"Never let a crisis go to waste."
What are the lessons from the pandemic crisis to benefit manufacturing?

Future Manufacturing: Bracing for and Embracing the Postpandemic Era

Jennie Hwang (NAE) is CEO of H-Technologies Group.

Jennie S. Hwang

As the world is entering the Fourth Industrial Revolution (dubbed Industry 4.0), one recurring question for manufacturing is what will be involved in terms of running a business and making products. The previous industrial revolution brought advances in electronics and information technology that enabled astounding economic prosperity and manufacturing automation. What does the Fourth Industrial Revolution entail? How will it affect the international standing of US manufacturing?

Impacts of Industry 4.0 and the Pandemic for Manufacturing

One way to define Industry 4.0 is the integration of cyberphysical systems, cloud and edge technology, high-performance computing, the internet of things and internet of services, and their interoperability and interaction with humans in real time to maximize value creation. Industry 4.0 will leverage digital technologies, advanced artificial intelligence, and reliable wireless connectivity to advance autonomous, intelligent cyberphysical systems (Hwang 2016). One of the elegant fruits of Industry 4.0 is intelligent manufacturing, which is manifested in the smart factory infrastructure.

Adding to this dynamic environment is the coronavirus pandemic, which has resulted in unprecedented disruptions in virtually every aspect of life. From a 30,000-foot view, global macroeconomics is facing gusty headwinds, bracing for impacts from social distancing, lockdowns, and economic slow-

downs and shutdowns. Compounding these impacts, the world's two largest economies—the United States and China—are butting heads on trade and geopolitical disharmonies.

Against this formidable backdrop, what are the lessons from the pandemic crisis to benefit future endeavors in industry? How should the manufacturing sector respond? And what are the main issues to be tackled in the near and long term?

There will be a new normal in business and manufacturing, just as in daily life. There is a saying, "Never let a crisis go to waste." For manufacturing, the current crisis is expected to propel progress toward fulfilling the potential of Industry 4.0. The pandemic has made the global manufacturing sector think more deeply and work harder to meet the need for innovative ways to run and monitor operations.

AI can identify manufacturing quality issues in real time and spot faults on the production floor faster than humans.

This article examines five fronts that are deemed essential to advanced manufacturing going forward: the role of new and emerging technologies; revised business strategies for outsourcing, with engineering as the core; data-driven manufacturing operation; supply chain strategy and management; and changes in workforce practices and skills. These five areas are expected to dictate the global competitiveness of manufacturing.

The need to look forward with a new perspective was well captured by robot pioneer Seiuemon Inaba, who created the largest manufacturer of industrial robots in the world (Fanuc Corporation, a spin-off from Fujitsu Ltd.): "There is history behind technology, but for engineers, the past doesn't exist. There is only creativity, always looking to what is next" (Tsuneoka 2020).

Role of New and Emerging Technologies

Industry 4.0 is expected to pull manufacturing into an intelligence-directed and technology-centric smart factory infrastructure characterized by agility, flexibility, automation, autonomy, and cost efficiency. Advanced manufacturing hinges on the development, deployment, and implementation of next-generation wireless technology (e.g., 5G and higher), the internet of things (IoT), advanced artificial intelligence (AI), and high-performance computing (cloud and edge).

One challenge is the seamless incorporation and coordination of these foundational technologies. Another is management and protection from cyberrisks and quantum attacks, an area that demands ongoing effort. It is essential to put the evolving technologies together to perform as a reliable cyberphysical system in the manufacturing landscape.

Those challenges are an area of ongoing global competition among scientists, engineers, companies, and countries. The ability to leverage technologies by integrating them in timely, creative, and reliable ways will afford competitors the upper hand, leading to business success and economic rewards as well as the nation's competitive edge. Government investment and regulatory policies will play an important role.

AI and machine learning (ML) have become everyday terms, although their potential is not fully developed. On one hand, there is exuberance about evolving capabilities that promise to advance business and manufacturing. On the other, there is trepidation about unknown or possible unintended consequences.

