Industry 4.0's Impact on Industrial Automation Branches

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As problem-solvers, engineers combine practical knowledge of science and mathematics to drive creativity and innovation for society's benefit. Engineering is a broad and diverse field, and the emergence of Industry 4.0—the combination of the Industrial Internet of Things (IIoT), automation, robotics, and additive manufacturing—is having a significant impact on the branches of industrial automation, including systems, process, and design engineering. That impact ranges from how products are designed for manufacturing in smart factories to redesigning the factory operations and manufacturing processes themselves.

Traditional manufacturing methods are optimized for mass production. Industry 4.0 factories are designed to support flexible manufacturing and mass customization. Mass customization and the delivery of more personalized products drive higher brand loyalties and increase business success. The various branches of industrial engineering are essential to developing the innovations needed to support Industry 4.0.

Coming out of universities, new engineering graduates all have fairly similar backgrounds with a carefully regulated set of required classes and only a few electives to explore their interests. Once they take that first step into the career of their choice, these engineers will embark on a wide variety of design roles, each requiring different elements from their education and different capabilities from the individual.

The following examines the roles of systems, process, and design engineers within the design chain of bringing new industrial automation products and projects to fruition and how those roles are expanding and evolving because of Industry 4.0.

The Development of System of Systems

The emergence of cyber-physical systems (CPS) and systems of systems (SoS) are two defining characteristics of Industry 4.0. CPS support increased human-machine collaboration with ubiquitous wireless connectivity that integrates computational and physical assets from the factory to the cloud. CPS is having a disruptive impact on the branches of industrial automation and are enabling the SoS development.

An SoS is a group of systems that work together to enable a new and more complex system that supports greater capability and performance than simplify the sum of the constituent systems. SoS is an emerging field in Industry 4.0, and systems engineers and researchers are still developing the quantitative analysis tools to optimize SoS.

Systems Engineering for Industry 4.0

The term systems engineering was first used during Industry 2.0 at Bell Telephone Laboratories in the early 1940s. Systems engineering consists of five phases, and while systems have become increasingly complex with Industry 4.0, the basic phases remain the same:

1. Preliminary system studies and program planning.
2. Exploratory planning, which includes selecting objectives, preliminary systems synthesis, and analysis, beginning to identify the preferred system solution.
3. Development planning, which includes refining the objectives, refining the systems synthesis and analysis, identifying a final system solution.
4. Development implementation, which includes the development of system elements and components and the integration and testing of these parts.
5. Concurrent engineering, a continuous process taking place while the system is operational and being refined and updated.

Systems engineering is a multi-disciplinary field. A system typically includes hardware, software, equipment, facilities, personnel, processes, and procedures needed to accomplish a given task or set of tasks. The primary purpose of systems engineering is to organize information and knowledge to assist those who manage, direct, and control the planning, development, production, and operation of systems. (**Figure 1**)

Figure 1: Systems engineering is a multi-disciplinary field including hardware, software, equipment, facilities, personnel, processes, and procedures. (Source: Gorodenkoff - shutterstock.com)

SoS engineering takes the systems engineering process further and focuses on planning, analyzing, organizing, and integrating the capabilities of multiple systems. The use of the IIoT and cloud computing can support the integration of multiple systems into an SoS. The collaborative yet autonomous systems can deliver greater capabilities than the sum of the capabilities of the individual constituent systems. Increasing the complexities that systems engineers must deal with when considering SoS implementations, the mix of systems can evolve and include yet-to-be-designed systems or capabilities and technologies.

The emergence of Industry 4.0, CPS, and SoS has increased the complexity of the challenges faced by systems engineers. Among these challenges are:

- Digital control and optimization of customized production
- Increasingly flexible and adaptive automation
- Growing human-machine interaction
- Artificial intelligence (AI) and machine learning (ML) from the edge to the cloud

The new generation of system engineers has developed skills for mining and analyzing data. Configuring how that information is captured is paramount. Increasingly, that data is captured by embedding an intelligent edge or gateway that seamlessly collects the correct data from the factory floor. That calls for the combined skills of process engineering to identify meaningful and valuable data and design engineers to develop equipment and devices capable of capturing and reporting data in real-time.

Process Engineering

Traditionally, process engineers are responsible for designing, implementing, and optimizing chemical and biochemical processes, especially continuous ones within the chemical, petrochemical, agriculture, mineral processing, food, pharmaceutical, and biotechnological industries. With the developments of Industry 4.0, that definition has expanded to include the processes needed to support mass customization of all types of products.

