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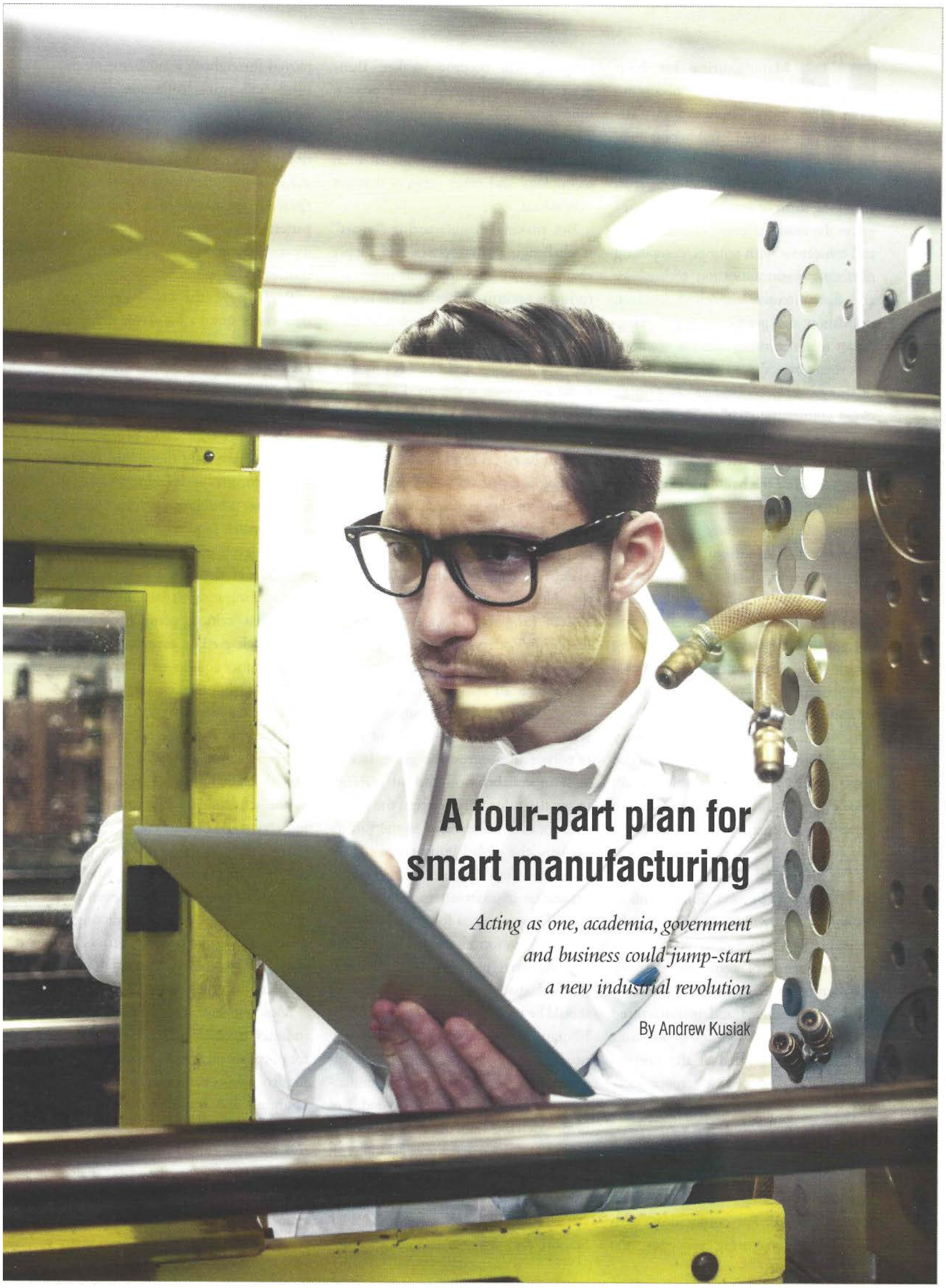


A four-part plan for smart manufacturing

Acting as one, academia, government and business could jump-start a new industrial revolution

By Andrew Kusiak

Manufacturing has been evolving and becoming more sophisticated, automated and computerized since its inception. Smart manufacturing is an emerging form of production that integrates the manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology and data intensive modeling, control, simulation and predictive engineering. Smart manufacturing uses the concepts of cyber-physical systems, the internet of things, service-oriented computing, cloud computing, artificial intelligence and data science. Once implemented, these technologies would make smart manufacturing the hallmark of the next industrial revolution.