AI processes data through ML and deep learning neural networks by collecting data, analyzing information, creating and training a model, and ultimately making decisions based on real-time events. It is expected that next-generation AI will not only create a model based on learning from continually generated *meaningful* new data but also advance that model through *unsupervised* learning to understand cause and effect (Toews 2020). For example, AI can identify manufacturing quality issues in real time and spot faults on the production floor faster than humans through monitoring and machine-to-machine and human-to-machine communication, thanks to superconnectivity and speedy, low-latency, high-capacity communication technology.

As the future of the internet is expected to move to wireless, it will depend on next-generation wireless technology, the gateway to IoT connectivity for greater levels of automation and autonomy. IoT sensors embedded in products and machines provide information about product performance during service life through data exchange between the production line and the product. This is a great use case for advanced

manufacturing, making tomorrow's factories run faster, more economically, and with more agility, flexibility, and autonomy.

The convergence of AI and IoT will create an intelligent network of devices that can gather and analyze voluminous data—from raw materials, production lines, finished products, warehouse activities, and customer complaints—remotely in real time and translate the data into intelligence and actionable steps locally. The IoT can also capture data on energy use, maintenance records, workers' safety, and other operational parameters.

In addition, connected, intelligent machines can trigger maintenance processes autonomously. Data analytics can facilitate the detection of process inefficiencies and thus reduce production costs and enhance product quality. It is also possible to monitor how customers use the products, helping companies with customer service, warranty management, and product design.

Better use of evolving technologies to enable real-time contextual understanding and monitoring of the manufacturing operation and environment leads to smarter decisions. Smart factory infrastructure can improve manufacturing and autonomous on-demand production.

To achieve these goals, one question to consider is, What is needed to accelerate the adoption of new technologies—to effectively leverage AI, IoT, 5G, and bolt-on technologies and supply chains in a timely way to achieve reliable manufacturing operations?

Revised Business Strategies for Outsourcing

The first order of business for manufacturers is to revisit and strategize their business model, with particular attention to the question of outsourcing—offshore vs. onshore procurement. Simply put, this is about finding a better or more cost-effective way to have products made or services rendered, freeing up resources and time for essential or long-term mission-critical tasks.

For the past 3 decades, technology-driven industries have been characterized by fast-paced technological development, down-spiral pricing, and market globalization. They also have been the top drivers behind manufacturing outsourcing. In a competitive climate and with sound business justification, the outsourcing of certain functions can be advantageous and a smart business move.

In the United States, it is reasonably fair to say that the electronics industry essentially pioneered the implementation of outsourcing in the late 1980s and early 1990s (depending on how the starting point is defined). Gradually but steadily, manufacturing outsourcing (on- or offshore) has spilled over to other sectors, from pharmaceutical to consumer staples, as well as to other operational functions, such as human resources and information technology management. With globalization, the scope of outsourcing has continued expanding and its capabilities have proliferated, so that it is an integral part of supply chain management and business strategy.

In a competitive climate and with sound business justification, the outsourcing of certain functions can be advantageous.

Manufacturing outsourcing can offer a number of advantages in business aspects such as the following:

- economics (cost savings)
- improvement in business focus
- operational efficiency
- technological prowess
- capital allocation
- time to volume
- speed to market
- geographical advantage
- proximity to customers
- risk shared or transferred among ecosystem participants
- streamlining (reduced complexity) of business.

In the aggregate, these potential advantages offer tremendous appeal to a business, particularly in meeting immediate competitive needs. The benefits can be vividly evident when a goal-oriented and well-thought-out strategy is effectively executed.

But caution is in order to ensure that technology-based companies do not forgo core engineering com-

petencies, including manufacturing technology, by outsourcing.

It is always a strategic decision to take advantage of the benefits of outsourcing without losing foundational knowledge and know-how. The decision requires assessing core competencies and sorting out the functions or products for outsourcing from those that need to stay in-house. Even if the decision is made to outsource a product or function, in-house engineering competencies are needed to pose the right questions in order to select the right service provider to produce quality products as intended. To outsource a task is one thing; to give up a core knowledge base is something else entirely.

