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UNIVERSAL-TRANSLATOR PROTOCOL

MOTOR MAINTENANCE MATTERS

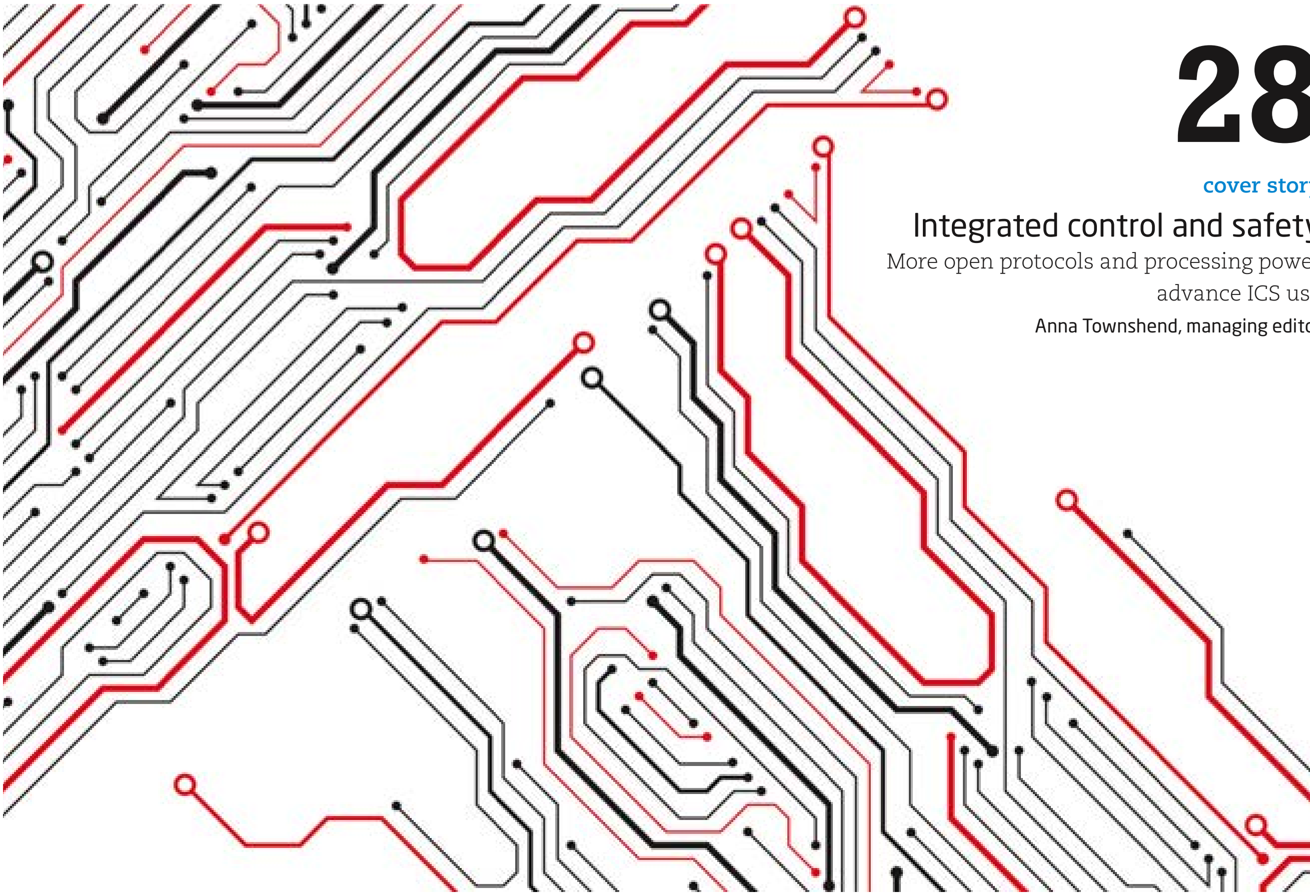
TSN IMPROVES PRODUCTIVITY

integrated

CONTROL & SAFETY

More open protocols and processing power advance ICS use

OCTOBER 2022



FEATURES

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COLUMNS

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Mike Bacidore

editor in chief
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Robots need to be in school

OVER THE NEXT decade, robots and automation will influence the look of employment, according to 80% of education professionals. But only a quarter of educational organizations are using robots in teaching programs, according to a survey from ABB (www.abb.com).

Investment in robotics and automation are planned by 70% of U.S. and European businesses over the next three years, as indicated in the 2022 ABB Supply Chain Survey, which also revealed a growing trend in U.S. and European businesses toward reshoring or near-shoring operations to build resilience in the face of global challenges. Most important to controls-automation and discrete-manufacturing professionals is a significant education gap identified by the survey in the skills necessary for these strategies to succeed.

A similar survey, the third annual UiPath (www.uipath.com) survey of U.S. business executives in C-level and senior management roles, revealed that 62% of executives are struggling with the current labor shortage, and so 78% of them are likely to invest or increase their investment in automation to manage high turnover rates. As a result, 85% say that incorporating automation and automation training into their organization will help them retain employees and attract new talent, according to the 2022 UiPath survey.

Despite this appetite for automation, a significant gap in education and training was identified.

Despite this appetite for automation, a significant gap in education and training was identified by the ABB survey.

The UiPath survey also indicated that one in three executives cites a lack of skills training as a reason why people leave their jobs. Only 51% of organizations offer automation training, according to this survey. Sixty-three percent offer on-the-job training of automation skills during work hours, while 29% train outside of work, but costs are subsidized by the company. Organizations are expanding access to automation technology to provide employees with automation skill sets, but will training keep pace with implementation?

Through more than 100 global partnerships with schools and universities, ABB generates curriculum materials with education providers to help educate future generations. Illinois State University (ISU) in Normal, Illinois, is one of those, using ABB robotics and software to train tomorrow's workforce. The Department of Technology (DoT) at ISU trains students to program and operate industrial robots. "One trend that I think we're seeing clearly is an increased demand for our graduates," said Dr. Kevin Devine, College of Applied Science and Technology professor in the ISU DoT. "The industry is clamoring right now for qualified people, and we're having a lot of trouble meeting that need." cd

M Bacidore

Jeremy Pollard
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When to purge and pressurize cabinets

WHEN DESIGNING AND implementing systems in hazardous locations, it's always a good idea to put on your student hat and dig in.

Dust and gas make up the two most volatile environmental substances we know. There are various classifications of each sector, with subdivisions in each. The main reason for automation devices in these locations is, of course, to bring the control to the operators and the process. But we can't have an operator pressing a button and blowing up the environment.

One of the main instruments of localized control and monitoring is the human-machine interface (HMI). The application of rated HMI screens and enclosures requires some pretty interesting strategies.

> The enclosure's metal gauge may have to be reinforced due to the increased pressure.

Do you place the actual touchscreen HMI within the confines of the environment allowing the HMI to directly access the control network? Or do you simply have a monitor with the computer running the HMI software in a non-hazardous location? Do you need an intrinsically safe video connection to feed the monitor?

There have been some interesting solutions, including a mobile tablet that connects wirelessly to the network, which mimics the HMI screen located somewhere else. This tablet would be rated for the environment.

The most common solution it seems is having a purge-and-pressurization system for enclosures that houses general-purpose equipment and can be employed in the hazardous location environment.

So, for HMI solutions you would use a rated touchscreen in the face of the enclosure and use a controlled purge and pressurization system for the content of the enclosure such as a standard board level computer with networking. Even the PLC/PAC could be mounted in the same enclosure.

In a hazardous gas application, the purge-and-pressurization system creates a safe environment for operation by first removing or purging the bad gas from the enclosure, and then it creates a positive pressure inside the enclosure to ensure that no other gas can infiltrate the cabinet seal.

In the good old days, a hazardous enclosure had a large flange that had to be milled to a certain spec, and the flange width had to be sized to allow any ionized air to be cool by the time it left the enclosure. These enclosures were large, heavy and expensive. To have an enclosure to house a PLC/PAC with an embedded HMI would be cost-prohibitive.

HMI design in these types of environments need to be specific for touchscreen or keyboard access. There are hazardous-location keyboards available, if needed, and thus the screen design can be tailored for use with a keyboard and mouse. Touchscreens with built-in function keys may be harder to find, so the screen design needs to take the operator-interface style into account.

In effect, using an HMI in hazardous locations simply requires the right enclosure and purge-and-pressurization system to be certified.

In a hazardous-dust situation, you have to physically remove any of the combustible material, which may have settled in there during installation, from the enclosure. Once completed, closing the enclosure and implementing the purge-and-pressurization system will keep the components in the enclosure clean, cool and safe.

While I haven't seen any large installations with my own eye, these types of systems can be used in very large enclosures where the control strategy for the application can be simplified since the design will be 'normal' with the addition of an adequately sized purge-and-pressurization system.

It's all about the internal air pressure after purging. Having said that, the enclosure's metal gauge may have to be reinforced due to the increased pressure introduced into the space. This is likely to depend on the volume of the enclosure since it would have larger surface areas of just plain metal. The gauge of these panels would be important.

It's always best to consult with an expert, as I did with Ian Verhappen, an oil-and-gas automation expert who guided me with some valuable information. It's really all about how you want to implement your hazardous-location HMI applications. There are intrinsically safe units available, but only for certain classes, divisions and zones. The selection process needs to be very complete, based on the environment. cd

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JEREMY POLLARD, CET, has been writing about technology and software issues for many years. Pollard has been involved in control system programming and training for more than 25 years.

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Ethernet/IP: universal-translator protocol

AS THE WORLD begins to come out from under the oppressive cover of a nearly three-year epidemic, the false starts and side trips that have plagued our journey on the automation highway can finally make some headway again. Like the highly anticipated family vacation, the desire to hit the open road with our projects leaves us apprehensive and, perhaps, a little sleepless.

Feeling slightly retrospective, I find myself looking back on the past 33 months with a small bit of wonder. How the heck did we survive all this?

While the health concerns were paramount, one lesson that we learned is that, no matter what challenge we face, underneath it all we are human and we still require the basic necessities. As a food producer, our objective of producing good, quality products never wavered but the virtual snowballs tossed at us as we struggled to keep our eye on the target made for some interesting times.

D- and X-code connectors are often used for bulkhead connections where field cables connect.

These are the moments where we learn what we are made of. The stress to do what used to be just ordinary things can teach a lot about the character of the people we work beside every day. Some crack, but most dig in their heels and take on the extra weight with focus and determination.

For those of us who design, the journey we have been on seemed more like a ride through a neighborhood full of speed bumps than a lung-clearing sprint down an expressway. While we all learned how to reach into a bin full of components that may not have been of our choosing, the one feature that brought our designs to life was the common pathway that connects them all together. I am speaking, of course, of the network.

Automation networks have come a long way. In the early years of automation, stepping into the world of control design was like walking into a meeting of the League of Nations. Everyone had something important to say, but no one knew what the other person was saying.

Like the evolution of humans, the logical place to start is to group things together that have something in common. As the group gets bigger, the desire to do more becomes a natural next step. Eventually, without realizing it, we have a large group of components that can talk to each other, but we are still left with the problem that these larger groups can't talk to each other.

This scenario, while painted with a broad brush by yours truly, represents the world we lived in back in the early 1980s. Manufacturers all had their own ways of talking—networking—and developed devices that broadened that box of goodies, but only for themselves. Automation companies were hoping that, once you were hooked on their bag of goodies, you wouldn't want to use any of the other guys' stuff.