The digital economy promises to revolutionize manufacturing. Increasing volumes of data and information are being collected on materials, products and equipment. Data analytics and predictive computer models are being developed to anticipate the failure of a mechanical component or disruption of a supply chain. Tracing product failures back to the source of error or faulty components enables problems to be fixed swiftly, avoiding expensive recalls and litigation. Quick improvements save resources and energy for the enterprises involved.

The shape of all industries will change in a decade and beyond. Some forms of manufacturing will be distributed, others centralized. Instead of producing a restricted range of items and shipping them around the world, many products will be customized and manufactured locally. Personalized drugs or implants could be 3-D printed at the hospital rather than produced at remote locations.

Local vs. global

A polarization of the coupling between manufacturing assets and the enterprise may take place. For corporations with generic manufacturing processes, the coupling will become weaker. Businesses versed in product and process innovation will see a strong coupling. The weakly coupled manufacturing assets may follow the path of information technology and other services that get outsourced.

But making manufacturing "smart" is challenging. Enterprises and supply chains operate globally, while manufacturing is optimized locally. This largely is due to the computer and manufacturing technology lacking the necessary connectivity and the organization structure, which is designed to serve a local enterprise. No single corporation can change complex, interdependent systems based on markets and emerging technologies that are uncertain.

Some of the lessons learned can be taken from past industrial initiatives, such as the Intelligent Manufacturing System Program (initiated in Japan) and the Next Generation Manufacturing System Program (U.S.) established in the 1990s. Both programs had high aspirations; however, the participants could not realize all the envisioned deliverables. The main contributing factors were differences in management styles of corporations across the globe, lack of trust in collaboration and an inability to see the value derived from the global collaborative efforts. But in the future, perhaps, the global outreach of today's industries offers a promise to accelerated realization of smart enterprises.

To boost progress four things are required. A platform is needed for publishing industrial problems and solutions. Physical spaces and cyber-laboratories should be provided to enhance such collaborations. Researchers and industry need to share data to develop models about manufacturing. Smart manufacturing friendly policies are needed. But before delving into the four-part plan, let's look at the current state, along with how the landscape is changing.

