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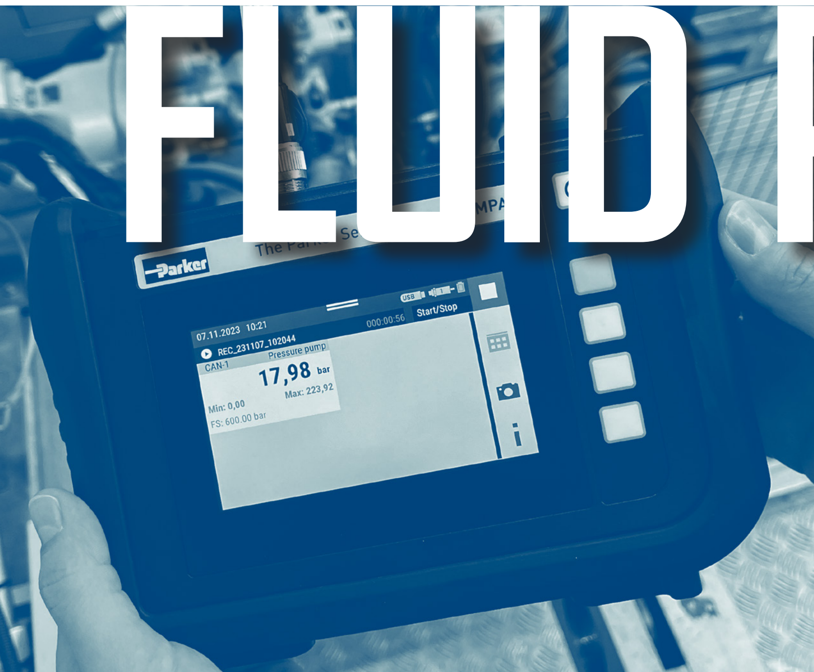
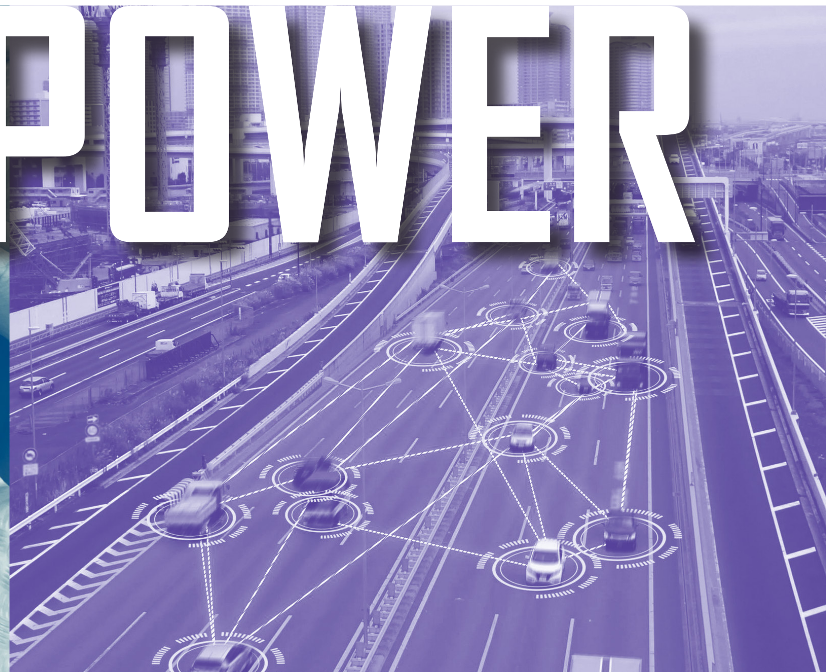
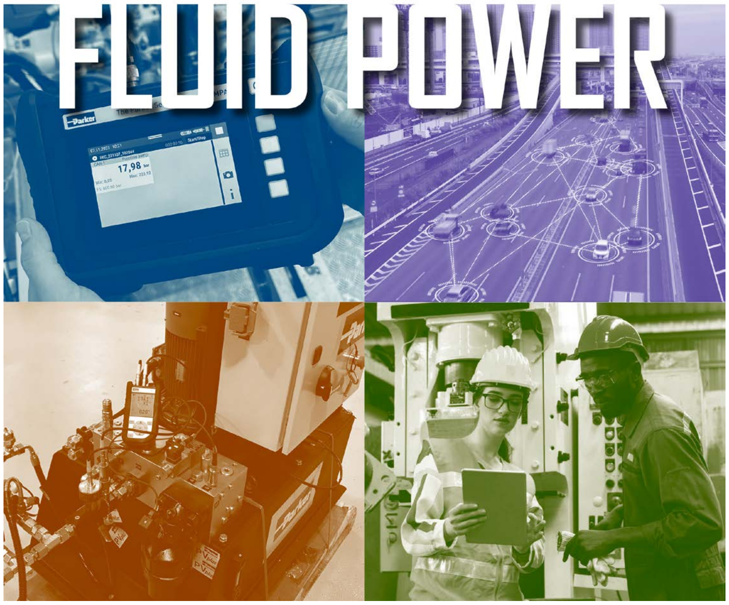
DATA AND CONNECTIVITY TRENDS IN FLUID POWER





DATA AND CONNECTIVITY TRENDS IN FLUID POWER



Sara Jensen,
Executive Editor,
Power & Motion

The desire for more data and connectivity between machines and their systems is driving many new technological developments in the fluid power industry. Integration of sensors, controllers, software and more are allowing the collection of performance data to enhance maintenance as well as enabling communication between machine systems to ensure optimized performance. All of this will aid the transition to higher levels of autonomy.