Like the automation components themselves, the industrial networks needed to go faster and further. Still thinking in the restrictive manner of a nation state, new network protocols were developed that talked to the same group of components but at faster speeds.

The new ones were faster than their parents, but they still were limited to communicating with their own neighbors. The communicating world back then used protocols such as serial communication, RS-485 standard, Remote I/O, Modbus, Profibus, CANbus, Factory Interface Network Service (FINS), Data Highway (DH), Data Highway Plus (DH+), because "plus" is better, of course, DeviceNet, ControlNet and an emerging protocol called Ethernet. What was missing, to give a nod to my favorite science-fiction genre, was the universal translator.

Over the years, manufacturers of automation components realized that making devices that only talked to your own network protocol severely limited the market in which to sell those devices. A few protocols rose to the top of the pile, based partly on the installed base of the components that talk with that protocol and partly because the technology behind the protocol advanced—got faster and easier to use—to the point where the other protocols were no longer practical.

The logical thing to do was to get together and work out a way to settle on one protocol with which all the various vendors would make products to communicate. As it turns out, much like the rest of humankind, not everyone could settle on only one winner in the protocol race, but it sure thinned out the field a lot.

One such protocol that has grabbed a large share of the marketplace is Ethernet/IP, the latest iteration of industrial Ethernet. Think of industrial Ethernet as the Ethernet used to connect your computer or laptop, but made more robust so that it can survive in a manufacturing environment.


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Ethernet/IP literally means Ethernet/industrial protocol. It combines the common industrial protocol (CIP) with standard Ethernet. Both standards are supported by ODVA, an organization formerly known as the Open DeviceNet Vendors Association. Members of ODVA are independent vendors who supply devices for industrial automation applications.

Ethernet that is designed for an industrial environment has additional protocols to make it deterministic and enable real-time control. Deterministic, as applied to networking, means that the exact time to transmit and receive a message is known and predictable. If the time to send a command and get a responding message back is known, then real-time control can be achieved.

Before the ability to make Ethernet deterministic, specialty network protocols were needed for time-critical events, such as motion control. Dedicated motion networks such as Sercos were used for this purpose, but significant additional hardware and cost were involved since the programmable controller could not be counted on for precision motion and position control.

An important feature of Ethernet/IP is that it is media-independent. This has permitted a variety of wiring methods to be employed, based on an application. The four primary types of cables for Ethernet are coaxial, fiberoptic, unshielded and shielded twisted pair. The most common cable technology is twisted pair with unshielded or shielded, a decision based on whether the environment is noisy, needing shielded, or not. The most common method of termination of twisted pair is RJ45.

RJ45 is a modular connector in which four sets of twisted pairs are trapped between two modular pieces in such a fashion as to penetrate the insulation of the individual conductors and create a connection to exposed, flexible copper strips. The connector, when plugged into a matching receiver, creates a reliable connection to upstream and downstream devices. An RJ45 connection is not sealed, meaning there is risk of exposure to powder and liquid contamination of the connection.

An alternative to the RJ45 connector is a D-code or X-code connector in an M12 format. M12 means a 12-mm-round connector that provides IP67 and IP68 environment protection. These two categories both have dust- and water-proof properties, with IP68 being more robust than IP67.

Both connectors usually employ four or five conductors and are easily identifiable by the shape of the insert inside the M12 outer shell.

The D-code looks like a D—round with a flat side—and the X-code looks round with an X through the middle. Both connectors can also have additional features—small cutouts that match opposing pegs in the mating connection—that make it impossible to connect in an incorrect manner.

Unlike the RJ45 connection, the D- or X-code connector firmly mates the correct conductors and completely encloses the exposed connection so that outside contaminants can't get into the connection points. Use of either of these two connection types varies by vendor and application and is a great way to make sure that a component isn't plugged into the wrong communication cable in the field.

D- and X-code connectors are often used for bulkhead connections where field cables connect to an electrical enclosure. Once inside the enclosure, standard RJ45 connections are suitable to bring the connection from the bulkhead to an Ethernet switch or device.

Regardless of the media or method of connection, the acceptance by most vendors of the Ethernet/IP standard with the common industrial protocol makes connectivity easy to set up and use in a control system.

One thing to keep in mind when selecting a programmable controller for your control system is to make sure you know how many devices will be directly addressed through your design. Most programmable-logic-controller (PLC) or programmable-automation-controller (PAC) applications will have a hardware tree in the development software that creates automatic tag connections for your application to use.

Each device will occupy a node on your network, and each PLC/PAC has a limit on how many nodes can be addressed in such a manner. While the nodes on any Ethernet subnet are limited to 254, the PLC or PAC direct addressing will be much less.

Examples of dedicated nodes would be servo and variable-frequency drives, encoders, safety relays and other devices that use a software profile, sometimes called an add-on profile, to automatically format the exchange of data words into recognizable tag structures. Not included are any devices that solicit information but don't create tags.

A good example of this is a human-machine interface (HMI) device. The device application will define where to read and write tags that are defined in the PLC/PAC without creating any tags of its own.

Think of Ethernet/IP as the universal translator that provides a common highway for your various components to talk to each other in a meaningful way. cd

RICK RICE is a controls engineer at Crest Foods (www.crestfoods.com), a dry-foods manufacturing and packaging company in Ashton, Illinois.


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Well-maintained motors last longer

WE DETERMINE MOTOR efficiency as the ratio of mechanical power output to electrical power input. When we look at power output we can determine this by speed and torque, and when we mention power input we determine this by voltage and current. Because energy is wasted during electrical to mechanical conversion in various forms, such as heat and friction, mechanical power output is always less than electrical power intake. The design of an electric motor seeks to reduce these losses in order to enhance efficiency.

Electric motors are critical components in many industrial processes, accounting for a large amount of energy required in a facility. The cost of downtime associated with failing motors can significant, given their vital significance for industrial processes.

> Undervoltage and overvoltage damage the stator insulation of the motor.

One of the most critical duties that maintenance technicians and engineers undertake every day is ensuring that motors are efficient and reliable. Benchmarking electric motors can show a loss of performance, allowing corrective action to be scheduled and reducing unwanted downtime and repair costs. In the case of a failure, benchmarking results may provide a glimpse into the underlying cause. The benchmarking procedure should proceed for the length of the motor's life. It should ideally start with controlled factory tests and then be incorporated into the motor's installation, use, service and repair. The level and extent of benchmarking should really be determined by the expense of benchmarking, the expense of repair, the cost of decreased productivity and the consequences of a premature failure.

When correctly applied, a well-designed motor-maintenance program can be characterized as preventive or predictive. Another option is reactive maintenance. Inspection cycles are influenced by the type of motor and the running conditions. Motors need regular maintenance to operate effectively.

In a preventive maintenance program, motors should really be serviced and evaluated at minimum every six months. Only after that can a motor's life and efficiency be sustained. The aim of preventive motor maintenance is to minimize operational problems and assure that the motor continues to work properly. Preventive maintenance is often a planned part of system maintenance.

The goal of predictive motor maintenance is to ensure that the correct type of service is done at the right time. To establish these two factors, it is necessary to regularly monitor the motor operation and thereby detect problems before they occur.

The main objective of reactive motor maintenance is to replace and fix the motor when it malfunctions. Reactive maintenance, also called as machine failure or breakdown, does not involve regular service or inspection.

Let's look at some issues you can find with motors that can cause trouble with efficiency and life. First, let us look at motor ventilation. If the motor is installed and operated in an unventilated area, the temperature may increase to harmful levels, degrading the insulation and bearing lubrication and causing the motor to fail.

Debris and dust can block airflow openings. As a consequence, wiping debris away on a routine basis is essential for keeping the motor from overheating. Even if motors are protected, it is important to install them in areas with continuous airflow to prevent damage to insulation and bearings from extreme temperatures. The greater a motor's longevity, the cooler it operates. As a consequence, the fan cover and cooling fin should continuously be as clear as possible.

Second, let's look at loose connections. All connections must be tightened and torqued to the standards. Fuses, cable connectors, contactors and circuit breakers are well-known for having loose connections and should be checked on a routine basis.

Finally let's look at undervoltage and overvoltage. Undervoltage and overvoltage damage the stator insulation of the motor. Undervoltage raises the insulation's temperature. Motors run hotter, slide more, create less torque, run at a poorer full-load efficiency and could have a shorter life at lower voltages. In most cases, overvoltage conditions can be handled by induction motors. But extreme overvoltage can result in turn-to-turn, phase-to-phase or phase-to-ground short circuits. The phases or the phases and the frame are shorted out in that situation. cd

Shawn Cox is a licensed master electrician/PLC programmer. He was co-owner/operator of Bobby Cox Electric for 15 years and is currently employed by BMW Manufacturing as an ESA.

Simulation and the digital twin

Model the complexity, explore the possibilities, go faster and stay integrated

by Mike Bacidore, editor in chief

FOUR INDUSTRIAL EXPERTS answer questions about simulation software.

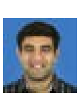
Dick Slansky is senior analyst, PLM & engineering design tools, at ARC Advisory Group. He is responsible for directing the research and consulting in the areas of product lifecycle management (PLM), including computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE); engineering design tools for both discrete and process industries; Industrial Internet of Things (IIoT); advanced analytics for production systems; digital twin; and virtual simulation.

Thomas Kuckhoff is product manager—controllers—at Omron Automation (automation.omron.com).

Giulio Camauli is Simcenter industry lead, industrial machinery, at Siemens Digital Industries Software (www.sw.siemens.com).

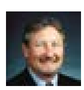
Zohair Mehkri is director of digital twin at Flex (www.flex.com).

What have been the biggest improvements to simulation-software technology in the past five years?

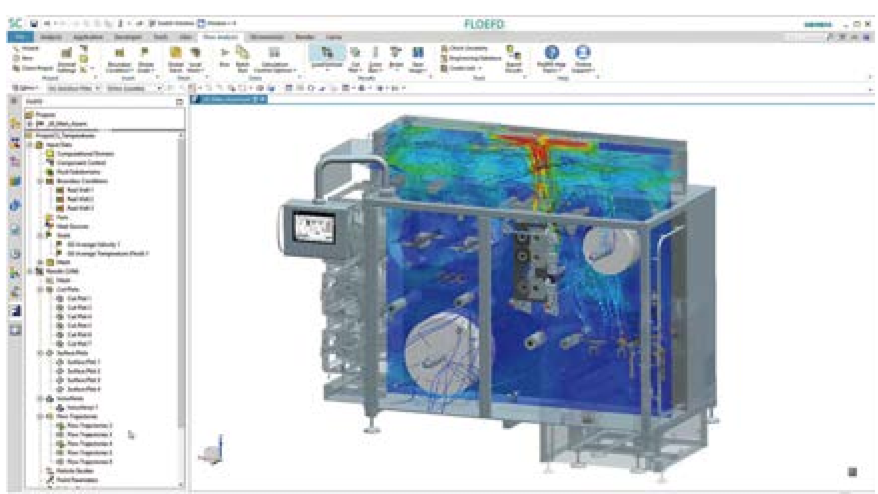


Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): That's a great question. It's funny because anyone that knows this market, any senior manufacturing leader, will say that, despite the buzz, simulation is not new. It's been around since the 1970s. But in the past five years, we've redefined what it means to simulate processes and operations.

I would say the most considerable improvements are the availability of data and the ability to process that data. Simulation software has a linear relationship in terms of quality to compute power. So, the advent of higher-powered computers, cloud computing, higher-fidelity models and the deluge of data sources provides us with immense new capabilities.