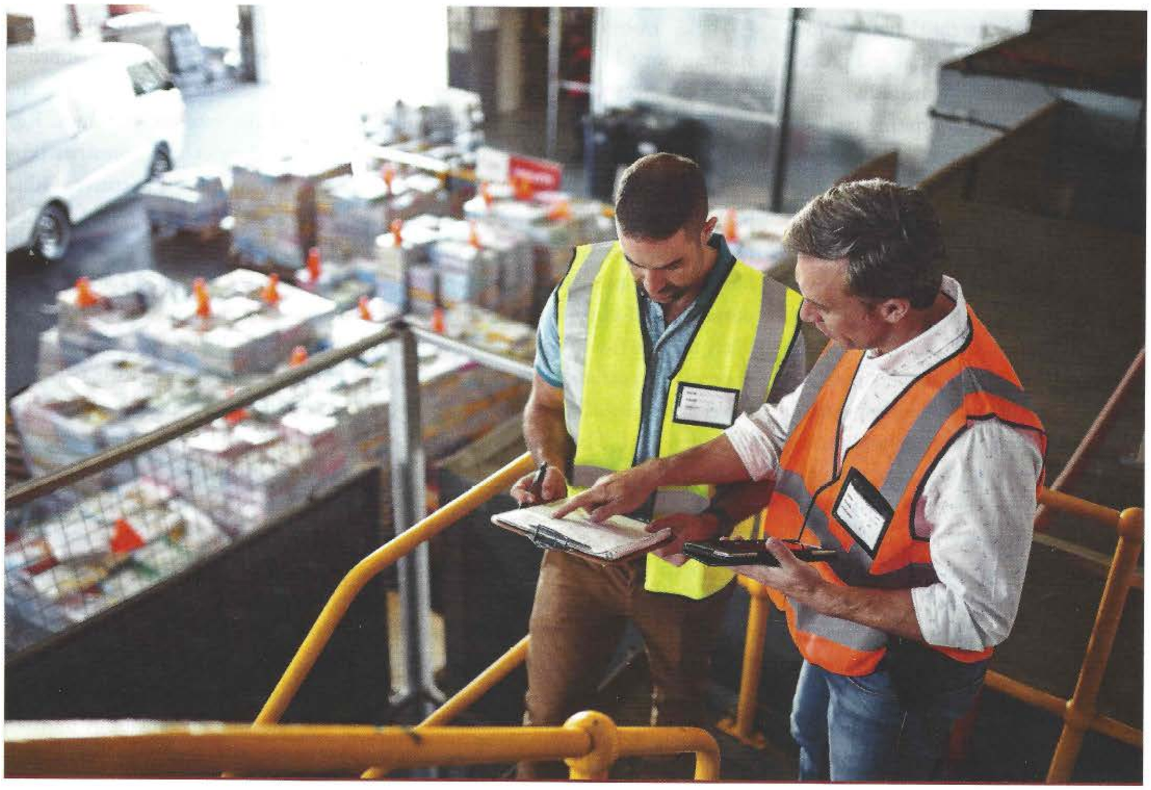
Smart enterprise

Sensors and wireless technologies deployed throughout manufacturing processes will enable collection of a wide range of data, from materials and process parameters, including material composition and properties through the health status of manufacturing equipment reflected in the temperature and vibration pattern to the anticipated product quality and information about products, customers and suppliers.

Right now, the collection of such data varies quite a bit across industries. Aircraft engine companies collect data on engines throughout their life cycles. Automotive companies gather vehicle data. And software companies assemble customer behavior data. While manufacturers have long monitored productivity, processes and product quality, the upcoming possibilities are much greater.

Computer modeling of processes at various levels of an enterprise and integration of data from diverse sources would bring insights into, for example, risks that critical components might not be delivered on time because of severe weather conditions and issues with manufacturing quality. Interactions between phenomena in disparate domains such as materials, processes, productivity and product quality could be explored. Models could show that product quality in the semiconductor or machine tool industry could be assured only if certain process parameters are used to process particular materials. New technologies such as 3-D printing create even more challenging problems of predicting the quality and properties of a printed part given the variability of material, geometry and the process itself.

Most current analysis performed in industry is based on the data collected for purposes other than modeling, ranging from process control to meeting accounting and regulatory needs. Years ago, the industry complained of having too much data, more than could be used, because back then the data analytics tools did not exist. In the spirit of waste reduction, in some cases lean initiatives have reduced the data collection to a



minimum. The manufacturing industry is largely unprepared for making use of big data as the data science is new. It has been rare that data science classes would be included in a standard engineering or business curriculum. Enterprise data are frequently stored in relational databases that were designed for storage efficiency rather than quick access of many parameters such as a long string of truck engine data (e.g., temperature, fuel consumption, mileage and dozens of other data points) that are routinely collected from the operating fleet.

Creative activities and decision-making will increasingly take place in a participatory environment, which will enhance innovation and lead to better decisions. Shared resource models are expanding from carpool rides aimed at reducing highway traffic to Uber-style services in transportation and Airbnb in accommodation services. Likewise, smart manufacturers will share access to manufacturing hardware, while the technology details and know-how of the manufacturing systems will be protected. A company that manufactures refrigerators may purchase production capacity at a wheelchair producer for components that the first manufacturer will install in refrigerators customized for disabled consumers. Buying manufacturing capacity rather than subcontracting components offers the refrigerator manufacturer greater flexibility in production management.