In this eBook you'll find articles examining how data and connectivity are being employed within fluid power systems as well as the trends shaping future developments.

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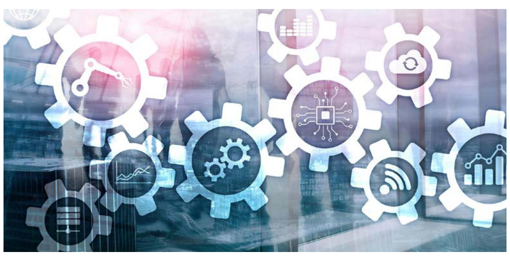

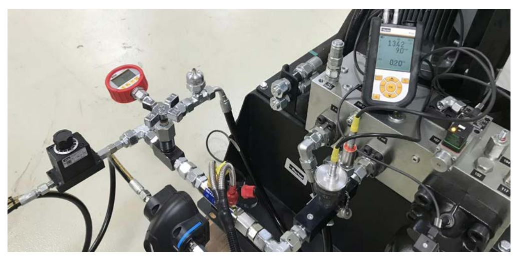

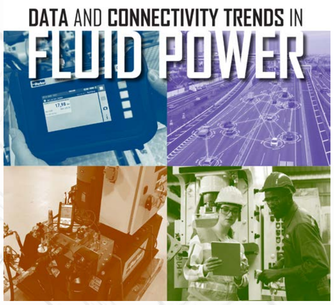

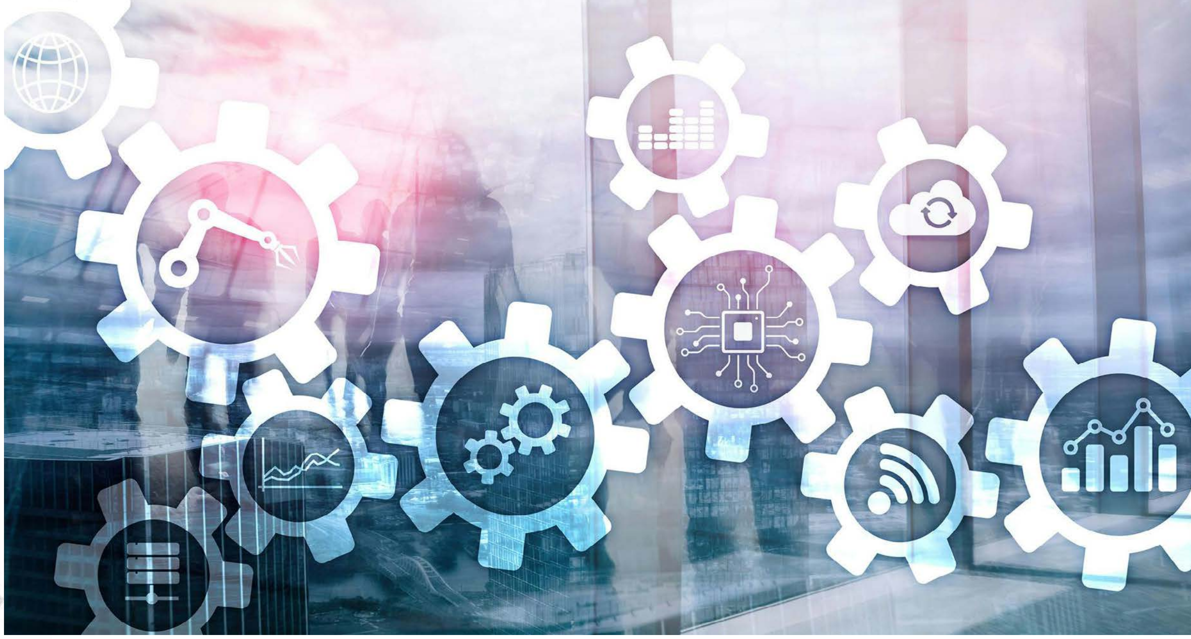

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CHAPTER 1:

Digitalization Improves Performance of Hydraulics and Pneumatics

SARA JENSEN, Executive Editor, *Power & Motion*

The digitalization of fluid power components is enabling improved control, communication and other performance benefits to create more productive and efficient machines.

Digitalization is a term that can encompass many things and take various forms when implemented. It often involves integration of sensors, software and controllers to improve the performance of systems and machines.

The fluid power industry is one of the many sectors in which digitalization is increasing, helping to bring about a range of performance enhancements that are helping to keep hydraulics and pneumatics as a motion control technology of choice.

In this excerpt from *Power & Motion*'s webinar "How Digitalization of Fluid Power is Enabling New Technological Advancements" three fluid power industry experts – Frank Langro, Director of Product Market Management, Pneumatic Automation, North America, Festo; Marcus Pont, CEO, Domin; and Nate Keller, Ph.D., Business Development Manager, Moog Construction – provide their insight on what the term digitalization means and how it is being employed in hydraulic and pneumatic systems.

**Editor's Note: Questions and responses have been edited for clarity.*

Watch the Full Webinar for More Insights on Digitalization

Register for on-demand viewing of the webinar "How Digitalization of Fluid Power is Enabling New Technological Advancements" which took place February 26, 2025, for the full discussion between Langro, Pont and Keller.

Power & Motion (P&M): How do you or your company define digitalization?

Frank Langro, Festo: Digitalization is one of those buzz words that you hear a lot about now. At Festo, how we define digitalization [is] we really tie it very closely to the customer journey from the product selection on through the whole product life cycle, because you start to bring digitalization into the products themselves. Right at the beginning [when] you are using web tools, for instance, to size or design a component, putting it into your shopping basket, all the way to grabbing digital data from the product to enable commissioning, troubleshooting or just overall machine monitoring. Digitalization really expands from cradle to grave in our view.

