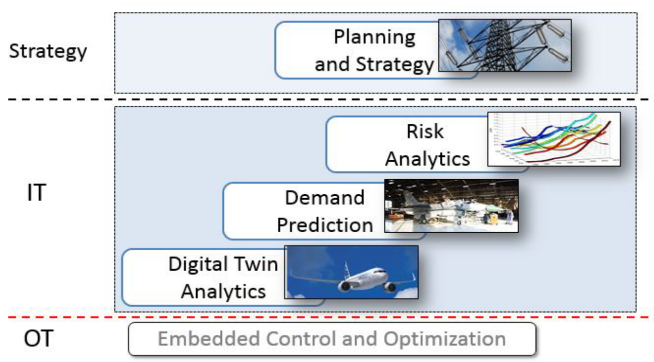

Figure 2 IIoT Analytics Stack; presentation by Dimitry Gorinevsky to GUIRR, October 26, 2016. Source: Dimitry Gorinevsky, Mitek Analytics.

Gorinevsky gave examples of work with industry at Stanford and his company, Mitek Analytics, including projects with NASA, the U.S. Air Force, and airlines to use "operational digital twins" for each aircraft and engine that evolve over time. Digital twins are computerized companions of physical assets that can be used for various purposes. Companies are interested in learning ways to improve predictive maintenance processes forfuel, energy, and inventory control efficiency.

Gorinevsky also offered an overview of the standard enterprise architecture in application to IoT technology; the architecture has four layers (see Figure 3). According to him, the bottom two layers—the technology architecture and the data architecture—define the platform. These two layers collect and manage the data and organize computing. These platforms are necessary to run applications and act as the basis for much of the movement on IoT innovation that has taken place so far in big companies and in Silicon Valley. The top two layers—IoT applications including analytics, and a business process layer—are where the value-add is for end users. But in Gorinevsky's opinion, work on IoT applications with business impact—these top two layers—is lagging.

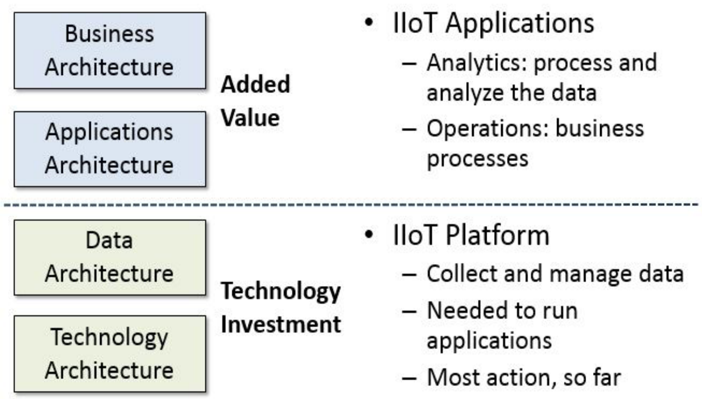

Figure 3 Enterprise Architecture View; presentation by Dimitry Gorinevsky to GUIRR, October 26, 2016. Source: Dimitry Gorinevsky, Mitek Analytics.

DIGITAL-PHYSICAL SYSTEMS

The next panel, moderated by **Steve Cross** of the Georgia Institute of Technology, explored digital-physical systems and opened with a presentation by **Al Wavering** of the National Institute of Science and Technology (NIST). Wavering noted some of the interesting and transformative advanced manufacturing technologies that are becoming viable and converging, including 3-D printing, advances in automation, digital model-based 'everything,' and advances in materials. For Wavering, "The introduction of these technologies raises many questions: Does the technology do what it is supposed to do? How do you measure and improve the performance of the technology? How do we make sure these different technology components can work together as seamlessly as possible?"

NIST's laboratories work on these kinds of questions using measurement science, performance standards, and interoperability standards to drive innovation and reduce the risk involved in adopting new smart manufacturing technologies. "We don't just sit in our labs," said Wavering. "The development of standards in the United States is largely a private-sector-driven activity, so NIST works with industry and with universities. NIST produces performance metrics, measurement and testing methods, and modeling and simulation tools—infrastructure that helps translate technologies from research to practice."

The agency focuses its efforts to develop use cases for measurement standards in manufacturing systems-oriented technologies and on two disruptive manufacturing technology areas: robotic systems and additive manufacturing. NIST has a program in smart manufacturing systems and design, which works on service-oriented architectures, modeling methodology for smart manufacturing, operations-driven performance measurement, and data analytics. Some of the operations planning and control projects include intelligent maintenance, cybersecurity, industrial wireless, the "digital thread" for smart manufacturing, and system analysis integration.

Other NIST lab work focuses on measurement science for additive manufacturing, and on the performance of robotic technologies for advanced manufacturing. NIST is working on new robotic technologies that can work safely in close proximity to humans, be more agile and adaptable to new tasks, deal with uncertainties in the environment, and operate in small and medium-sized manufacturing environments.