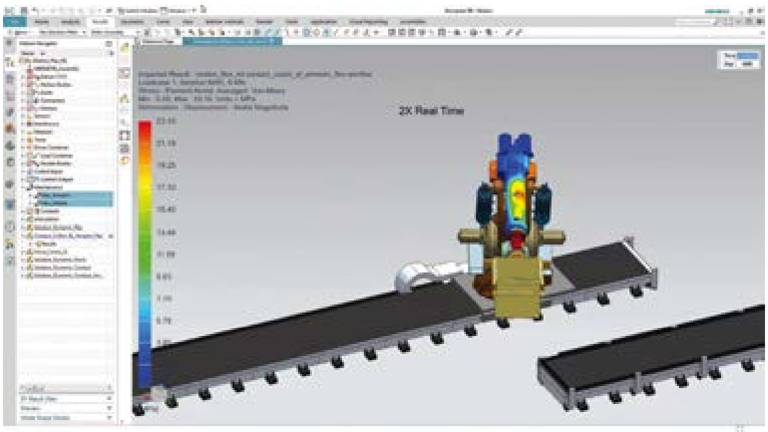


Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): Artificial intelligence (AI) and machine learning (ML), generative design, digital transformation, hyper scaled simulation, and digital-twin simulation. One of the most significant improvements is what I would call the democratization of simulation. Advanced simulation platforms are designed to accommodate non-subject matter experts. That is, designers can use simulation tools for complex testing, such as finite element analysis (FEA), computational fluid dynamics (CFD), multi-physics, electromagnetics and systems integration, that required simulation experts before. Additionally, with the emergence of the digital twin across multiple industries, simulation technology providers are offering comprehensive tools to build



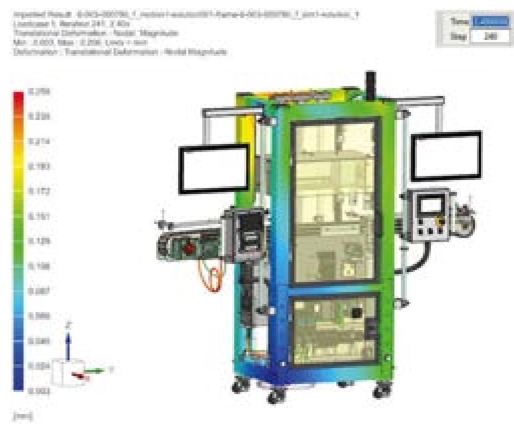
Thermal analysis

Figure 1: Simcenter solutions allow you to model complexity all the way from material behavior to performance of entire systems, including coverage for a broad range of physics including structures, flow, electromagnetics, motion and thermal.



Standalone and integrated

Figure 2: Simcenter includes solutions available for intelligent-design space exploration, both standalone and integrated into various simulation software.



Structural analysis

Figure 3: Simcenter includes innovative new solutions or generative engineering spanning structural and fluid topologies and also system architectures.

digital-twin applications, merging the virtual world with the physical world.

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): Graphics and ease of use. Omron's engineering team has focused on user interface and graphic performance to give the software robust performance, regardless of the intricacies of the application.

Giulio Camauli, Simcenter industry lead, industrial machinery, **Siemens Digital Industries Software** (www.sw.siemens.com): Simcenter solutions allow you to model the complexity all the way from material behavior to performance of entire systems. This includes coverage for a broad range of physics including structures, flow, electromagnetics, motion and thermal (Figure 1).

Simcenter includes solutions available for intelligent-design space exploration, both standalone and integrated into various simulation software (Figure 2). Additionally, Simcenter includes innovative new solutions or generative engineering spanning structural and fluid topologies and also system architectures (Figure 3).

Within Simcenter, we are investing resources in developing methods for reduced order modeling (ROM), workflow automation solutions and AI-driven usability enhancements as just some examples of how we enable individuals, teams and entire organizations to go faster.

Finally, we invest significantly in integrations within Simcenter and with other solutions within Xcelerator. We recognize that Simcenter exists within an ecosystem that includes many other software applications. Hence, our solutions are designed to be open and support industry standards.

Use of Simcenter delivers a number of benefits to customers including the ability to design and engineer better products, gain earlier insights on performance, accelerate innovation which helps them gain market share and achieve greater productivity, be it at the individual, team or organizational level.

What's the most innovative or efficient simulation-software technology application you've ever seen or been involved with?

Giulio Camauli, Simcenter industry lead, industrial machinery, **Siemens Digital Industries Software** (www.sw.siemens.com): Since the introduction of numerical modeling, the simulation industry is innovating constantly to bridge the gap between the virtual world and the physical world. Within Siemens, we want to enable manufacturing industries to leverage multiphysics insight in real time to support the product-development lifecycle from design to production and operations. This led to a new wave of digital twins—the executable digital twins. The executable digital twin (xDT) is a self-contained smart, connected virtual representation of a physical asset that models its behaviors and combines them with physical data to provide augmented information.

The xDT eliminates the barriers preventing simulation information from flowing across the product lifecycle. With newfound access to high-fidelity design information during operations, plant operators and facilities gain valuable insights into machine operation and status.

Manufacturers can improve energy efficiency, increase throughput, enhance quality and reduce waste by leveraging the executable digital twin across the design, production and service phases.

Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): When I think about the most efficient project I've been involved in, I think about our work with a medical-device vendor looking to bring a new product to market in 2020. With the power of simulation, we reiterated the product model hundreds of times over several hours, ran "what if" scenarios and tested dozens of variables. As a result, something that would have taken three months was reduced to three weeks.

We were also able to optimize scheduling to meet higher-than-expected demand. We initially projected roughly 5.5 million units per quarter, falling short of the 8 million requested by the customer. With simulation, we tested various scenarios and optimized scheduling to produce 8.1 million units per quarter, exceeding expectations.

Some other benefits included increasing workstation output by more than 70%, eliminating bottlenecks and optimizing cart availability by more than 20%, and delivering other essential business, operational and cost-saving benefits.

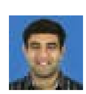
Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): There are multiple areas of new innovations being applied to simulation applications. AI-powered generative design applied to simulating the most efficient design for additive manufacturing is one. Designers can render designs based on fit, form and function parameters and additionally include requirements for the part to be manufactured using additive-manufacturing (AM) methods. AI algorithms will produce a design specifically for AM, where the part is light-weighted, uses more advanced materials and even exceeds functional requirements. The manufacturing engineer can build simulations of the complete manufacturing process, including fixtures and virtual dynamic simulation of the 3D printing machine.

How has simulation-software technology benefitted from remote connectivity and networking?

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): Traditionally program troubleshooting and training interfere with critical operation processes, often requiring production to come to a halt to find the root problem. Troubleshooting and training team members on machine programs through a simulation environment can be accomplished without stopping machine operation to allow for troubleshooting to not interfere with production goals. This allows maintenance teams and production teams to work in parallel, which yields some great efficiencies.

Giulio Camauli, Simcenter industry lead, industrial machinery, **Siemens Digital Industries Software** (www.sw.siemens.com): In addition to simulation experts and advanced users, an increasing number of project engineers and technical salespeople need access to simulation models. Those project engineers and technical salespeople need to share predictive information with their customers without expert knowledge or training in specific simulation solutions.

Within the Simcenter portfolio, we provide a solution that enables access to system simulation models without a desktop application. Identified by their logins, users only need an Internet connection and a Web browser to access models, run simulations and inspect results from anywhere in the world, at any time and on any kind of device.



Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): The COVID-19 pandemic changed the way we work forever, from the corner office to the factory floor. And remote connectivity and advances in networking played a huge part in that. These powerful tools enable colleagues and customers to see things without traveling or physically being on the factory floor.

The combination of tools helped teams answer questions far beyond optimization. Questions like:

- Can I see a model of a line?
- What does the shop floor look like?
- Can we see how changes impact output?
- Can you show a customer what the model of a line looks like without having to show them the physical line?

Remote connectivity and networking bring simulation capabilities anywhere, saving time, money and effort spent traveling and physically updating strategies.

Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): A typical simulated test application for FEA, CFD or multi-physics can be very computing-intensive. The design must be converted to large mesh models to do product testing. Many smaller engineering houses don't have the in-house computing resources for large scale CAE testing, often requiring many hours of computing time. By using cloud-based computing resources, they can upload and run their test applications often in a matter of minutes, rather than many hours, saving valuable design/test time. Also, engineering organizations can share simulations remotely with other engineering groups.

Can you explain how improvements in simulation-software design and production have impacted industrial applications?

Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): Manufacturers can use virtual simulation tools to simulate production lines, work cells, production machines, robots and automated assembly. These tools enable them to simulate the entire production process and validate their automation and control systems virtually before the physical systems are turned on. This is called virtual commissioning (VC) and is used extensively across manufacturing. The digital twin has taken this process to another level: Where VC is a one-time validation, implementing a digital twin is a continuous process-improvement method, merging virtual and physical systems using advanced analytics and AI.

Giulio Camauli, Simcenter industry lead, industrial machinery, **Siemens Digital Industries Software** (www.sw.siemens.com): Manufacturers across industries accept two common truths:

- Decisions made during the early concept stages lock nearly 70 to 80% of the development cost.
- The cost to fix defects rise as you proceed further down the process from concept to production.

Bringing multiphysics capabilities directly into the computer-aided design (CAD) environment can empower designers to make the right decisions.

Frontloading engineering: While embarking on any innovation challenge—from optimizing multiphysical behavior to adopting new manufacturing technologies like AM or even to implementing new lightweight materials, such as composites, simulating early and often is essential to avoid product failure or cost overruns.

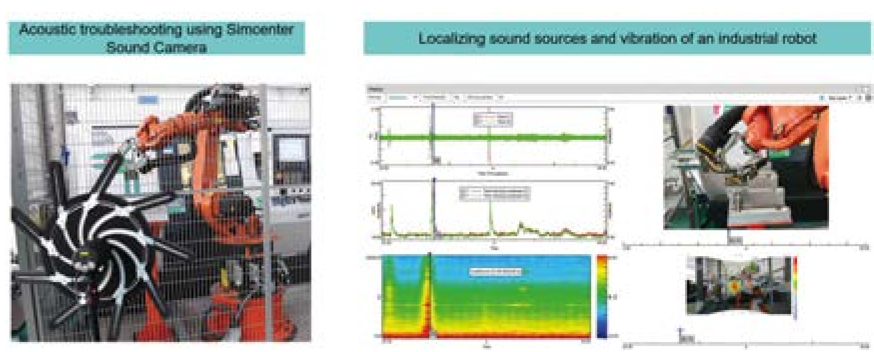
In certain applications, frontloading requires running multiscale simulations from the microstructure level to predict performance at the macro level.

Furthermore, products today deliver their functions through the integration of mechanics, electronics and software; accessing their functionality and performance limits through frontloading is vital to deliver competitive products.

Generative engineering: Generative design has proven powerful and effective in transforming criteria and requirements into geometry and design. Companies have realized innovative designs by applying it at subsystem and component level. Generative engineering expands upon key elements of the generative-design concept to encompass an overall systems-level view of product design where computer-augmented robust design, design exploration and design-synthesis technologies combined with other AI-based methodologies such as machine learning and deep learning methods are utilized to identify optimal architectural design alternatives needed to meet complex cross-domain functional requirements.

Generative-engineering applications are diverse and include computational-fluid-dynamics-based topology optimization, using systems models to optimize system architectures and system concept generation and selection.