Frank Langro, Director of Product Market Management, Pneumatic Automation, North America, Festo Festo Corp.

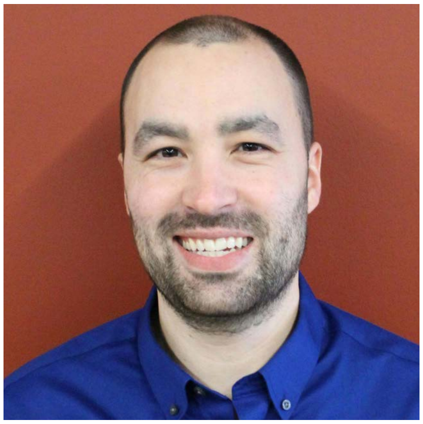
Marcus Pont, Domin: I'd agree a lot with what Frank said there. It's a word that means a lot of things at the same time and a lot of different things to a lot of different people. I most commonly see it used to try and communicate that a company is doing things in a modern way, and that's the message that people want heard when they say that. At Domin, we're really keen on language, and really keen to ensure that language creates common understanding and helps give a bit of meaning out of what can sometimes be complex things. And Frank's absolutely right, there's the customer journey side, there's the tools that you use in your business and at the product.

Marcus Pont, CEO, Domin Domin

[I'll share] what we think of digitalization at a product level for Domin. We break it down into three different areas within our hydraulic products. The first is the most simple and it's just the means with which you communicate to the product, the means with which you control a product. And so, for example, that might mean that instead of using current or voltage to communicate a demand signal you use a digital communication protocol such as Ethernet, EtherCAT, CANopen or anything like that. At its most basic, this allows for a more simple, more advanced and even more effective control and communication of a product. The second thing that we think about is configuration, and that's where we start thinking about being able to change almost the personality of a product via software. So rather than having to change the hardware, we're changing the way that the product behaves via software. And that's the next stage of digitalization for Domin.

Within our products the final stage for us is around a fully digital hydraulic system. And that's a big, complex thing that we can spend a lot of time talking about another time. But if I were to give you an analogy, it's about digitally controlling hydraulic fluid in a similar way that transistors digitally control electrical current. Historically, we started with electrical resistors, and we moved to transistors, and we believe the future of hydraulics ends up with that kind of transistor-level control of hydraulics, and we think that has the same potential and the same impact that electrical transistors had on that industry.

Nate Keller, Moog Construction: [Total agreement with] Frank and Marcus, and I love the three levels Marcus spoke to. So, I'll speak from a little bit of a higher level; digitalization as we see it is the process of changing from analog to digital. In the off-highway vehicle sector, it involves transforming vehicles from simply completing tasks [such as doing] functions like picking up a boulder or digging in the dirt. It changes from just performing a simple task to now doing it efficiently, productively and safely. This transformation is achieved by incorporating electronic sensors that gather this important machine information.



Nate Keller, Ph.D., Business Development Manager, Moog Construction Moog Construction

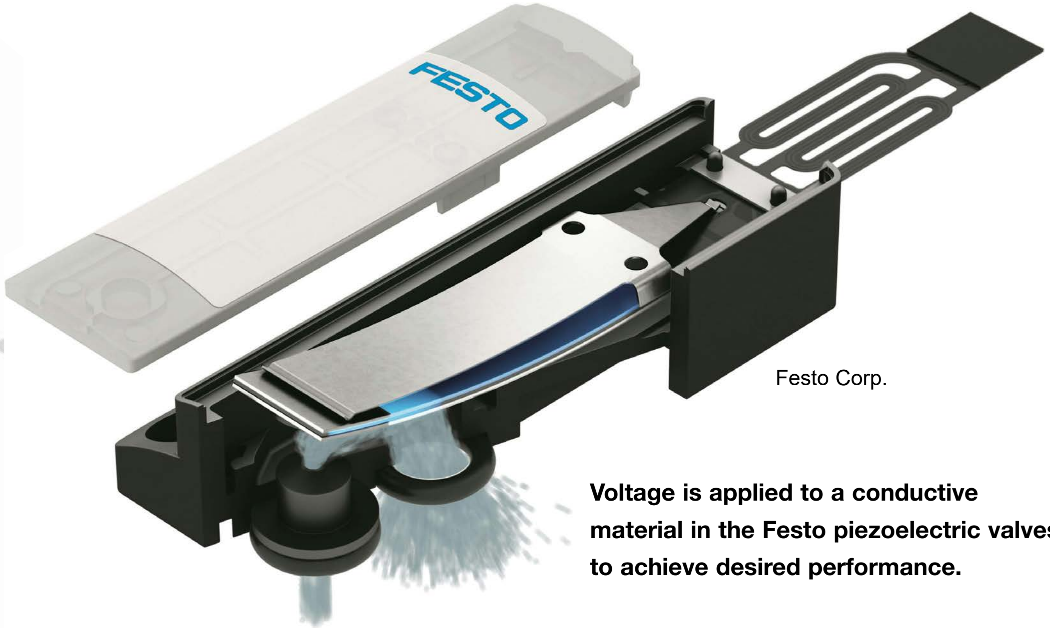
And as Marcus said, instead of communicating analog now you're communicating digitally, as well as [incorporating] an intelligent motion control system, or an intelligent controller that collects, organizes and processes all of that data, and then it can execute commands to optimize the operation of the machine. As far as Moog Construction is concerned, we're more focused on the off-highway sector which is a very large sector for the mobile hydraulics market, [and] we definitely see digitalization as the key next step for this industry.