Tom McDermott of the Digital Manufacturing and Design Innovation Institute (DMDII), a public-private partnership with industry, academic, and government partners charged with increasing the competitiveness of U.S. manufacturing through digital technologies, presented on DMDII's goal: to be the preeminent organization in the world for digitizing data across all processes throughout product lifecycle, and integrating it to drive better decision-making.

DMDII has 50 projects, 60 percent of which are underway today, and its focus areas have been in product design and developing the "future factory." One project, for example, provides designers with data so they can see their design's implications for the manufacturing process, which helps them avoid pursuing dead ends. Another project is on how to create augmented reality work instructions. "Going forward, DMDII needs to create a place where all of these projects can be integrated and seen together," said McDermott.

One of DMDII's roles is facilitating multi-party collaboration. If one company has a problem and others have either a solution or similar interests, they can come together easily to work together on that problem, and then disband when they have solved it and go work with other companies on separate sets of problems. A core asset of DMDII is that it uses a common legal framework to create rules of engagement for multi-party stakeholders ahead of time.

"We have realized that it's not sufficient to restrict our operations to certain levels of technology readiness," said McDermott. "We need to make sure that someone is there to catch the ball when we are done and carry it all the way through. Here is our real litmus test: Is this technology actually being used in manufacturing somewhere in America? Getting it to a pilot phase is not enough; we need to get the technology into use."

DMDII is halfway into its 5-year cooperative agreement, and McDermott noted some lessons he has learned so far: (1) Digital manufacturing is nebulous and poorly defined. Helping people understand what it is and how it can help them improve their operations is incumbent on our organization, in partnership with others. (2) Speed is important; innovation in digital technologies is happening quickly. (3) Multi-party collaboration is necessary to enable innovative solutions. (4) It is incumbent on DMDII to truly solve the "valley of death" problem in digital manufacturing technologies—not just shift it to another actor in the ecosystem. (5) DMDII members are demanding guidance to integrate the new technologies at scale.

The next presentation was given by **Bill O'Neill** of Siemens, a global company headquartered in Germany. O'Neill works at a center of competence whose goal is to affect significant change by helping U.S. manufacturers move from their current, sometimes stagnant, state to an exciting future state.

"The vision of a cyber-physical manufacturing future comes into play in two areas," said O'Neill. "One area is the top: What can we do differently at the top to inspire boldness and leadership in industry in the United States? The other area is the "bottom," which refers to young people feeding into careers in industry: What do we need to do to help workforce development?"

"As previous speakers have noted, technological forces are transforming industry—changing the way products come to life and how they evolve through data analytics," said O'Neill. "Siemens is focused on the combination of advanced robotics and additive manufacturing. The company has spider bots working collaboratively, using additive manufacturing, to build large structures in ways that couldn't be built before."

O'Neill also offered Siemens' view of the value chain. "Today all of the elements of the value chain are disparate and disconnected," he said. "The key is organizing them and connecting them via a digital thread, so that things that would otherwise cause errors or delays—a change to the product design, for example—do not, because everything is woven into a coherent system that works together. Taking a holistic approach allows you to create a digital twin of the entire value chain, from product inception to service. Data analytics information is fed back into the digital model effecting changes to the product, which then prompt changes to the process."

The final presentation of the panel was given by **Paul Davies** of Boeing, who specializes in visualization and augmented reality in manufacturing. Augmented reality (AR) considers how humans access information and how they interface with the digital world.

Davies said, "Thirty years ago, we would go to a book for any information we wanted. Then we used library databases. Then basic search engines such as Altavista, and then Google with natural language search. And now our smartphones. All of these media forms are separated by a screen and divided in two. The digital content is on one side of the screen and we are on the other. Augmented reality is going to be the next medium to communicate digital information into the real world. AR is anything where some part of the scene you are viewing is real and some part is virtual. In manufacturing, AR is mostly on the real-world side; a worker would see part of an assembly he or she is building and a scene at the bottom with work instructions."

This is difficult to achieve, Davies explained, and there are other challenges beyond the technical, such as security requirements for data, safety, and cultural readiness. "But there are big reasons to pursue augmented reality in manufacturing. We believe that if we implement an augmented reality system, we will see reductions in assembly errors, assembly time, and training requirements. AR will help people remember instructions better and will assist in transfer of tribal knowledge from senior mechanics to junior ones. All of these improvements contribute to decreasing manufacturing cost and increasing the build quality."

Davies suggested there is good evidence to support this, and described a study in which Boeing partnered with Iowa State University to look at different ways to deliver work instructions and the impact on quality and schedule. The study found that workers who got work instructions through a tablet with augmented reality had fewer errors and a shorter learning curve than those who got instructions by a PDF accessed through a desktop computer or tablet.

He identified the roles that government, university, and industry partners can play in furthering this technology. "Industry needs to do a heavy pull for the next generation of these technologies and put some funding toward it; academia needs to partner with industry on lower tier technology development; and government needs to clear a path and reduce regulatory burden. All three need to work on bridging the valley of death to get these technologies from research into use."