Service and contract models, where production takes place at a facility operated by a third party, are not new to the manufacturing industry. Such models save money by foregoing investing in technology that is rarely used or unproven. With smart manufacturing, these models likely will be deployed at larger scales and with more sophistication.

For example, the rapid manufacturing (a predecessor of 3-D printing) service model was established decades ago. Even large companies were reluctant to invest in rapid manufacturing equipment because of the high initial cost of the technology, its learning curve and uncertainty about its utility. Time has shown that rapid manufacturing technology did not extend much beyond building prototypes, and decades have passed before it re-emerged in an enriched form as 3-D printing.

While the logistics of leasing manufacturing equipment and sharing commercial software could follow the Uber model, sharing the modeling space is a challenge, as investing time and contributing ideas need to come ahead of deriving benefits from the collaborative modeling. Sharing digital models of manufacturing akin to Facebook and Wikipedia may take decades to realize fully. Investing in ideas from a common good is much different than traditional business investment.

Smart manufacturing should enhance sustainability by focusing on materials, manufacturing processes, energy and pollutants. Organic and biomaterials may be produced using little energy in an environmentally friendly way. Three trends are emerging: sustainable product design will impact manufacturing processes; sustainable manufacturing processes will influence the design of products; and product, material and process will be designed simultaneously.

The impact of 3-D printing technology on the market of components and product is barely noticeable despite an extremely high level of interest in this technology. One of the reasons is that the design knowledge of 3-D printed components and products is limited. Though a product of almost any shape can be printed, its quality and structural properties cannot be guaranteed without the proper design. Remanufacturing, reconditioning and reuse are growing. Sustainability will blur the line between manufacturing and service, for example, by reconditioning used products.

Minimizing transportation distances for products and components will reduce costs and environmental harms. There are two broad industrial transport categories: internal, which involves moving items using specialized factory equipment or various trucks, and external, which moves the materials, components and products across the supply chain on ground, water and air transport. Robots and autonomous flying, floating and driving vehicles will increase the autonomy of transport and enhance its sharing. Some autonomous transport technology, especially ground vehicles, is almost ready to be deployed. Pending solutions to some regularity issues, human factors and overcoming the initial cost barriers to their deployment could happen tomorrow.

Changing global manufacturing supply, value and profit chains requires collaboration across industrial sectors. This should start with energy and healthcare, as they have the greatest societal impact. For example, energy generators could be manufactured in smart factories with no negative impact on the environment throughout their life cycle. Wind turbines generate electricity from the wind, which is an environmentally friendly process; however, various materials (predominantly metals) are used to construct the turbines.

These materials and components are transported, quite often across the world, to erect a turbine that one day (usually in approximately 20 years) will become obsolete. Questions need to be asked. For example, how much thought has been given to the design of a turbine to minimize its native environmental footprint in its manufacturing, transportation and disposal phases? It is not likely that the fate of wind turbine components, the gearbox, generator, nacelle, tower and miles of cables has been carefully designed. The same question applies to the vast majority of consumer and industrial products.

International collaboration efforts have been initiated in the past. In the 1990s, the Intelligent Manufacturing System (IMS) Program in support of industrial research was promoted in Japan. It was clear that the industry of one country alone could not reshape manufacturing and that international cooperation was needed. Major companies from Japan, the United States, Korea and Europe have initiated collaborative efforts for the future of manufacturing, with Japan having the largest number of actively participating corporations.

In the United States, with a strong industrial presence from Japan, many of the IMS activities have taken place under the umbrella of the Next Generation Manufacturing System Program, which was established as a not-for-profit venture. Later, the intelligent manufacturing program was expanded, with the European Union supporting the IMS effort and establishing research programs in intelligent manufacturing. Perhaps the main lesson learned from these collaborative efforts was that besides technology, trust, will, conviction and policies are needed to accomplish a common good.