P&M: What are some of the technologies you see being employed in the fluid power industry to aid with digitalization of hydraulics and pneumatics, and of these what technologies is your company currently utilizing or evaluating?

Nate Keller, Moog Construction: Generally speaking, the first technologies that come to mind…[and] are fundamental to digitalization are sensors and controllers. However, sensors and controllers can only do so much with the physical hardware, such as valves, because this physical hardware is so critical to the performance, efficiency and capability of the machines that these hydraulic systems are working on.

For example, an excavator operator may be demanding finer, more precise control. Position sensors and a controller can certainly help with that control. But you can only go so far. And as Marcus spoke to earlier, you have to at some point start changing hardware if you want to make the control even better. So, for example, you would need to change the control valve, the null cut on the control valve, or go to a different type of control valve to get you in finer control. Well, Moog Construction helps OEMs create the next generation machines that allows for the machine to really be infinitely tunable because it's digitalized. You can tune the control and the feel of the machine without having to change hardware. You're able to flash that [with] over-the-air updates through software without having to modify that hardware.

We have developed and manufactured several technologies here at Moog; core digitalization technology at Moog Construction is our ruggedized electronic solution which consists of control, power management, thermal management, and tunable software that completely integrate with the machine. But then you take the controller and sensors, and you now integrate them with other products that Moog also can provide [such as] electric motors and electromechanical actuators. Now at this point, you have a full system that can communicate with…the sensors, the controller and you can do over-the-air updates without having to change hardware of the system.



Festo Corp.

Voltage is applied to a conductive material in the Festo piezoelectric valves to achieve desired performance.

One other area that Moog has a long, extensive history is in what are called electrohydrostatic actuators, or EHA. This is another way of saying that hydraulics is not going away, and we know that. If electromechanical actuators are not the right fit for a particular application, well then maybe something like an EHA would be. EHA eliminates these valves, and you would be able to, with the sensor and controller, now do fine adjustments and have a more digitalized hydraulic system.

Learn more about Moog's electrohydrostatic technology in the article "Electrohydrostatic Actuation Captures the Best of Hydraulic and Electromechanical."

Marcus Pont, Domin: Electromechanical has somewhat of an advantage at the moment with respect to digitalization, because, like Nate said, you have to have electrical sensors, electrical controllers. You've got to be able to measure things within a product. In order to be able to make it digital, you've got to know what is happening. Because just as Nate described, we've got to be able to make products more effective, more efficient, more intelligent, and to do that, the systems have to be able to make decisions. And to make decisions, they have to have knowledge, and to have knowledge, you've got to be able to measure things.

I think hydraulics is in a really interesting place at the moment where it needs to take a bit of a leap forward in order to catch up with that inherent advantage that electromechanical has, because it has electrics on it by definition. Where we see the technology being pulled to start off with is sometimes just in the most simple form in hydraulics, that is putting electronics inside the hydraulic components. So rather than having a really simple mechanical hydraulic component and then that being controlled from an electromechanical control system, we're seeing a real pull towards putting electronics onto the product where you're directly sensing, directly measuring and controlling within the product. We see that within our direct drive servo valves. A big pull from customers is to increase the level of intelligence in their systems by having electronics on board the valves.

Learn more about Domin's desire to advance hydraulics in the article "Modernizing Hydraulic Systems Through New Technology Developments."

The other thing that we've discovered over the journey is…often the limiting factor in hydraulics is not the ability to write software. It's not the ability to control things, it's the hardware. And one of the really great things for us is when we designed the products that we have, we already were in the world of digitalization, so the hardware has been designed with software and digital control and digital configurability in mind, and the example that Nate gave around null cut on a valve is something that we've thought about in the design of the hardware to ensure that we can do more with software than was previously possible with the hardware that's limited. Hydraulics is definitely not going away. What we're investing in is to ensure that all the benefits that hydraulics bring, which are numerous, broad and large, don't become outweighed by the downsides of not being digital.

And I love the electrohydrostatic actuator discussion. That's something that we see as a real steppingstone towards achieving that, and it's a big part of the technology that we're developing in Domin. We've seen, again, real pull from our customers to put that into a real variety of applications in order to add that value proposition for them. And I think we'll see ever more pull towards that as people are trying electromechanical in some of these spaces, and just realizing that it doesn't achieve the goal for the vehicle, and having to requestion that and say, "Okay, we want the benefits of hydraulics, but we don't want to give up the fact that we can sense and we know what's happening" and that's where we see this push within what we're doing.

Frank Langro, Festo: It's interesting taking the perspectives from three different companies in different technology areas, doing things slightly differently, but coming back to the same basics of digitalization. Our emphasis has really been on software development where we build data models to replicate pneumatic functionality. And this becomes very important in understanding how a pneumatic system, a pneumatic device, works so that you can start to think about how to predict this behavior going forward.

Software is a key piece here, but hardware and hardware limitations were also mentioned – we've seen hardware limitations, for instance, with the pneumatic valve. For many years, pneumatic valves have typically been actuated with solenoids, and they have their limitations. What we've been doing is using piezo electrics as the valve actuation. Applying software to that piezoelectric actuator has opened up a whole other world of how do I, using Marcus' term, change the personality of that valve.

Read "Improving Pneumatic Control with Piezoelectric Technology" to learn more about Festo's use of piezo electrics in its pneumatic components.

The software is changing the personality of the product. And so now that physical hardware can be used to do different things. You see in a lot of industries machine changeover; rather than shutting a machine down and retooling to run different product lines, with the push of a button, a menu change, a program trigger you change the way that machine is running because of a different product size or a different force requirement and so that's [enabled by] the software being inherent in the product.