To outsource a task is one thing; to give up a core knowledge base is something else entirely.

Outsourcing should be considered as a well-planned strategy, not as a relief tactic. And the strategy should distinguish between a temporary lift and long-term business enhancement.

The following questions are important to address when considering decisions about factory siting:

- Are factories logically, strategically, and preemptively distributed in terms of geographical locations to ensure reliable manufacturing operation?
- Is there a need for redundancy of factories?
- What are the critical criteria for redundant factories?

A number of years ago, during a dinner meeting with Kazuo Inamori, founder and chair of Kyocera Corporation, I asked about his view of outsourcing manufacturing. He replied candidly (paraphrased), "How can an engineer not do manufacturing and an engineering company not produce products!" I appreciated his sentiment.

In a product development cycle—from innovative concept to technology development, manufacture of the product, and introduction of the product to the marketplace—each milestone is essential to the product's eventual success. The spirit and the principle of manufacturing are part of a product and should be thoroughly embraced and incorporated with or without outsourcing.

It is prudent and wise business practice for original equipment and original design manufacturers to continue acquiring and maintaining engineering strength and know-how to ensure future readiness. Government can and should play a role in incentivizing and reinvigorating the country's manufacturing prowess.

Data-Driven Manufacturing Operation

Creativity propels technology, which in turn builds a new paradigm. With human-machine teaming, for example, synergistic performance is achieved by integrating judgment-focused humans and prediction-focused AI agents. AI should be responsibly implemented to augment human cognition and capabilities without causing ethical and social concerns—an ongoing challenge.

One of the challenges of deploying technologies such as AI as reliable tools is the lack of sufficient relevant, bias-free, and accurate data. AI requires a vast amount of data to function as desired. Accordingly, preparing AI and edge computing to facilitate manufacturing operations by initiating a robust program to collect, clean, manage, prune, and use data is increasingly important.

Data tell the story! With privacy and security precautions, data capabilities for remotely monitoring factories can provide a clearer view of operations, equipment performance, and maintenance, allowing the operation to speed up production, reduce waste, and avoid downtime by quickly identifying maintenance and production issues. Identification and extraction of relevant data to feed into artificial intelligence can facilitate the prediction of production and supply chain problems. Factories can shift from reactive analytics, reporting on what happened, to proactive analysis of what could happen and suggested actions, asking the right questions at the right time and solving problems in real time. For today's factory and in preparation for the future, figure 1 illustrates the IPC Connected Factory Exchange (CFX), enabling contextualized data exchanges and machine-to-machine interactions to help move manufacturers toward smart factories.

Manufacturing companies need to develop a thorough understanding of the available technologies that can be utilized to translate business objectives into business roadmaps for operational excellence to produce competitive, reliable, and economical products that perform in the intended marketplace in a timely fashion. The smart factory of the future is poised to run essentially