Model-based engineering: Product and machines manufacturing those products comprise multiple systems: pneumatic, electric, electromechanical.



Condition monitoring

Figure 4: Consider machines on the factory floor that not only need to communicate with the machinist but with other machines, robots and maintenance operators.

To achieve the desired machine performance the interaction between different systems has to be simulated.

Consider machines on the factory floor that not only need to communicate with the machinist but with other machines, robots and maintenance operators (Figure 4). Collaboration is needed to optimize the performance of not just individual products, but also the overall behavior of these complex manufacturing systems. All this requires a model-based approach to product development.

Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): The feature improvement over the past decade has been astounding. Of course, much is because of the computing power, data fidelity and increased data sources we discussed earlier. But most simulation software today goes beyond that and now infuse artificial-intelligence (AI) modules or machine-learning (ML) capabilities into the platform to bolster intelligence.

Another capability we see is the ability to tie into various data sources. In the past, it was Excel files or a structured-query-language (SQL) database. Now, we can tie into systems, databases, cloud and anything on the shop floor that has been digitized. The technology is expanding accessibility and usability.

There have also been some incredible user-interface advancements. Gone are the days when you had to program each step. Now it's drag and drop. You see a person or machine; you drag them into the simulation. So, there's been a lot of user-interface and experience improvements.

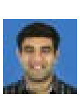
Finally, we've seen significant enhancements with various types of calculations. For example, now you can start calculating things you couldn't do before, like cross-functional calculations or how people act in a given space. We can even calculate agent-based modeling about how things in an area react to each other. These types of measures were not possible with legacy simulation software.

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): 3D models are now the norm in the mechanical-engineering field. Combining these models in their current format, AutoCAD and SolidWorks, these models can become the bridge to join programmers and mechanical engineers, and, as we know, we all "get by with a little help from our friends."

How do simulation-software technologies figure into digital-twin platform models being used by manufacturers?

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): Simulation software is the beginning of the digital-twin platform. Being able to model the machine and its environment is the first step. The next is to integrate material properties and algorithms for predicting life of wearable components. While the digital-twin concept is cited heavily in publications, the first step is to ensure robust performance as many of the hurdles to production capacity is felt through system integration and start-ups.

Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): Advanced virtual simulation is a fundamental component of the digital twin where there is a merging of the virtual world and the physical world. While building virtual models to accurately simulate physical systems, production equipment and assets in the field is fundamental, it is just as critical to capture accurate physical configuration. When implementing, companies need to include physical context within the digital twin configuration. For predictive analytics or Industrial IoT to be effective, the context, or physical configuration, of the asset and system are required to know exactly what is needed to collect the relevant operational and performance data. Companies implementing any digital-twin project should begin by capturing and managing the actual physical configuration of the asset. Comprehensive digital-twin implementation platforms are designed to cover both the virtual simulation along with methods to capture physical configurations.



Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): You can't do a digital twin without simulation. You can have simulation without a digital twin, but you can't do it the other way around. Simulation is the base of every digital twin project.

Think of simulation as a model of digital space. Then, when you take it a step further and start adding in other factors, like IT systems, finance programs, variables like humidity and temperature of an environment, people and physical features like pipes and walls, that's a digital twin.

Giulio Camauli, Simcenter industry lead, industrial machinery, **Siemens Digital Industries Software** (www.sw.siemens.com): Analyzing complex systems and simulation models and tuning the configuration toward optimal behavior is vital not only in the design stage but also during operation. Simulation models evolve and expand beyond product engineering:

- working together with real hardware during operation enabling improved data interpretation, reconstruction of variables and parameters during operation that is difficult to measure or not even measured.
- providing 3D visual instruction for the assembly line workers reducing errors and improving throughput
- monitoring product health in real-time, reducing unforeseen operation shutdown and performing preventive maintenance when required
- educating front-line support engineers through interactive visual 3D demos.

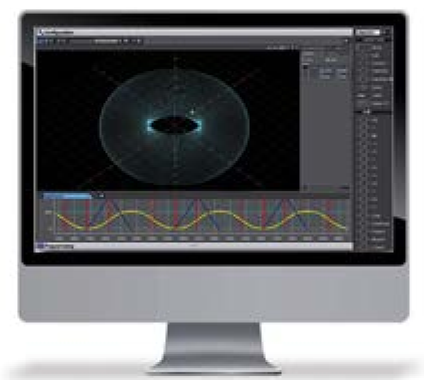
Digital twins can, on the one hand, enable virtual commissioning and, on the other hand, be used for rapid online diagnostics by enabling edge computing in the form of an executable digital twin (Figure 5).

Executable digital twin

Figure 5: Digital twins can, on the one hand, enable virtual commissioning and, on the other hand, be used for rapid online diagnostics by enabling edge computing in the form of an executable digital twin.

When will simulation-software technology become IT-friendly enough that engineers/IT professionals are no longer required for installation and operation?

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): When the highest-performing facilities no longer need the highest degree of efficiency and reliability. With improvements on the software and hardware growing at an exponential pace, getting the most out of the machine requires an understanding and creativity, which can grow at a similar pace (Figure 6).



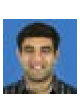
Simulation configuration

Figure 6: With improvements on the software and hardware growing at an exponential pace, getting the most out of the machine requires an understanding and creativity.

Of course, there is a focus on making simulations easier and simpler, but the applications that suit these simulations are commonly not the ones making the monumental leaps in production.

Machines making these leaps in performance often require the tools that can handle high amounts of computation and hardware, which can crunch the numbers with CPU availability for the next version.

The time we are comfortably able to say that the simulation software can be completed without engineers is the time we will be talking about the precision of digital-twin software.



Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): This will take a couple more years. IT teams are incredible technology generalists. These teams create, maintain, develop, secure and store applications and associated data that belong to a specific organization. And they're very good at it. They keep organizations running smoothly.

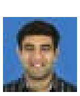
Simulation was designed for manufacturers and engineers to mirror digital spaces and allow for increased efficiency, time savings and throughput. And it's good at accomplishing this task.

Our IT team at Flex is very supportive and collaborative. We've had a very tight partnership. So, while I think we're a couple of years away from IT-friendly simulation, in the interim, close collaboration between IT and engineering can bridge many of the gaps.

What future innovations will impact the use of simulation-software technology in manufacturing operations?

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): The integration of the industrial Internet of Things (IIoT) into the digital-twin algorithms. When algorithms begin to adapt based on particular application trends, the algorithm has the ability to generate the inertia to overcome the sheer amount of variables, which can affect the life of a machine. When the industrial Internet of Things becomes prevalent enough to start affecting the digital-twin life, machines can not only become predictive to their own lives, but can take action to extend their lives.

Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): While manufacturing-simulation tools are very advanced and enable manufacturers to virtually simulate entire production systems, including robotic work cells, machines and equipment and production work flows, this simulation technology continues to evolve. Moving from virtual commissioning to full implementations of a digital twin is one aspect of this. The progression goes from condition monitoring to predictive analytics to prescriptive self-healing systems to ultimately completely autonomous factory systems. All of this requires advanced simulation tools to validate and implement, along with AI and ML algorithms to run the expert systems.



Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): Three innovations will impact the future of simulation and digital-twin technology.

The first relates to consumption: how will simulation and digital twins be consumed? Typically, that's on a high-powered computer with 20 people crowded around one monitor, and that's not going to be the case in the future. Our team is hyper-focused on consumption and working on displaying this tech on a computer, phone, tablet and even headset where augmented and virtual reality intersect.

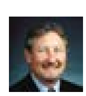
Innovations

Figure 7: Simulation technologies fit in the metaverse and dataverse.

The second revolves around how digital twins and simulation start to increase in terms of computing and scale. This means that you'll be able to tie in even more systems, data sources and applications than you could ever imagine doing so before.

The final innovation is where these technologies fit in the metaverse and dataverse (Figure 7). In particular, how it enables the metaverse and creates new capabilities in the dataverse. It's still early days for every organization for this application, but it will be interesting to see the role simulation and digitization play in these areas.

Tell us about state-of-the-art simulation-software technology.



Dick Slansky, senior analyst, PLM & engineering design tools, **ARC Advisory Group** (www.arcweb.com): Simulation-software technology is an integral component across the entire design/build/operate/maintain lifecycle. Traditional CAE applications, along with advanced simulation platforms enable engineers, scientists, manufacturers, builders and even consumers to virtually simulate the physical world to test, validate, optimize and virtually experience our products, systems and environment.

The simulation-software market has significantly expanded in scope to include many industries and areas of science.

This includes everything from communications, automotive, aerospace, consumer electronics, military systems, transportation systems, smart buildings and cities, industrial controls, pharmaceuticals and biotech.

Scientists and researchers are able to simulate at the molecular level virtually, allowing them to create new compounds for drugs and new materials for various industries. Designers can plan and create 3D virtual cities and infrastructure for the next generation of smart cities. Manufacturing engineers are now able to create and fabricate parts by creating new materials specifically for additive manufacturing and design shapes and functions that could never be made using conventional methods. All of this is enabled by advanced 3D simulation tools that are transforming science, industry and our physical environment.

Zohair Mehkri, director of digital twin, **Flex** (www.flex.com): Flex is a $26 billion diversified manufacturing company that makes everything from vacuum cleaners, coffee machines and autonomous car modules to diabetes equipment, industrial machinery and cloud-data-center equipment. We partner with some of the most prominent organizations worldwide to create products that create value and improve people's lives, and simulation plays a big part in that.

We've completed more than 1,000 simulation projects over the past few years. Our simulation stack consists of off-the-shelf offerings combined with middleware and proprietary software we've developed over the past four to five years. We utilize this powerful technology to drive operational efficiencies and simulate sites, shop floors and factory lines.

We've built an excellent simulation organization across our sites and are now evolving from being simulation-focused to a digital twin team.

Thomas Kuckhoff, product manager—controllers, **Omron Automation** (automation.omron.com): Sysmac Studio is Omron's premier machine control software. Designed to integrate into Omron's breadth of controllers, as well as I/O, the software allows for quick start-up time without jeopardizing scalability.

Simulating machine performance is a big part of this as the software simulates the entire system. In addition to PLC logic simulation to validate ladder logic, safety simulation ensures robustness of safety controls, HMI simulation solidifies strong user interfaces, and the 3D software also offers visual verification of overall performance.

This feature allows the importing of AutoCAD and SolidWorks files to create a rendering of the machine environment. Validating the program in safe environment, before machine build is complete, allows for full solution vetting prior to bringing programs to automation equipment. Furthermore, validating the entire system simultaneously on single software eliminates programming blind spots.

Giulio Camauli, Simcenter industry lead, **industrial machinery, Siemens Digital Industries Software** (www.sw.siemens.com): In order to take advantage of the opportunities afforded by digitalization and digital-twin technologies, companies need to mature their capabilities in simulation and test. Drawing upon our years of experience helping companies in this space, we have identified four key dimensions along which organization capabilities should evolve and mature their capabilities.

Model the complexity: One of the first requirements our customers ask for is the ability to predict/measure behavior/performance in the best possible way. This means capturing all complexity, be it from the geometry, the physics, or the usage environment, all of which can influence performance. Greater accuracy leads to greater confidence in the predictions and therefore in the decisions.

Explore the possibilities: To truly gain an advantage from investments in modeling complexity, companies need to leverage those models to run experiments. An increase in complexity also means an increase in the degrees of freedom available for adjustment. Through a systematic and intelligent exploration of the design space, they start to gain tremendous value from the models. So investments in design exploration are critical.