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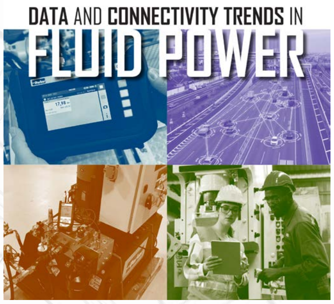


Igor Borisenko | Dreamstime.com

CHAPTER 2:

The Changing Landscape of Communication Protocols for Fluid Power Systems

SARA JENSEN, Executive Editor, *Power & Motion*

A new NFPA report examines how increasing digitization and other industry trends are expanding the communication protocols used in mobile equipment with which fluid power systems will need to work.

In August 2024, the National Fluid Power Association (NFPA) released its *Communication & Data Protocols for Mobile Equipment* white paper. The goal of the document is to help educate members of the fluid power industry on commonly used communications and data protocols in mobile equipment, one of the largest customer markets for the sector.

Major industry trends such as connectivity, electrification, and automation are bringing about changes to fluid power system designs, including the communication networks and protocols with which they need to interact.

During the NFPA's Industry & Economic Outlook Conference (IEOC) held in August 2024, a panel discussion was held to discuss information included in the white paper with some of the association's members who helped develop it.

At that time, Eric Lanke, President and CEO of NFPA, said many fluid power system integrators and manufacturers struggle to make sure their componentry and systems integrate well with these evolving systems at the machine level and understanding that data protocol environment is really key.

As such, the association felt it would be valuable to create a resource which could help improve their understanding.

NFPA's Mobile Technology Task Force — comprised of members across the supply chain who work in the mobile equipment space — came together to share information and industry perspectives to create the white paper which provides definitions of terms as well as reviews of current and future technology considerations.

Download the Communication & Data Protocols for Mobile Equipment white paper from NFPA's website.

Why the Fluid Power Industry Needs to Look Beyond CANbus

Networks and communication protocols are terms used for how electronic devices on a mobile machine "talk" to one another. Per the NFPA white paper, they can be wired or wireless and communicate using various protocols (i.e., rules allowing devices to transmit information) based on application requirements.

There are currently several types of networks and protocols used in mobile equipment applications, but the ones primarily utilized are the CAN network and SAE J1939 protocol. Use of CAN-J1939, as it is referred to, became widespread due to its adoption by diesel engine manufacturers for their electronic control units (ECU) in the late 1980s.

As the ECU was the primary electronic component in most vehicles for many years, OEMs chose to adopt CAN-J1939 for other components, including hydraulics and pneu-

NFPA Technology Task Forces Aim to Identify Technology Needs in Fluid Power

The NFPA's *Communication & Data Protocols for Mobile Equipment* white paper is one of several projects the association is undertaking to help members of the fluid power industry better understand the trends shaping the future of hydraulic and pneumatic designs.

Many of these projects are guided by the 2023 NFPA Technology Roadmap – a document designed to provide an R&D roadmap for the fluid power industry by overviewing trends impacting the industry and potential development areas to ensure hydraulics and pneumatics remain a motion control technology of choice.

After the publishing of this document, NFPA established two Technology Task Forces, one focused on mobile applications and the other on industrial applications. These task forces are working to identify technology areas in which more information may be needed and provide educational tools for the fluid power sector such as the communication protocols white paper.

Eric Lanke of the NFPA (far left) led a panel discussion of industry members to discuss network and communication protocols that could impact future fluid power systems. Pictured from left to right: Eric Lanke, President & CEO of NFPA; Michael Brooks of OPS Controls; Chris Vandermeer of Scanreco; and Mike Terzo of Xirro.
S. Jensen

Autonomous driving capabilities in agricultural equipment and other mobile machines are creating a need for new communication network and protocols with which fluid power systems will be required to interact. Ekkasit919 | Dreamstime.com

matics, as well to have a cohesive in-vehicle communication system. This helped to reduce wiring and development costs.

Read "A Guide to Basic Components in Modern Fluid Power Systems" to learn more about the role CANbus plays in current fluid power systems.

However, as technologies have evolved so too have the networks and protocols available to the mobile market. The automotive industry, which first developed the CANbus networks now common in so many vehicles and machines, has moved on to use of faster and less expensive options according to the NFPA white paper. Technology and trends in this industry usually find their way into the mobile equipment space as well.

Mike Terzo, CEO and Founder of Xirro — a developer of hybrid and electric vehicle power systems — said during the IEOC panel discussion that industry conversations about moving past J1939 are due to what is flowing over from the automotive sector, a lot of which is around electrification. Digitization is also a factor, but he said most of the new protocols now coming into play have primarily been driven by increased development of electric vehicles.

He noted that automation can be lumped in with this too, and that really all of it has to do with the digital technologies which are moving onto vehicles. This is bringing many pain points for manufacturers in regard to determining how best to integrate the technologies while also reducing the cost of protocols and ensuring fast enough bandwidths for the solutions coming into the market.

Other industry trends driving a re-evaluation of networks and protocols include:

- functional safety

- cybersecurity
- increased connectivity.

With these there comes a need for safe and secure communications, some of which is either not possible or more difficult to achieve with current protocol technologies.