HUMAN TECHNOLOGY FRONTIER

The final panel, moderated by **Tilak Agerwala**, formerly of IBM, focused on the human-technology frontier. It opened with a presentation by Fay Cook of the National Science Foundation (NSF), who spoke about work at the human-technology frontier. "We are on the cusp of major transformations in work and the workplace driven by new and emerging technologies—artificial intelligence, machine learning, the Internet of Things, and many others," said Cook. "This transformation is going to change the way we produce goods, provide services, and collaborate with our colleagues." Cook identified three thematic areas in which NSF is proposing to support research: (1) studies to understand the benefits as well as the risks of new technologies; (2) investments to develop technologies that enrich the lives of people in the workplaces of the future and to improve workplace efficiency, labor productivity, and economic growth; and (3) resources to support the education and lifelong learning of tomorrow's workforce. "Let's imagine the workplace of tomorrow," said Cook. "It will be a collaboration among humans and machines and cyberspace. Humans, working with smart technologies that can identify our needs, synthesize and analyze lots of data, and then respond appropriately to improve manufacturing, provide services, and enable teamwork. It might be an actual physical space or it might be a virtual workplace in which we are all interacting wirelessly from remote locations."

For Cook, first understanding human-technology interactions—how we influence technology and how that technology influences us—is a key enabling component of the optimized workplace of the future. Second, it is critical to create systems that are tailored, optimized, and continuously adapted for humans. And third, given the rapid pace of technological change, continuing education and lifelong learning will be critical to create a workforce that will succeed in the new workplace. "To get there, we envision a framework of use-inspired research in various work contexts, such as advanced manufacturing, health care, and learning environments. And underpinning that will be research foundations in artificial intelligence, cyber-physical and cyber-human systems; and education and discipline-specific learning; and social and behavioral sciences," she explained.

Cook spoke about the partnerships that NSF sees as necessary to enable this future, which, she noted, are the very types of partnerships that GUIRR works to establish. Industry conducts a tremendous amount of research to develop the technologies discussed and to train the workforce; universities are in the business of research and education in all disciplines; and government agencies provide the funding for basic and applied research.

Larry Sweet of the Georgia Institute of Technology spoke next on the future of collaborative robotic manufacturing. Sweet opened by citing a McKinsey & Company forecast that suggested industrial robot use would have a cumulative annual growth rate of 10 percent or more over the next 10 years—a rate two to three times higher than it has been over the past two decades.

Sweet participated in a survey that asked 200 companies—from large manufacturers to small or medium sized businesses—what they hoped to get out of robotics over the next five to ten years. Encouragingly, over 90 percent of the survey respondents focused on robotics supporting business growth, rather than saving on direct labor; they sought automation to provide flexibility that allows them to make more diverse and more customized products. "They saw the potential to grow their businesses by 30-50 percent. This sounds like a lot," said Sweet. "But I have personal experience in leading projects that led to gains in that range."

The vast majority of collaborative robot applications deployed to date are sequential operations—the robot and the person are physically separated, with a buffer in between so that if either partner stops, the other can continue working. "Most people think of collaborative robots as robots that are human-safe—a robot that cannot cause a physical injury or pain," said Sweet. "Where the big potential exists going forward is the human and the robot actually working together, so that they understand and trust what the other wants to do and have ways to communicate. This type of collaboration is in the research phase right now, but it will be key to realizing the full potential of these technologies."

He closed by speaking about technology transfer and stressed that this technology requires innovators and technologists working in tandem with technology transfer experts, so that they really understand the requirements of the operating environment.

Elizabeth Baron of Ford Motor Company, the final presenter, discussed Ford's Immersive Vehicle Environment (FiVE), which is a virtual space at Ford that is "filled" with a life-size virtual vehicle. Engineers wear a headset to walk around the car to evaluate it, just as if they are in a showroom. The tool allows the evaluation of design, fit and finish, manufacturing, maintenance, and human-machine interaction factors—all of which are viewed holistically as part of the product development process. Baron explained, "This is a global tool for collaboration that lets remote workers anywhere connect to the vehicle to understand the health of the car at any point in the process. The engineers can simulate variations, for example, moving around body panels to replicate vehicle assembly. The system always simulates a potential reality; it is usually a characteristic that engineers believe is adequate, but they want to know if it is still optimal in combination with a lot of other variables in the vehicle."

The team also has a virtual-physical hybrid approach that allows them to interact with the vehicle in a seated driving posture. Ford has three stations—an adjustable vehicle; the virtual space; and the cave—which allow them to interact with the technology and design in a number of different ways. Both the hybrid and the virtual tools allow Baron's team to connect the production and design process to enhance and ensure the quality a customer will experience in the finished vehicle. "The purpose of all of these efforts is to bring the voice and needs of the customer into the vehicle development process," Baron said.

DISCLAIMER: This Proceedings of a Workshop—in Brief was prepared by **Sara Frueh** as a factual record of what occurred at the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, or the National Academies of Sciences, Engineering, and Medicine.

REVIEWERS: To ensure that it meets institutional standards for quality and objectivity, this Proceedings of a Workshop—in Brief was reviewed by **Amanda Arnold**, Arizona State University and **Yannis Yortsos**, University of Southern California. The review comments and draft manuscript remain confidential to protect the integrity of the process.

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