Go faster: The traditional pressures of time, cost and quality still apply, even as complexity increases. And increasing complexity can slow down the organization's ability to make the right decisions. Therefore, companies need to find a way to go faster despite the complexity that they work with. This can include investment in process capture and workflow automation, cloud and high-performance computing (HPC).

Stay integrated: As product development has become increasingly complex, there are more opportunities for misalignment between teams. Development in different functional areas happens simultaneously. An optimal decision in one area could prove to be sub-optimal for another and cause delays in development or, worse, field failures. So, companies need to mature their use of solutions that help the team stay integrated across all relevant functions. cd

BY ANNA TOWNSHEND, MANAGING EDITOR

integrated CONTROL & SAFETY

More open protocols and processing power advance ICS use

FOR A LONG TIME, functional safety maintained its priority over control to stop operations in the event of a fault or safety issue. Disconnected machines and systems, proprietary, closed protocols and brand-dependent systems kept control and safety separate, but increased computing power and data analytics have made system response times faster and allowed them to coexist on the same network.

The evolution of ICS

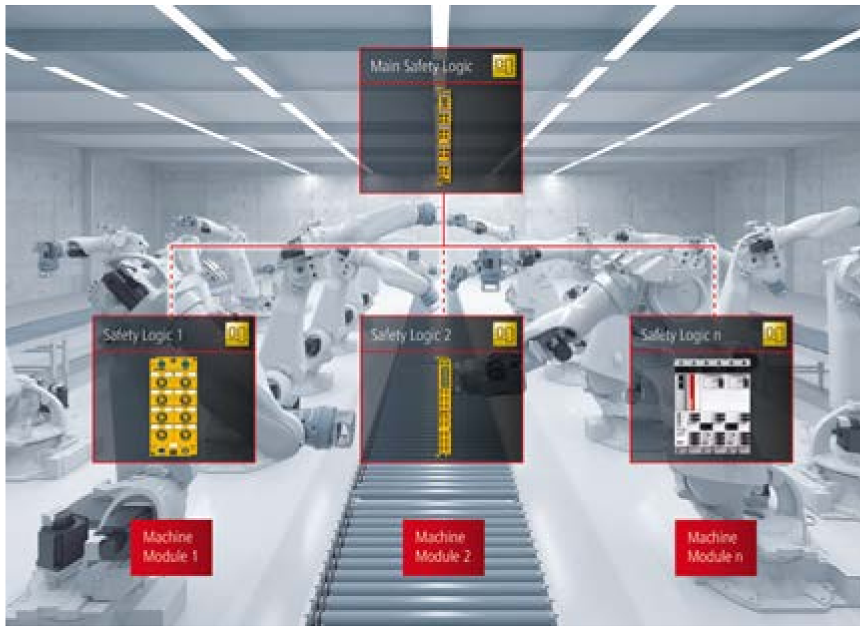
"Safety and non-safety are converging," says Christopher Woller, safety product manager at Beckhoff Automation (www.beckhoff.com). "Automation portfolios are evolving such that all functionalities are integrated into the overall control system—from HMI to measurement technology, IoT, vision, PLC and motion through to safety. Integrated control and safety (ICS) effectively end the historically strict separation of safety and non-safety technologies."

The United States has been on the slower side to embrace safety PLCs and safety fieldbuses, Woller says. First released in 1997, the National Fire Protection Association (NFPA) 79 standard restricted machine safety to electromechanical devices, and, in 2002, when NFPA 79 incorporated International Electrotechnical Commission (IEC) 61508, safety PLCs were permitted. "Only in 2007 did NFPA 79 allow variable-frequency and servo drives as the final switching device in safety functions," Woller says.

Safety systems have evolved from individual devices to centralized safety networks (Figure 1). "Modern safety technology therefore covers a very broad range of tasks, with appropriate safety solutions required in all areas of automation," Woller says. "Most recently, safety technology has evolved beyond standalone architectures and even centralized safety control with distributed I/O and functions, to incorporating logic into all components in a system. This allows simple applications to preprocess data and specialized safety functions, reducing the complexity of the central safety application."

While an ICS system is all about connecting safety and control, Michael Warren, product manager of safety components and safety controllers at Omron (www.omron.com), notes, safety still requires some separation from control. "Although safety is in the same platform, it requires a separate safety CPU, communication modules and I/O cards," he cautions. A common software platform allows operators to switch between safety and control. "It's together but separate," he explains.

Advances in processors and processing power are in part what makes integrated control and safety possible. "We now have processors that are failsafe PLCs rather than safety processors and PLCs," says Mark Russell, tech application support manager at Allied Electronics & Automation (www.alliedelec.com). Early CPUs had some failsafe memory but generally weren't for safety, other than recovering from faults. "Now, we have failsafe PLCs that really allow you to program the actual safety code on top of the PLC," Russell says. A separate processor within the same unit processes safety code, so it maintains priority.



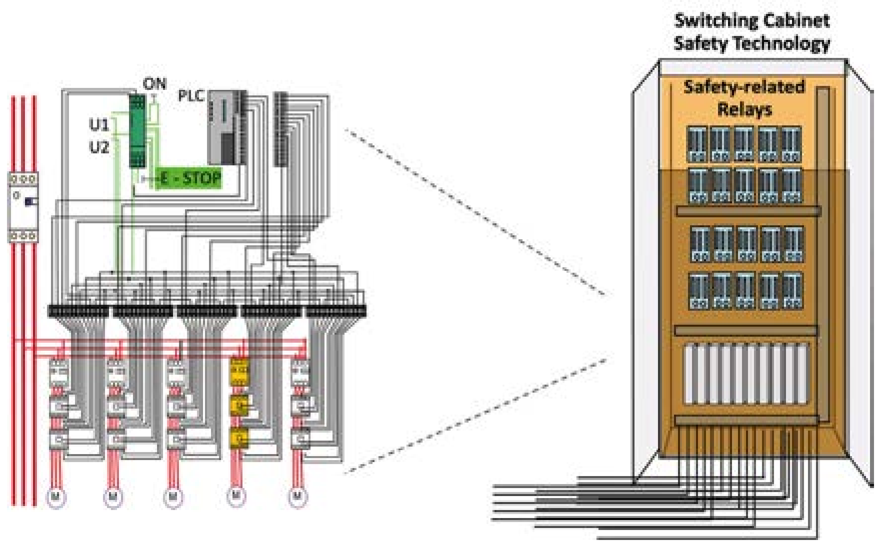
Centralized infrastructure

Figure 1: Integrated safety allows engineers to implement more safety throughout the machine while eliminating the need for costly hardwiring. (Source: Beckhoff, 2022)

What is ICS?

"ICS components work together to ensure that the machine, process and operators are protected in the event of a machine or process having a safety fault," says Noah Greene, product specialist for safety at Phoenix Contact (www.phoenixcontact.com).

Before safety networks, hardwired safety relays used simplified logic for



Hardwired vs. network

Figure 2: Hardwired safety solutions require many wires, and a single wire is employed with a safety network.

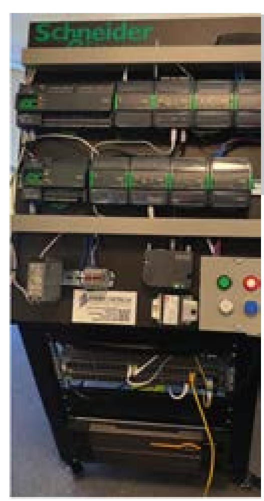
basic safety functions. "The inputs and outputs are wired directly to the safety system and processed. This method works well within a smaller machine footprint or when there is not a large variety or amount of safety inputs," Greene says.

Now, via Ethernet or another industrial communication protocol, a safety network can connect various safety components. "This allows for reduced wiring overall by placing the I/O modules closer to what is being monitored," Greene says. "The safety logic takes over only when there is a safety fault, such as a guard door being opened during normal operations or a motor going out of its allowed speed range."

Code designers simplify how the system will handle faults from the identified risks in the process and write code to perform the appropriate safety function. "Within the IEC 61131 standard, generic function blocks could be written and shared across many machines where similar safety risks are likely to occur," Greene adds.

A safety network provides a cost savings from the large reduction in needed hardware, Bowne of PI North America says (Figure 2). "Safety-by-wire solutions require many wires being 'homerun' from the field to a cabinet. Terminal strips and marshalling racks are then often needed. Finally, the solution is implemented via many relays to perform safety mechanisms. In safety networks however, a single wire is employed, fewer, if any, terminal blocks or marshalling racks are needed, and instead of performing safety via relays, the safety is done in logic, in other words, in a Programmable Logic Controller (F-PLC)," he adds.

An integrated control and safety system bridges safety and operations systems, says Rudy de Anda, head of strategic alliances at Stratus (www.stratus.com). "However, the safety components—controllers and sensors—need to continue operating independently of the control systems to ensure that, if a machine needs to be stopped, an operator can step in to do so," de Anda says (Figure 3).



Bridge the gap

Figure 3: An integrated control and safety system bridges safety and operations systems.

The move from analog wire relays to digital systems, or networks, for communicating between field devices and logic controllers helped to eliminate some wired applications that were cost-prohibitive and made systems easier to troubleshoot or integrate with the control system when there were issues. "With digital networks, companies can network their safety and control systems so that operations shut off if safety systems are out of place," de Anda says.

Michael Bowne, executive director at PI North America (us.profinet.com), outlines the four basic components of an ICS: the safety input, for example, an e-stop button or a light curtain; the safety network that ensures the safety message gets back to the controller; the controller, typically an F-PLC; and a device that may need to act in response to safety messages, typically a robot or drive.

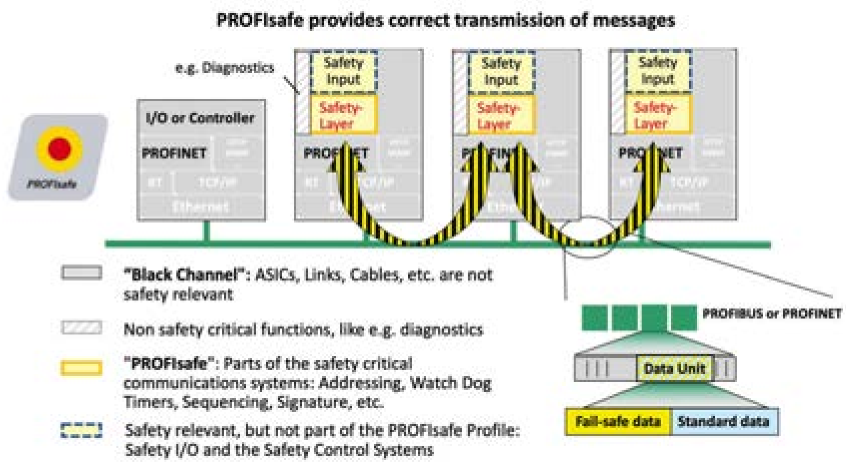
Functional-safety protocols use a technique known as the black channel principle, Bowne says, meaning the protocol is solely responsible for ensuring safety messages get from one end of the network to the other (Figure 4). “The underlying transport or physical layers are unimportant. The only thing that matters is that the safety message sent by the light curtain is received by the F-PLC, for example,” Bowne says.