The Communication Protocols to Watch for in the Coming Years

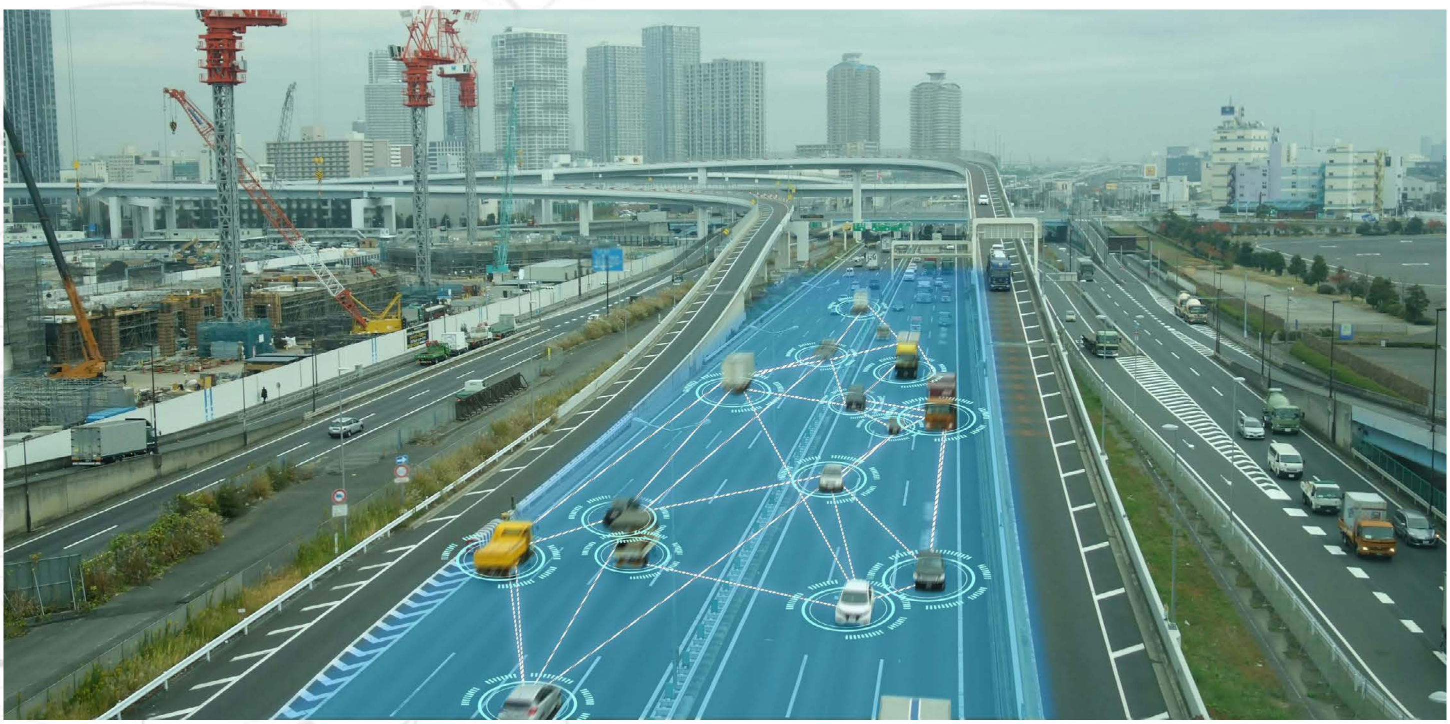
A key part of the NFPA white paper is its outlining of 16 communication protocols that are currently being used or up and coming for mobile equipment applications. Charts in the document provide technical data for each, their pros and cons, as well as examples of how they are used in some mobile machines.

Terzo said these charts were included to help provide a quick and easy reference to help the fluid power industry understand the various protocols in the market and what may or may not work for a given application.

For his own company's products, Terzo said LIN (local interconnect network) is utilized because it is the least expensive protocol. This is also why it has become more commonly used in the automotive sector. He said LIN is incorporated into Xirro's products because it is more cost effective than other protocols when also integrating several sensors.

He said going with LIN can help reduce costs associated with hardware wiring and in terms of implementing it at the board or software level because it is easier to use. While it has a limited bandwidth, it is a good option for simple, low-speed functions.

Watch our interview with HAWE, "How Telemetry and Wireless Communication are Improving Productivity in Agriculture" to learn more about evolving communication networks in mobile equipment.



Advancements in communication networks used in the automotive industry are making their way to the mobile equipment market as well, bringing new technology needs. Ekkasit919 | Dreamstime.com

Cost is an important factor for many, and a driver for the increased presence of various communication protocols in the market. Terzo noted implementing a protocol onto electronic components can be cumbersome and expensive. But there is a proliferation of cost-effective peripherals such as sensors entering the market; this paired with new protocols which are easier to work with is expanding networking options for OEMs and their suppliers.

Visit our State of the Industry page for more economic and technology market trend information related to the hydraulic, pneumatic and electromechanical motion control industries.

One caveat pointed out by Michael Brooks of OPS Controls during the IEOC panel discussion is that many hydraulic sensors don't come with LIN capabilities. Therefore, it is important for OEMs and their fluid power suppliers to assess available technology early in the design process if wanting to use something other than CAN-J1939.

Chris Vandermeer of Scanreco said there is no silver bullet on what communication protocol to pick. And often times there is more than one protocol being utilized in a single system.

Brooks added that his company's most common ECU has three CANbuses on it, and many in the industry have four, each of which may be running a different protocol for specific vehicle functions. One bus might be for video, the other for the hydraulics, and so those aspects need to be kept in mind when determining which protocol to utilize.

Visit our State of the Industry page for more economic and technology market trend information related to the hydraulic, pneumatic and electromechanical motion control industries.

With many mobile machines today containing multiple ECUs, and thus multiple buses and protocols, they have become more complex than ever before. Automotive Ethernet is viewed as a potential solution to this as it has high-speed capabilities for bandwidth-intensive applications but utilizes fewer wired connections than other technologies.