Some new collaborative efforts already have been initiated. The Smart Manufacturing Leadership Coalition was established in the United States to develop a shared infrastructure for the implementation of smart manufacturing capabilities. The Industrial Internet Consortium (U.S.) has been launched as a global organization promoting the growth of the internet of things. Key German industries and ministries promote the Industrie 4.0 initiative. Other regions and countries have launched their own efforts: the European Union's Factories of the Future, a public-private partnership with an investment of 7 billion euros by 2020 to develop a blueprint for smart manufacturing; Japan's Monozukuri; and China's Made in China 2025 initiative.

The expansion of globalization has eased some of the reservations that industry might have had toward collaboration. This, in concert with developments in computer, communication and manufacturing technology as well as advances in artificial intelligence and data science, have served as disruptors for transforming the previously initiated intelligent manufacturing efforts into smart manufacturing.

The four-part plan

The progress in smart manufacturing would benefit from four actions.

1. Establish problem definition networks. Science, business and engineering professions focus on solving problems. However, there is no well-established forum where practitioners and researchers could discuss, develop and publish specifications and formulations of emerging industrial problems. Establishing such online platforms for interdisciplinary problem specification and definition would accelerate the progress.

A crowdsourcing site allowing for communication among users could serve as a candidate for an initial business model of the problem definition network. The demonstrated success of crowdsourcing businesses could be used to demonstrate value from the envisioned networks.

2. Develop cyber-platforms of modeling and innovation. Creating a network of open development platforms involving key industries and

A revolution in silk and diamonds

The coming fourth industrial revolution will bring unheard of technological innovations, including high-quality silk made from juice manufacturers' waste pulp, diamonds mined in labs and fabric made with milk that feels like the best cashmere, according to the *Financial Times*.

The newspaper discussed the possibilities in an interview with Miroslava Duma of Fashion Tech Lab (FTL Ventures) – and the exotic ideas are closer to reality than you might think.

In fact, the Italian luxury house Salvatore Ferragamo launched a capsule range of print scarves and dresses made in collaboration with Orange Fiber (the peel-recycling company). According to the newspaper, the silk mix was manufactured in large part from the recycled fruit. And the lab mining concern already has raised $100 million in investment, piquing the interest of celebrities and fine jewelry houses.

research communities would broaden the scope and scale of collaboration. Different forms of such platforms could be explored, from online forums to maker spaces and face-to-face innovation spaces.

The maker movement is growing largely in academic settings. Some industry players, e.g., SRI, PG and Google, have invested in the innovation spaces. The U.S. National Science Foundation is promoting similar solutions in limited industrial and academic settings. These experiences, when broadened, expanded and shared, could be transformed into the proposed platform. The platforms would promote the development of data-driven models and software tools. Some of the platforms would naturally become viable businesses, but scaling up the collaborative modeling makes it complex and costly. Issues of trust and revealing information must be overcome. Diverse ideas, cultures and openness are needed. Getting small and medium enterprises involved is crucial.

Cyber-platforms with shared spaces for expert-to-expert and beyond interactions, data management, model development, solution generation, benchmark studies and transformation of the deliverables into commercial products are needed.

3. Make data sharing a reality. Neither of the two suggested platforms – modeling or innovation – could be developed without data. Despite the growing interest in data, industry generally does not know whether their existing big databases contain useful information. Quite often, such data has not been analyzed, and therefore its value is not known. It is almost certain that additional data will be needed to accomplish the smart manufacturing transformation. The sooner the data needs are determined and the data is collected, the better for the industry.

The task of sharing big data to feed the collaborative platforms is more complex. Elaborate data sharing and protection schemes are needed. Feeding and managing such data are problems that all entities involved – industry, academia and government – would need to solve. The increasing awareness of the potential value hidden in data helps academic access; however, the road to massive data exchanges is long. The data will be a cornerstone of collaboration from the problem formulation to the development of enterprise models.

4. Enact policies that are friendly to smart manufacturing: There is no doubt that industry should drive the transformation to smart manufacturing. Yes, the government has a role to play in filling gaps that may either lack ownership or be too risky for industrial investment. The renaissance of manufacturing has been a topic of intense discussions in the last few years with plenty of hypotheses, calls for actions and implementation plans emerging.

By acting as one, industry, government and academia can make the next industrial revolution a reality. ❖

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