ICS benefits

ICS systems put safety at the forefront of machine design. “The purpose of having an integrated control system is to be able to implement safety in the network as part of a system, not as an afterthought, but rather as part of the design and the operation of it,” says Warren of Omron. “It’s part of the initial design. This serves both a safety purpose, obviously, but it also serves an efficiency process. It works with timing and device response and efficiency of the cell.” Safety design up-front leads to a more efficient process on the back end (Figure 5).

A single programming environment can decrease development time, with less software to learn and manage and a smaller learning curve, says K.C. Mangen, product manager of safety sensing at Omron. Safety networks, in general, require less wiring, which is all done through standardized quick disconnect (QD) cables. “Once the devices are on the network, the entire thing becomes more modular, and you’re able to scale it much more easily,” Mangen says.

In the current labor market, technically skilled workers are in demand, and many have different levels of programming experience. “The more intuitive it is, the more integrated it is, the faster the learning curve is,” Warren says.



Black channel

Figure 4: The black-channel principle for functional-safety protocols is responsible for ensuring safety messages get from one end of the network to the other.

Safety first

Figure 5: ICS systems help incorporate safety design from the beginning, not as an afterthought.

Cost savings

Figure 6: Fewer components means lower infrastructure costs and maintenance with fewer failure points. (Source: Beckhoff, 2022)

ICS systems give users more visibility into safety issues for faster setup and maintenance. “Too often a black-box safety approach leads to difficult-to-trace faults with little user visibility into the safety system,” says Woller of Beckhoff. “A single programming environment allows the engineer to easily map state and diagnostic information from any safety hardware or software component to the rest of the larger automation system, allowing for efficient commissioning and troubleshooting.” Distributed safety intelligence throughout the network can lead to faster reaction, when critical, making machines faster and safer, Woller adds.

ICS has infrastructure savings, too (Figure 6). “Reducing the number of components means simpler designs and fewer points of failure. It can also lead to reductions in control cabinet and overall machine footprints, saving valuable space on the production floor,” Woller says.

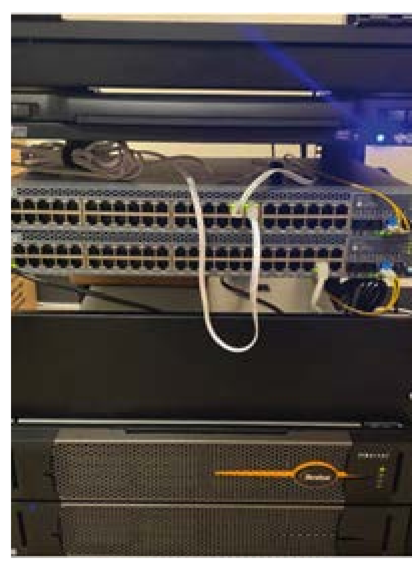
The initial cost of integrating safety and standard I/O may be more, but the savings in the long run that comes from monitoring and scheduled maintenance, as opposed to reactive maintenance, will save more long term, says Don Leathers, production manager II of automation and control at Digi-Key Electronics (www.digikey.com).

This also provides speed in commissioning. “Integrating the system needs to start at the time of design,” Leathers adds. “The main function is to improve productivity and user safety, reduce cost and increase the lifecycle of the equipment.”

Allowing developers to see the machine-process code and safety-system code in one place saves time in development and software maintenance. “Having to switch between windows or having multiple windows open can increase the time spent debugging a program and verifying functionality,” says Greene of Phoenix Contact.

A single integrator or controls engineer can support both systems without needing additional training (Figure 7). “It is simpler to connect safety and control systems to move data between the two, so each piece of equipment is on the same page,” says de Anda of Stratus. “Both safety and control environments are on a single support environment, so it is easier to make upgrades and keep track of when updates need to happen in the product lifecycle.”

An ICS can also enable remote support and troubleshooting. “If a company’s safety system is integrated with control, then many times operators don’t have to spend time troubleshooting an interlocked and shut-down safety system,”



One place for code

Figure 7: A single integrator or controls engineer can support both safety and control systems without switching between multiple windows.

Better communication

Figure 8: Industries using ICS are forward-thinking companies, concerned with traceability and Industry 4.0.

says de Anda. And ICS system can also point operators to the first interlock that triggered a fault, as well as the timeline, de Anda adds. “This is crucial to quickly getting operations back up and running,” he says.

Integrating safety and control I/O can reduce architecture costs upfront, but de Anda notes that operators may have to increase the reliability of the I/O, which could add cost overall and in the long run.

With an integrated system, where control won’t conflict with the safety system, this can also bring benefits for testing and commissioning, says Russell of Allied. “If you put them all in one environment, you can see how they’re going to react. When you simulate everything, you simulate in one environment, and you can play with the same system,” Russell adds.

The safety system can’t trigger a failure, without the PLC acting in tune. The controls and safety systems work in harmony, so that if something fails, it fails in a safe manner, Russell says. For example, the stop may not be quick enough or stop in a bad position. “You have a better way of maintaining the two things together,” Russell says.

The machine design process will include considerably less technology and physical components, Russell says. Fewer network and I/O cables and one computing module means less infrastructure and also fewer points of failure for improved maintenance over the long term.

Larger, more complex machines

Russell recommends ICS for an application that is a relatively low-risk system and relatively simple, meaning a low number of safety zones or low axes of motion—industries such as conveyance and packaging; groundwater and wastewater; and oil and gas.

The industries that are using ICS, in general, are forward-thinking, says Warren of Omron. These industries—food and beverage, logistics, automotive, pharmaceuticals and semiconductors, for example—are concerned with traceability, sustainability, IoT or Industry 4.0 control and integration (Figure 8). “Each of those major industries are required to have traceability from basically cradle to grave of their output,” Warren says. The combination of control and safety makes errors easier to trace, which is vital in high-capacity industries with strict standards for human safety.

A wired relay system may still be the best route for a small system with few requirements. “A large machine will have a much easier time with a safety network,” says Omron’s Mangen. Signal loss over long stretches of wire could be an issue without the network, and many different devices all integrated differently present separate challenges for upgrades or replacement, Mangen adds. “For a large machine, in particular, the safety network should win hands down.”

Integrated safety generally applies best to machines with three or more safety functions or those with distributed I/O and controls, says Woller of Beckhoff. "These include but are not limited to intralogistics, packaging and converting and pharmaceuticals. However, we have helped implement integrated safety effectively in just about every sector," Woller says.

Traditional safety relays and standalone safety controllers may fall short in machines and systems with complex requirements, Woller says. "In these cases, a distributed safety system is more appropriate. Modern safety fieldbuses generally must comply with IEC 61784-3 leveraging a black-channel approach to safety related messages," Woller says. Safety over EtherCAT (FSoE), for example, uses the standard EtherCAT network to send safety information with the necessary safety measures (Figure 9).

"This integrated approach allows safety controllers, I/O and other safety-related parts of the control system to be scattered across a network yet still maintain an appropriate level of performance," Woller says.

"We've still seen the adoption of highly scalable safety architectures fully integrated into the control system grow exponentially," he adds. In many cases traditional safety systems aren't providing the needed functionality for modern automation systems. "As supply-chain issues resolve, this trend toward integrated safety will only accelerate," Woller says.

ICS' future: Open protocols and data analysis

As the industry moves toward more open protocols, this will also open new avenues for integrated control and safety. "Open communications are an absolute must," Woller of Beckhoff says.

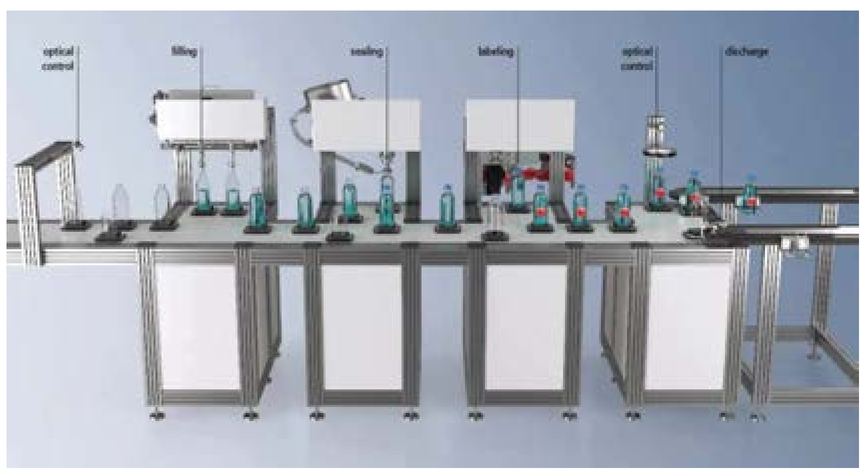
Consider a modular filling line. "Perhaps the OEM sells a filler, a sealer and a labeler as separate machines, and customers may purchase one, two or all three cells together," Woller says. Open machine-to-machine communication is needed to work a simple emergency stop across all three machines (Figure 10).

"This is why TÜV-certified and IEC 61784-3-standardized protocols are so important. Without this open communication, it is left to the end user of the filler, sealer and labeler to perform an additional risk assessment and reduce

Measure / Error	Sequence Number	Watchdog	Connection ID	CRC Calculation
Unintended repetition	✓			✓
Loss	✓	✓		✓
Insertion	✓			✓
Incorrect sequence	✓			✓
Corruption				✓
Unacceptable delay		✓		
Masquerade		✓		✓
Repeating memory errors in switches	✓			✓
Incorrect forwarding between segments			✓	

Safety priority

Figure 9: Safety over EtherCAT uses the standard EtherCAT network to send safety information with the necessary safety measures. (Source: Beckhoff, 2022)



Machine-to-machine communication

Figure 10: Integrated safety supports modular machine designs better, such as this filling line. (Source: Beckhoff, 2022)

risk accordingly. This can lead to an undesirably complex safety function that is hard to maintain," Woller says.

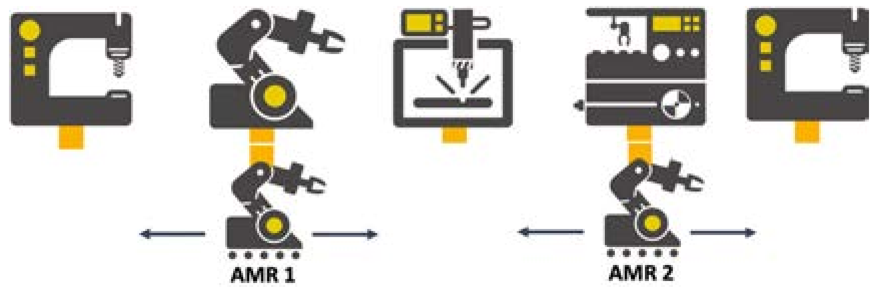
Fully integrated safety also simplifies diagnostics with loads of data. "Having the safety data available in that standard environment would be a major advantage to provide visibility into overall machine performance beyond information on throughput, quality and condition monitoring," Woller says.

Bowne of PI North America also supports the advancement of open protocols. PI North America supports Profibus and Profinet fieldbuses. "In the case of a Profinet network, the safety messages are transported via Profisafe. They are merely Profinet messages but with some extra data to guarantee safety messages get from a sender to a receiver," Bowne says.

"Until recently, machine-to-machine functional safety communication has been the missing link in any modern safety network," Bowne adds. Without vendor-agnostic standards, solutions were highly customized and/or proprietary. Bowne said that changed when the OPC UA Safety Core Specialization was released in March 2020.