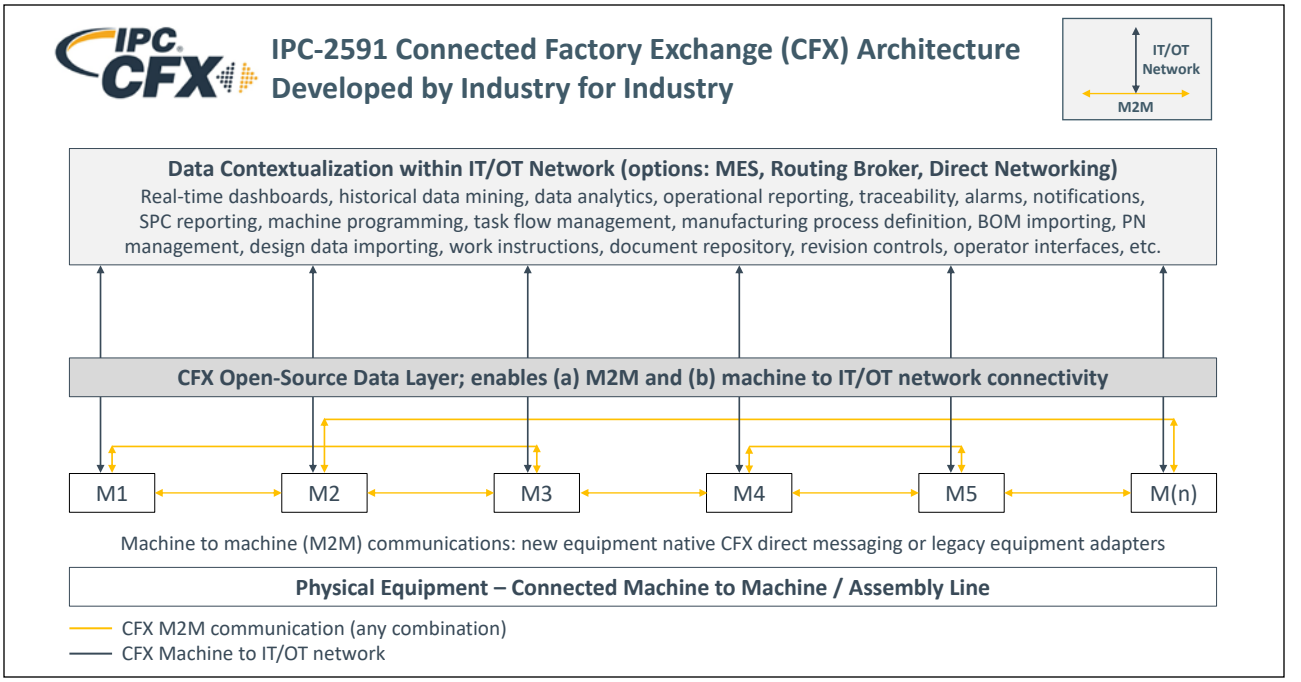

FIGURE 1 Connected Factory Exchange (CFX) architecture developed by industry for industry. BOM = bill of materials; IT/OT = information technology/operations technology; M1… = machine 1…; MES = manufacturing execution system; PN = part number; SPC = statistical process control. Courtesy of IPC Association, Matt Kelly, chief technologist.

autonomously without human intervention on the production floor, learning and adapting in real time with self-correcting and self-optimizing ability.[1]

In the manufacturing environment of the future production facilities and logistics systems will be synchronized without the need for on-site human tasks.

Supply Chain Strategy and Management

In the postpandemic era, inventory and supply chain management will be even more important for manufacturing efficiency and even a manufacturer's viability. Plans must be developed to address immediate needs as well as medium- and long-term strategies.

In the long run, factories' ability to keep track and control of inventory in terms of dollar value and days' worth is crucial to a company's bottom line. Doing well in this area reduces the likelihood of production outpacing demand and avoids cash flow traps.

Using cyberphysical systems, supply chains can be fully integrated and automated. Such systems deployed throughout the value chain generate the link between data and material flows, enabling complete and constant visibility of the supply chain. For example, IoT devices can be outfitted at checkpoints in the distribution process to keep track of parts and products as they are shipped from factory to warehouse and customer sites. Such real-time tracking enables the formulation of reliable inventory forecasts, timely reaction to unexpected changes in the production line, and avoidance of unscheduled downtimes.

What are the lessons learned from the pandemic crisis? I suggest several pragmatic questions that should be addressed strategically and operationally:

- Is a reliable dependency of the chain of suppliers in place?
- What is the technology used to monitor the supply chain?
- Is a risk management program in place?
- What is the risk mitigation plan and its order of priority?
- Are policies and procedures to address risks and threats in place?
- Do all strategic raw materials have alternate source(s), if justified?

[1] Another viable approach is to leverage the digital twin concept to create virtual counterparts of physical assets (Kube 2018) to optimize data flows from design stage to process engineering to manufacturing to the customer.

- Do all mission-critical components have alternate source(s), if justified?
- What is the desired level of visibility throughout the supply chain?
- What is the predictability of the supply chain?
- Is there an adequate system in place to ensure internal and external cybersecurity to minimize cybersecurity-related risks and disruptions to the supply chain?