Figure 2: Massive deployments of wireless sensors and the growing use of additive manufacturing (also called 3D printing) technologies are new opportunities and challenges for process engineers. (Source: Gorodenkoff - shutterstock.com)

Almost everything is connected in Industry 4.0 factories—and sensors are everywhere (**Figure 2**). Process engineers need to maximize the value of massive networks of connected sensors. What data is relevant, what is not required, should the data be analyzed on the edge of the machine or robot, or in an on-site data center that has more computing power, or in the cloud with even more computing power? At all levels, process engineers use sophisticated software that collects, transfers, and processes sensor data to monitor production processes and identify inefficiencies in specific processes and machines in need of preventative maintenance. Adding AI and ML results in operations that are data-driven and self-optimizing in real-time.

Many factories include a mix of equipment, including legacy machines without intelligent controls, sensors, or communications, and new systems optimized for Industry 4.0. That can result in production islands in which parts produced by one set of machines go to another for the next step in the production process. Still, the various islands are not connected, and data from the first production island does not follow the part of the next island. This is another place where IIoT can be leveraged. Using wireless sensors and IIoT, process engineers can connect previously isolated production islands and significantly improve the factory's operation.

To achieve maximum benefits, process engineers analyze each process to determine the leanest approach to provide a flow of meaningful data between the islands and a central monitoring and control platform. Process engineers are empowered to implement continuous improvement programs throughout the factory with the proper sensors and interconnects.

Additive manufacturing (AM) is another powerful new tool that process engineers can leverage in Industry 4.0. AM can produce structures with internal lattices for lightweight parts with increased structural strength. Using AM, process engineers can design systems to customize personalized components such as medical devices and implants that are fitted to individual patients. AM is also being leveraged in various market segments, from consumer devices to defense and aerospace systems. Effectively developing AM processes requires a close partnership between process engineers and design engineering. Design-engineering tools for AM are increasingly sophisticated and enable component consolidation and product simplification and generate complex internal structures.

Design Engineering 4.0

Figure 3: Design engineering for Industry 4.0 can combine AM and VR technologies to develop customizable products. (Source: FrameStockFootages - shutterstock.com)

The tools that design engineers have available to them in Industry 4.0 have advanced. New computational modeling techniques such as digital twins and virtual reality are emerging. Together with the development of AM, these new modeling techniques support the development of complex shapes and lightweight and strong internal structures (**Figure 3**). Conventional computer-aided design (CAD) tools do not help model highly complex surfaces, shapes, and interior structures. New design platforms appear to create and validate thousands of options in real-time, identify the design with the best cost/performance tradeoff and deliver the design files ready for use by automated AM work cells.

Digital Twin technology is the most advanced of the new computational modeling tools that design engineers can use. A Digital Twin is a digital representation of all the aspects of a physical object, including its geometry, various constraints, performance capabilities, manufacturing parameters, and so on. These Digital Twins can be individual components or complete assemblies whose design and production needs can be optimized simultaneously.

Using these virtual design tools, engineering teams can collaborate from different locations in real-time throughout the design process. Because Digital Twins is based on complete multi-physics modeling, they are robust and optimized for specific manufacturing process capabilities. The use of Digital Twins also supports rapid innovation and shorter product development timelines.

Virtual reality (VR) technology is also expanding the tools available to design engineers. VR can be used to produce a virtual prototype. Using VR to supplement or even replace traditional CAD tools can accelerate and enhance innovation, speed the identification of operational obstacles and refinement of features, and support collaboration between a range of specialists in real-time. Designing products suited to mass customization requires that product design and simulation of manufacturing processes occur interactively, and that demands the real-time interaction of teams of specialists.

Design engineers have always operated as part of a team with other engineers and designers, including process engineers, test engineers, project engineers, marketing specialists, industrial designers, etc. The development of virtual environments and tools will increase opportunities for collaboration.

A trend in Industry 4.0 design engineering considers energy efficiency and energy savings issues on a more holistic basis. Expanding on the concept of energy efficiency, the new focus is developing methodologies that can quantify energy consumption throughout the entire product lifecycle chain, including obtaining the materials, manufacturing the product, and even recycling or disposing of the product when its useful life is over.

Conclusion

Industry 4.0 is having an enormous impact on all branches of industrial automation. It is changing the systems, processes, and products that are being designed to support mass customization. It is changing the tools available to engineers and the interactions that engineers have with other members of the design teams. It also is changing how products are defined to include comprehensive measures of energy consumption and energy efficiency for manufacturing processes and product operation and use.