OPC UA Safety was initiated as a joint working group between the OPC Foundation and Profibus and Profinet International (PI), an international umbrella organization, but has now been merged as a technical working group under the auspices of the Field Level Communication (FLC) initiative (Figure 11). OPC UA is based on the black-channel principle and currently addresses controller-to-controller communication using OPC UA clients and servers.

Bowne says OPC UA Safety takes machine-to-machine (M2M) safety even further with features such as dynamic addressing. "Traditionally, safety nodes' addresses are static, as this helps support data authenticity. But in a world where autonomous mobile robots (AMRs) are becoming more prevalent, dynamic addressing is required. An example would be safety-related communication between a stationary machine and an AMR that has arrived just-in-time to complete a task before moving along," Bowne says.



Open protocols

Figure 11: OPC UA Safety Core Specialization was released in March 2020.

Mangen of Omron says the biggest driver of ICS-system adoption is the increased desire to collect more data and use analytics to improve processes and predictive maintenance on equipment. Omron was already seeing increased interest in safety networks, and, in some ways, the pandemic has increased the desire for more connected systems. A single integrated software environment helps fewer workers manage a larger network, Mangen says. "From the safety networking side, I think there was also a real pressure to be able to view things remotely," he adds.

Also, in some ways, the slowdown from COVID-19 gave companies downtime they didn't have before and the time to consider new tools and training, he adds. "It kind of hit a little bit of a reset button," Mangen says.

"COVID really showed the need for customers to be flexible," Warren of Omron says. This is true in terms of the types of safety equipment and networks companies use and also how those machines communicate. "The trend is to get away from proprietary networks to open protocols," Warren says. More often, Omron sees customers with a mix of equipment and brands. "Customers are diversifying their needs, so they don't lock in with just one vendor in case of supply and demand challenges," Warren says. This equipment mix depends on even more open protocols and M2M communication.

The future likely holds more for integrated control and safety. "I think the biggest innovations coming are going to be more capability on the internal side—being able to run your safety, being able to visualize your safety system more efficiently," Russell of Allied says. Even with integrated systems, he says, often highly competent safety engineers are needed to work with safety systems.

"I think the integrated systems are going to bring that back to a more industrial base, and that's going to be very helpful," Russell says. "I think that's probably the future, making safety a little more seamless and a little easier to integrate, and hopefully a little more foolproof, so that we don't have holes in our safety system." cd

4 ways TSN can boost industrial productivity

Key manufacturing sectors can reap benefits by leveraging time-sensitive networking

by Thomas Burke, CC-Link Partner Association

TIME-SENSITIVE NETWORKING (TSN) is considered by industry leaders as the future of industrial communications. In effect, it is poised to bring data transfer to the next level, improving control and enabling Industry 4.0 applications.

While the adoption of TSN is still in its early stages, with future-oriented businesses picking up the pace, this technology holds enormous potential for numerous manufacturing sectors.

1 Simplified machine design and higher performance for the converting sector

One of the key features of TSN that can bring great benefits to manufacturers is its ability to synchronize all network devices with high accuracy, especially when used with gigabit bandwidth. As a result, it is possible to ensure deterministic communications for time-critical, high-speed applications, such as motion control.

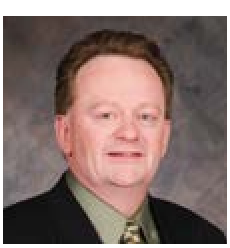
For example, when this feature is adopted in networks used in the printing or converting industry, plants can achieve accurate synchronization between multiple axes on a machine. By being able to control the motion of many different axes simultaneously over one network, facilities can optimize product quality and production processes, as well as increasing the flexibility of their architectures and machines, while simplifying the mechanical setup. The end result is reduced time for retooling and maximized product yield.

2 Transparency and traceability for the pharmaceutical and food-and-beverage industries

Prioritized and timely communications, as offered by TSN technology, is also extremely important when transparency and traceability are crucial.

The success of sensitive industries, such as pharmaceutical and food and beverage, relies heavily upon key process data, which need to be monitored to ensure product quality and compliance with relevant regulations or good manufacturing practices. This data requires accurate timestamps that support visibility of equipment states and operation in the production process, eliminating any blind spot where issues can grow unnoticed.

By building a fully synchronized device network, TSN can support precise timestamping for operations analysis. In this way, pharmaceutical and food-and-beverage facilities can rely on a high degree of traceability throughout their networks and guarantee product quality and safety.



Automotive companies can use TSN to build production lines that maximize throughput and reliability, as the technology combines advanced synchronization with traffic prioritization capabilities.

3 Greater throughput in automotive

TSN technology, particularly when combined with gigabit bandwidth, can also push manufacturing facilities to speed up their production processes, while ensuring determinism. This can be particularly useful for automotive assembly plants.

These facilities are responsible for the production of a wide variety of models, each characterized by different trim levels. Hence it is mandatory for these manufacturing systems to handle large amounts of data generated in real time during the assembly of various car parts. Only in this way, manufacturers can ensure that the different combinations of possible model variations do not slow down cycle times and the allocated parts are fitted correctly on the right models, at the right time, in a traceable manner. Automotive companies can use TSN to build production lines that maximize throughput and reliability, as the technology combines advanced synchronization with traffic prioritization capabilities. The latter allows the network to deliver time-critical traffic exactly when needed, while allowing less critical traffic to co-exist on the network. Consequently, total cost of ownership (TCO) can be reduced since multiple types of networks can now be combined onto a single hierarchy. This means higher performance, lowered costs and simplified maintenance. This finally translates into better quality vehicles.

4 Higher levels of integration for semiconductor manufacturing

Synchronicity and traffic prioritization are also key to combining different types of process control on one network and effectively handling different activities across multiple machines and stations.

For example, TSN can support the semiconductor industry, which is characterized by numerous processing stages, all requiring process, discrete and motion control, along with integration of robots, cameras and analysis equipment with IT systems. TSN-based networks for the sector allow businesses to mix time-critical data for high-performance, high-speed motion control with slower, less time-dependent traffic—for example, for machine vision process monitoring, or the configuration/tuning of devices with management software. Furthermore, manufacturers are given the opportunity to integrate auxiliary systems into their processes and associated networks.

Ultimately, semiconductor producers can enhance flexibility in the network architecture and in their processes.

More than TSN

While TSN offers a number of advantages to manufacturers, per se, it provides a comprehensive solution when combined with an open network technology that offers high bandwidth. In this way, businesses are better positioned to handle the large volume of data that Industry 4.0 applications will generate. As a result, they can further enhance, productivity, reliability and quality while maximizing profits. cd

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control design

The only magazine exclusively dedicated to the original equipment manufacturing (OEM) market for instrumentation and controls—the largest market for industrial controls.

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Keep it safe

Components create environments for safety-encompassed applications

Safety switches

SI-RF series safety switches from Banner Engineering use RFID technology to monitor doors, gates and other movable mechanical safeguards that separate personnel and equipment from a hazard. The compact, low-profile design fits in any space, and single and cascade models are available to protect one or multiple entry points. This non-contact system operates at the highest levels of safety, resists tampering and nuisance trips and offers diagnostic capabilities that make it easy to resolve problems and minimize machine downtime.

Digi-Key Electronics / www.digikey.com

Safety light curtains

The SLC4 safety light curtains are short, compact and designed to safeguard points of access and operation on smaller production machines and similar equipment.

They have 14-mm (finger detection) or 24-mm (hand detection) resolution models available, sturdy interior aluminum housing and an end-to-end sensing design with no blind zone. Additionally, they have versatile mounting options, including rotating end and side mount brackets, which are sold separately. Finally, they are designed to be highly immune to electromagnetic interference (EMI), radio-frequency interference (RFI), ambient light and strobe light; are safety-PLC-input compatible, per OSSD specifications; and FMEA-tested to ensure control reliability.

Allied Electronics & Automation / www.alliedelec.com

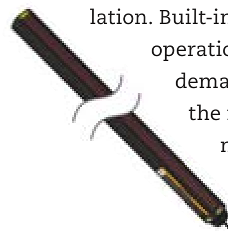
Left-alignable extension system

The SPLC 1000 is designed to make it easy to customize PLCnext Control devices. The AXC F XT SPLC 1000 is a left-alignable, safety-oriented control for operating Profisafe devices. The SPLC 1000 is connected to the AXC F 2152 or AXC F 3152 modular controllers from the PLCnext Control series and can be configured as a Profisafe F-Host or F-Device, allowing for support and control of up to 32 Profisafe devices. The AXC F XT SPLC1000 can implement safety control up to SIL 3.

Phoenix Contact / www.phoenixcontact.com

Safety light curtain

Mini-Array Basic two-piece measuring light curtain is configured for material-handling and logistics applications with auto-stream serial output, two discrete outputs and EIA-485 communication.



It incorporates the two-stick Mini-Array emitter and receiver design and ease of use to simplify installation. Built-in features are designed to simplify the operation customized to specifically address the demanding requirements needed to be used in the material-handling and logistic environments for high-speed detection without the need for a separate controller.

Newark / www.newark.com

Pneumatic safety valves

The externally monitored P33 redundant safety valve is designed for two-channel control architectures. As part of Parker's global focus on factory automation, the safety valve can easily be integrated into a controls circuit to exhaust trapped energy from a machine on e-stop or should a fault occur in the safety circuit. The safety valve offers connectivity using two M12 connectors for solenoid and pressure sensor connections and can integrate to an array of safety-rated devices. The patented fail-safe design ensures safety on the machine for up to Category 4, performance level e applications, is maintenance-free and requires no additional silencers or mufflers.

Parker Hannifin / www.parker.com

Gas analyzers

ATEX In-Situ Zirconia Oxygen Analyzers are designed to optimize combustion efficiency and are compliant with environmental standards, designed for continuous measurement in combus-

tion control for boilers, incinerators and furnaces. Lowering CO_2, SO_x, and NO_x emissions while saving energy, they feature a user-replaceable zirconia element, response speed from 4 to 7 seconds, dust- and water-proof and/or flameproof enclosure and HART communication.

Fuji Electric / americas.fujielectric.com

Safety controller components

AutomationDirect's ReeR MOdular SAfety Integrated Controller (MoSaIC) is designed to make it easy to manage safety systems and sensors. It is modular, expandable and configurable for managing all safety functions of a single machine or an entire plant. The new MoSaIC-MV series speed monitoring expan-

sion modules are an addition that allow speed monitoring of rotating machinery via proximity sensors or TTL, HTL and SIN/COS encoder inputs. Also added is the M1S enhanced controller master module that includes built-in safety I/O and supports safety modules, including two combination safety I/O modules that support eight or 12 inputs, as well as four individual OSSD safety outputs, a safety output module with four single- or two-pair OSSD outputs and four configurable I/O and a safety analog input module.

AutomationDirect / www.automationdirect.com

Non-contact safety sensor

The Smart non-contact safety sensor SRF from Altech is designed to protect machine operators from potential injury by monitoring movable separating protective devices, such as doors, gates, panels and hoods, and shutting down or preventing startup of a machine when a device is not properly closed. The Safety RF (SRF) sensor integrates an intelligent diagnostic system, which collects data for early detection of machine faults and allows for timely maintenance fixes. Sensors are available with diagnostics function that can be monitored with IO-Link supporting Industry 4.0 implementation and smart-factory operations. SRF sensors are 36.5 x 26.2 x 15 mm and designed to suit any application where safety switches (Type 2) or sensors (Type 4) would be used. Data

for up to 20 different switch conditions can be monitored for each individual sensor, even when they are connected in a series for monitoring multiple access points. Critical data is stored in the sensor with a time stamp and can be reviewed even in the event of a power failure. The collected data can be viewed on a computer via IO-Link or displayed on smartphones via NFC technology. Two levels of diagnostics, basic PNP and extended daisy-chain, are available. Up to 32 SRF sensors can be connected in series using standard four-wire unshielded cables with M12 connectors.