Weighing overseas (offshore) sources against domestic (onshore) sources in terms of quality, cost, delivery time, and in-time availability is a strategic as well as an operational imperative. Implementing newly available technologies to minimize risk and optimize the efficiency of supply chain management is increasingly a necessity.

Changes in Workforce Practices and Skills

The pandemic catalyzed remote work, and the required social distancing has prompted the need for more sophisticated ways to monitor factory operations, including the farther and faster deployment of data management and analytics. As the pandemic continues and social distancing remains advisable, near- and long-term plans should be formulated and implemented to ensure workers' safety and health while optimizing workforce productivity and manufacturing efficiency.

Remote work and social distancing have prompted the need for more sophisticated ways to monitor factory operations.

Unlike other industry sectors, manufacturing still depends on the physical presence, to some extent, of skilled and well-trained workers. But some functions can be performed remotely (e.g., through work from home). One of the advantages of remote work is the removal of geographical barriers in hiring, enabling employers to seek the best-skilled workers regardless of where that talent resides.

Many in the workforce have cited the flexibility of off-site work as an advantage. One recent survey found that more than 75 percent of respondents would like to continue working remotely at least occasionally, and more than half want it to be their primary way of working after the pandemic crisis ends (Torry 2020). Asked what it is about remote work that has worked well, respondents' top three answers were no commute, reduced meetings, and fewer distractions. In a separate survey, 87 percent of workers wanted the ability to choose where, how, and when they worked, blending office-based and remote work (Reuters 2020).

As wireless technology becomes more available and more reliable for required connectivity, so will innovations in how people work to achieve maximum efficiency and output, including in their work from home. Going forward, a hybrid work model is most likely to be implemented throughout the companies and organizations, although the extent may vary depending on the nature of the business and the organizational operation.

With the massive amounts of data generated from different checkpoints, data management is crucial, including efforts to ensure data quality, accuracy, and security. Over the next decade, a skilled and educated workforce, bolstered by continuing education and training programs—especially in data science, data engineering, advanced computing, and system integration—will be essential to manufacturing competitiveness in the global landscape.

Concluding Remarks

I have been engaged for more than 3 decades in electronic hardware innovation and manufacturing, in both hands-on and advisory capacities, for onshore and offshore operations ranging from fledgling entrepreneurial businesses to robust enterprises operating on three continents. This firsthand experience has shaped my perspectives in manufacturing.

The best way to prepare for tomorrow—and further unexpected crises—is to do today's work well. Technologies' benefits for manufacturing are abundant, yet challenges remain. The implementation of technologies is not a one-time or one-size-fits-all decision. It calls for continuing and targeted efforts. As Industry 4.0 strides ahead, the adoption of new, evolving technologies is critical to a business's viability and its effectiveness in confronting the challenges resulting from the pandemic, associated blows to the economy, and ongoing Sino-US tensions and trade uncertainty.

The pandemic crisis has created an unprecedented opportunity to boost individual manufacturers' competitive edge as well as the country's global competitiveness in manufacturing. "Winners" will be those that work most effectively with emerging technologies and adapt adroitly to the changing environment. The manufacturing workforce's ability to adapt to change has been tested and in many ways enhanced, and supply chain management is expected to be more resilient.

There is a rainbow after the storm. Crises can create opportunities to build a better normal, and that is certainly true now. Let's brace for the challenges and embrace the opportunities!

References

Hwang J. 2016. The Fourth Industrial Revolution (Industry 4.0): Intelligent manufacturing. SMT Magazine, July.

Kube G. 2018. How to use digital twins to disrupt manufacturing. Digitalist, Apr 4.

Reuters. 2020. Nearly nine of 10 workers want to keep work-from-home option: Survey. Oct 14.

Toews R. 2020. The next generation of artificial intelligence. Forbes, Oct 12.

Torry H. 2020. Many want to keep working from home. Wall Street Journal, May 28.

Tsuneoka C. 2020. Japanese engineer transformed factories with Fanuc robots. Wall Street Journal, Oct 17.