Terzo said he is optimistic automotive Ethernet will come to the mobile equipment market soon given its wide adoption in the passenger vehicle market in recent years. As such, Xirro plans to launch products next year capable of working with automotive Ethernet.

He said the global supply network has really expanded and believes within the next 5 years or so it will be more commonly used within the mobile off-highway machinery market as it offers many benefits for the vehicle's communication backbone. It won't be used for smaller support networks, such as those used for sensors, he noted, but instead for integrating aspects such as ADAS (advanced driver assistance systems), autonomy and functional safety.

For these a deterministic protocol is needed and currently there is no better option due in part to the fact there are so many connectors and other components for it available now in the market. Automotive Ethernet is still the most expensive option, but like any technology as its uptake grows the price of implementing it will come down in the years to come.

Going forward, Terzo said it will be important to watch the system architectures that are utilized by OEMs as that will have a large influence on the protocols they employ – and thus with which hydraulic and pneumatic components will need to work.

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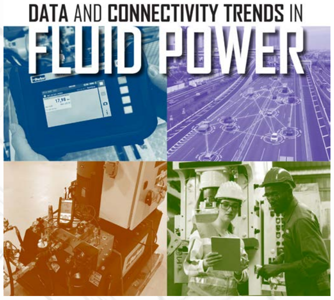
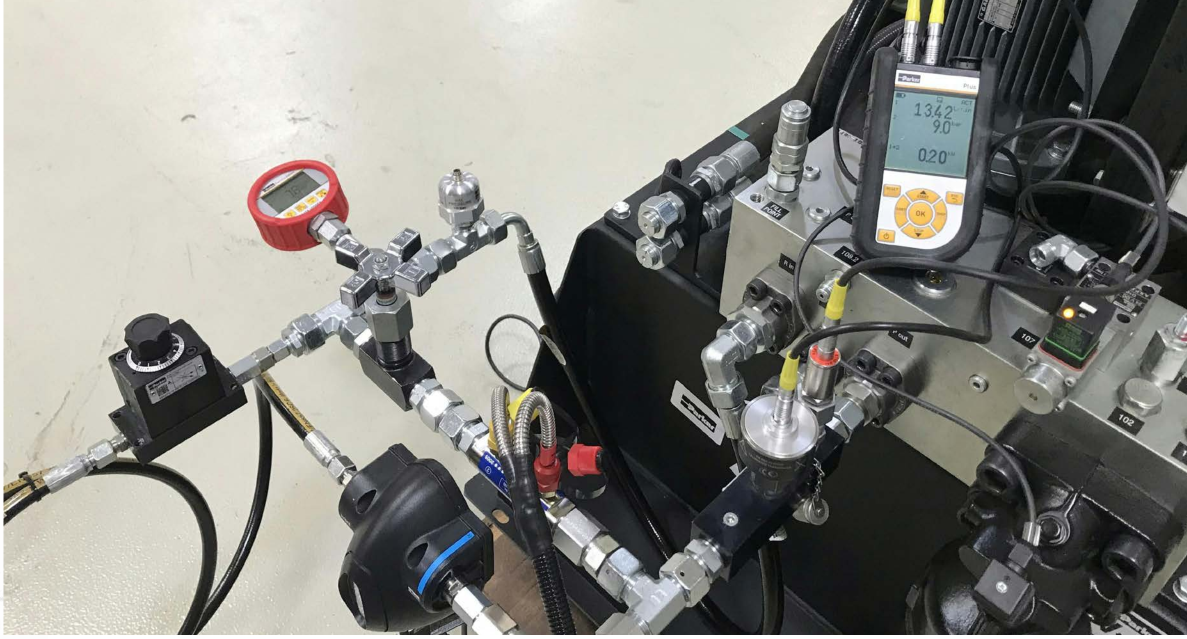




Parker Hannifin Quick Coupling Division

CHAPTER 3:

Preventative and Predictive Maintenance in Fluid Power: The Technologies and Benefits

SARA JENSEN, Executive Editor, *Power & Motion*

Integration of sensors and other technologies into fluid power systems is enabling a shift from reactive to proactive maintenance to minimize unplanned downtime.

Proper maintenance of hydraulic and pneumatic systems is critical to ensuring long-lasting performance. Typically, maintenance practices over the years have been more reactive in that a problem is fixed only once it is detected.

With the reactive approach to maintenance, it is simple and intuitive — if a motor wears out, it gets replaced. There are low up-front costs because no sensors or networking capabilities are required. But when that motor does fail, hopefully a replacement is available otherwise production is held up for the machine and every worker who depends on it, said Connor Dudas, Application Engineer at Schroeder Industries, during a presentation given as part of the National Fluid Power Association's (NFPA) March 2024 Quarterly Technology Conference.

If that motor is used in a CNC which makes manifolds, for example, he said all the parts assemblers that depend on production of the manifolds to complete their work are also impacted by the machine going down. "This reactive maintenance strategy has a costly, cascading effect," he said.

Integrating sensors, telematics and other technologies into a machine and its fluid power systems to move toward more preventative and predictive maintenance enables machine owners to better determine when there is an issue and be more proactive about addressing it before downtime occurs.

Understanding the Differences Between Preventative and Predictive Maintenance

While the goals of preventative and predictive maintenance are similar, understanding

Parker Hannifin's SensoControl measuring devices for mobile and industrial hydraulic systems can measure flow, temperature and pressure to detect potential maintenance issues. Parker Hannifin Quick Coupling Division

The HYDAC CSM-E Contamination Sensor Module combines sensors and gateway devices to provide predictive maintenance capabilities. HYDAC

how they differ can ensure deployment of the system which best meets the needs of end-use customers.