Altech / www.altechcorp.com

Intrinsic safety in IP67 form factors

With the EPX module series, Beckhoff offers a compact option for Ex i signal acquisition from zones 0/20, 1/21 and Div. 1 as an addition to the wide range of EtherCAT Box modules. With robust IP67 protection, they enable direct and decentralized installation on machines and systems, even in harsh environments. Interface op-

tions are available for HART, NAMUR and FDT/DTM standards. As an alternative to IP20 solutions with additional enclosures, the IP67-rated EPX modules are designed to enable reliable data collection, even in hazardous areas. The EPX series initially comprises three modules with four or eight input channels.

Beckhoff / www.beckhoff.com

Fail-safe I/O

Siemens Simatic ET200 series includes a wide variety of I/O systems available for standard and fail-safe automation. The modular design allows you to scale the ET 200 systems in small steps, for example, to expand with fail-safe I/O modules. Built-in design features include: one system for standard and safety automation; uniform safety functionality for all Simatic devices; uniform operating capability of the TIA Portal enabling intuitive safety function engineering; compact design to reduce space required; seamless system; and external safety solutions not required.

Siemens / new.siemens.com

Servo drive with integrated functional safety

The KEB S6 servo drive delivers integrated functional safety options, including failsafe-over-EtherCAT (FSoE), safe-torque-off (STO) and safe limited speed. These safety features can be controlled over the SIL3-rated bus protocol. The S6 supports many communication protocols and features Safety over EtherCAT to reduce the amount of discrete wiring going in and out of the cabinet. FSoE offers machine builders a way to simplify wiring, shorten installation times, reduce cost and help with diagnostic capabilities. The S6 is designed for high-performance servo applications requiring real-time communication, advanced SIL3 safety functionality and integrated brake control. It is compatible with various motor types, ranging from induction and ac servo motors to linear and synchronous reluctance motors.

KEB America / www.kebamerica.com

Non-contact door switch

The D41D is a tamper-proof door switch that helps to prevent bypassing of safety solutions and keep workers safe thanks to its high-coded RFID technology, which makes it harder to defeat and ideal for hazardous application. The D41D offers three different actuator options with the ability to detect them from different positions adding flexibility to guard design and making it easier to meet installation requirements in tight areas. In addition, the D41D is designed to lower the cost of ownership by being easy to install with automatic paring for quick installation for one up to 31 switches, if connected in series, and its three-color led indicator is designed to simplify the programming process, as well as troubleshooting.

Omron Automation / automation.omron.com

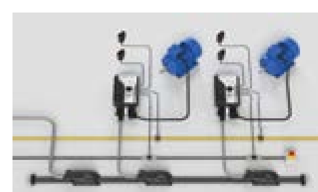
3D time-of-flight PL c safety sensor

The safeVisionary2 is a compact 3D camera designed to increase productivity and reimagine 3D safety for mobile robots. The camera was developed to support customers in becoming fully autonomous in addition to providing 3D localization and object recognition. It is designed to be effective for use on autonomous mobile robots (AMRs) because it provides precise 3D measurement data that allows for autonomous and intelligent mobile robot navigation. This compact 3D camera helps to increase productivity and provides precise 3D measurement data to enhance automation. The 3D environment detection is designed to enable seamless protection of numerous applications requiring performance level c (PL c). With a 2-m safety range and up to four field switching cases, the safeVisionary2 is based on the same ToF platform used by Sick's Visionary-T Mini.

Sick / www.sick.com

Decentralized motor starter for safe operation

Motors in conveyor systems need to be switched off safely, but the wiring and energy distribution involved is complex. Wieland Electric developed a motor starter designed to reduce the complexity of installation and improve the safety of conveyor systems. The podis MS 5HP is a compact, robust and user-friendly drive component with an integrated safe-torque-off (STO) function that disconnects the power supply from the emergency-stop circuits. The STO circuits need no routing through a central distributor and assignment to a specific energy branch, making the system less susceptible to interference.



Wieland / www.wieland.com

Magnetic non-contact safety switches

The PSENmag series of magnetic non-contact safety switches from Pilz Automation Safety are designed for monitoring safety gates and guard positions. Their magnetic sensors are manipulation-proof, offer hidden placement and provide safety monitoring even in non-magnetic surroundings. With a compact design, flexible cable and actuating distances from 3 mm to 8 mm, they are designed to provide flexible, quick and convenient installation in a time-saving, low-cost, high-safety solution.

Galco / www.galco.com cd

Harvest energy from sensors

A CONTROL DESIGN *reader writes:* Our new companywide initiative is challenging us to reduce energy and our carbon footprint. A wireless sensor network powered with energy harvesting seems like it might have potential. Where might we implement energy-harvesting sensors for factory automation, measurement, including process variables, and control? What conditions need to be present for energy harvesting, and is it available on all types of sensing devices? What about smart devices with wireless Ethernet connectivity? What functions can we expect from these sensor nodes, and what other benefits do they offer besides power and carbon reduction?

Answers

Wireless sensors and monitoring

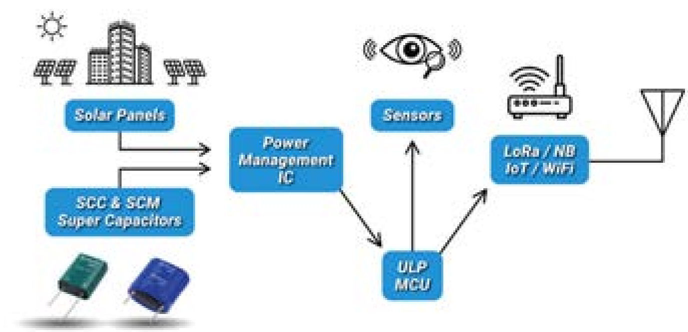
There are many places you could implement energy-harvesting (EH) sensors in factory automation and measurement applications. For example, remote or hard-to-access applications that currently rely on physical equipment inspections for status updates could be converted to a wireless sensor network.

There has to be enough energy available for capture to power the circuit, and the circuit must be efficient. Supercapacitors have extremely high power densities compared to batteries, which allows them to deliver and receive large currents and effectively supplement peak power needs. Efficient circuitry extends supercapacitor battery life.

Energy-harvesting smart devices require both efficient power delivery and efficient power-off processes. Ultra-low power (ULP) modules address these needs by decreasing the threshold of when a circuit is off, which effectively reduces leaked current or wasted current; operating at very low currents, which makes traditionally low-energy harvesting sources, such RF scavenging, viable; and using very small, volumetrically efficient tantalum capacitors to power the start-up sequence.

Wireless monitoring is a key function of EH sensor nodes, but actions such as closing or opening an electric latch and even powering motors are well within the realm of possibility given supercapacitors' ability to effectively handle large currents (Figure 1).

The main benefits of EH sensor nodes include reduced maintenance requirements and costs, overall improved safety, and, of course, energy efficiency and carbon reduction. For example, a solar-powered air-quality-monitoring module designed to be installed in vents and equipped with a ULP microcontroller and a supercapacitor storage bank would reduce the power bill and provide timely notifications for filter replacement.



Current harvest

Figure 1: Wireless monitoring is a key function of energy-harvesting sensor nodes, but other actions are possible given the supercapacitor's ability to effectively handle large currents.

DANIEL WEST

lead technical applications engineer / Kyocera AVX / www.kycera-avx.com

Data diagnostics

From a practical standpoint, I've yet to really see energy harvesting sensors on the factory floor. In the meantime, a better approach may be to work toward energy harvesting that can be recaptured and fed back into a system's power supply.

In terms of implementation, it depends on the energy source and the type of sensor. Light capturing, thermal recapturing, electromagnetic energy through RF waves and vibrations are the main technologies behind energy harvesting. I would first look at your plant for any sources of heat and light as the obvious areas to attempt to recapture some of those energies.

With smart devices with wireless Ethernet, certainly the primary benefits are less wiring resulting in cleaner installations and more data. Devices can be configured, process data monitored, and oftentimes preventive maintenance diagnostics are also available. Looking down the road toward artificial intelligence (AI), all of this data is useful because it can empower greater decision-making capability in the future.

PAUL ANDERSON

technical manager / Omron / automation.omron.com cd

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Ready-made process variables come on skids

PROCESS SKIDS OFFER a modular approach to manufacturers who are facing process-development challenges in the current work environment. Utilizing a process skid to overcome the challenges of getting a new process up and running is just one way that creative thinkers have discovered to reduce cost, leverage the available labor pool and save time and money as they build the next generation of production lines.

A process skid is a stand-alone, purpose-built frame. This can be a single application-specific process or can contain a series of operations that are completed within the skid itself. Each stand-alone unit is inserted in the line where that particular application or system is needed to complete the full process.

> Anything the product 'feels' could be described by one of these four process variables.

Certain complex processes that are very extensive in scope can benefit from a process skid's being utilized for a number of reasons. One of the benefits is that the skids can be factory-certified for compliance and functionality before it is delivered to the production site. This offers reliability for the process and ensures that the unit is fully tested off-site by the manufacturer, which gives the integrator confidence in the product and eases the integration process as it is simpler to connect the unit than to build and test the whole application or process on-site.

Another useful benefit is the reduction in the amount of time it takes to integrate a factory-tested unit into the production line. Instead of having to build everything from the structure to the elements of the application, the integrator can focus the available man-hours and energy on making the developed skid work within the system and move more quickly to the next task. Additionally, one of the more important benefits is the increased cost efficiency. Less labor needed is money saved, less time needed is cost driven out, and a proven and reliable system is a well-placed investment.

With the application-specific nature of each process, there is a high level of expertise and knowledge that is needed for successful integration. By utilizing an outside source to build the process skid you have the advantage of leveraging their expertise in the build project. The other consideration is the transfer and reduction of risk taken that is part of being the builder of the system.

The OEM is responsible for and able to certify that the process skid will do the job and meet the needs of the application. Often you will be assigned a project manager from the OEM who is able and responsible to answer questions or deal with matters that may arise, from the design all the way to the delivery and integration of the unit into the full system.

If we wait to build the individual processes and applications until after the facility's manufacturing process is complete, we could lengthen the build process.

Generally, a skid will contain process control instruments to continually measure or regulate specific processes within the system such as temperature, humidity, level, conductivity, pressure or flow. Monitoring and being able to measure these variables is critical to process control and helps to ensure the quality of the product. For example, if we are measuring flow with a flow meter, we gain an accurate measurement of a specific proportion of a fluid to meet the requirements of our production process.

The four most common process variables that we measure are pressure, temperature, level and flow. These factors all influence the development and modification of a given process over a course of time.

Anything the product "feels" could be described by one of these four process variables. Each variable would have a set point (SP) and a process value (PV) that are monitored. For example, a furnace might have a SP of 1,000 °F and a PV of 1025 °F during operation.

In the past, process control was fully mechanical and required an operator to be available to read the process indicators and adjust the controlled components.

Technology, however, has helped to make great strides in process control through the advent of electronic instrumentation. The conversion from mechanical transmitters, controllers and valves to electronics has helped to reduce costs of maintenance while increasing efficiencies and production as they are more accurately and easily controlled. cd

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