Preventative maintenance, also referred to as planned maintenance, uses historical data to estimate maintenance needs. Often, maintenance is scheduled for an optimal time to minimize costs, such as during a planned facility downtime.

However, there are disadvantages associated with this approach. Dudas said if you have a pump with a rated lifespan of 8,000 hours continuous duty, which is about 333 days, but conducting maintenance every quarter, you could be missing out on as much as 2 months of that component's lifespan. "That's roughly 20% of the estimated lifespan that you're paying for but not able to use."

Predictive maintenance, on the other hand, requires more data that is machine specific. This allows individual decisions to be made about an individual machine. It typically uses sensor technology and data analytics to monitor real-time asset condition, Dudas explained. "This is a further improvement upon preventative maintenance strategies," he said.

There are upfront costs associated with predictive maintenance systems for the sensors and networking capabilities, but Dudas noted these have come down in recent years and most companies have the IT infrastructure in place already which also helps to reduce system costs.

And these costs are going to be lower in comparison to an unplanned downtime event that might otherwise occur.

Downtime is directly responsible for unproduced goods, which means a company's product is not getting into the market and creating revenue.

There are also costs associated with employee wages that still need to be paid during a downtime event, ordering of emergency spare parts, contractual obligations possibly not being met, as well as potential safety and legal issues.

Dudas cited data from a Siemens Senseye study which showed there has been a 50% rise in costs associated with unplanned downtime since 2019 for manufacturers in various industries, demonstrating the value preventative and predictive maintenance systems can bring.

READ MORE about the benefits of predictive maintenance in the article "Predictive Maintenance Systems Enable Better Machine Monitoring."

Sensors Improve Failure Detection

The ideal scenario for any hydraulic or pneumatic component is to get as much life out of it as possible without experiencing downtime. Unfortunately, this will not always be the case.

Therefore, being able to detect potential downtime issues is beneficial to extending the useful life of components when feasible. Dudas said there are many indicators for machine quality and typically those which are most observable are those indicating impending failure. Here again he gave the example of a motor — if it is hot to the touch and noisy, those are easy to tell in person but also dangerous indicators of failure.

These types of indicators often show up moments before catastrophic failure "and the component has likely already lost significant efficiency by then," he said.

However, there are places where predictive maintenance strategies can be implemented, typically for those aspects which are harder to observe. "We can use sensor technology to monitor things like vibration, fluid condition and thermography to help estimate remaining oil and component life," said Dudas.

Easy to observe indicators of machine failure, such as a hot or noisy component, often show up moments before catastrophic failure. Yodrak Sangprom | Dreamstime.com

Pressure sensors such as those pictured from HYDAC can help to detect potential performance issues in hydraulic systems. HYDAC

He said there are three main parts to predictive maintenance systems — sensor integration, gateways and IoT (Internet of Things), and analysis. Sensors used in these systems can come in many forms; those most applicable for the hydraulics industry include:

- particle
- saturation
- oil life
- temperature
- flow and pressure
- vibration.

By incorporating these sensors, it is possible to continuously monitor various performance aspects instead of relying on manual observations, which may not even be possible for some of these parameters.

From Schroeder Industries' perspective as a developer of hydraulic filtration technology, fluid condition monitoring sensors (particle, saturation and oil life) are the most valuable and effective, said Dudas. "These sensors allow you to get to the root of the problem and make a meaningful, holistic solution."

He said vibration sensors are valuable in that they can tell what pump is failing, but it can't tell you why whereas fluid condition sensors can. For instance, if a particle sensor is reading higher than standard, it may be because a filter needs to be changed. With that information, machine owners can be proactive about replacing the filter to prevent downtime.

READ MORE: Sensors Improve Monitoring of Hydraulic Oil Conditions

Maintenance Technologies Need to Provide Valuable Information

Dudas said data without analysis is meaningless. "Sensors are necessary and useful,

The SensoControl handheld device from Parker Hannifin's Quick Coupling Division can help diagnose maintenance issues with hydraulic systems in mobile and industrial applications.

Parker Hannifin Quick Coupling Division

but only a small part of the [predictive maintenance] story."

It is not feasible to hire people to monitor sensor data all day, which he said is where the second part of a predictive maintenance system comes in, the gateway devices and IoT. "These devices allow us to pull meaningful data from all of the sensors [and] analyze trends to predict failure," he said. "We know the warning signs of machine failure in hydraulic systems — excessive heat, vibration, noise, decreased efficiency. All of these are useful and detectable symptoms of failure."

He continued that gateway and IoT devices can help isolate meaningful data and communicate it to a centrally located system where it delivers the signs of failure and delegate maintenance tasks to address them. "Analysis without action is pointless," said Dudas.

Understanding the need to provide actionable maintenance information, Parker Hannifin's Quick Coupling Division developed its SensoControl measuring devices for mobile and industrial hydraulic systems. The portfolio includes sensors capable of measuring flow, temperature and pressure as well as handheld devices which read data from these sensors and provide information to diagnose potential maintenance issues.

Cameron Koller, Market Development Manager at Parker Hannifin's Quick Coupling Division, said the technology is typically used when there is an indication of a problem to determine what it is and how to address it, enabling maintenance personnel to prevent further issues downstream. "You can get active measurements and record them in real time while [still safely] using a machine," he said.

This enables machine owners to gather information and start diagnosing potential issues as soon as possible to mitigate larger and more costly downtime issues. The ability to provide rapid, accurate information on hydraulic system performance is an important part of SensoControl's value proposition he said. "That allows [end users] to make much more informed decisions and define how they can solve the problem before it becomes a bigger problem."

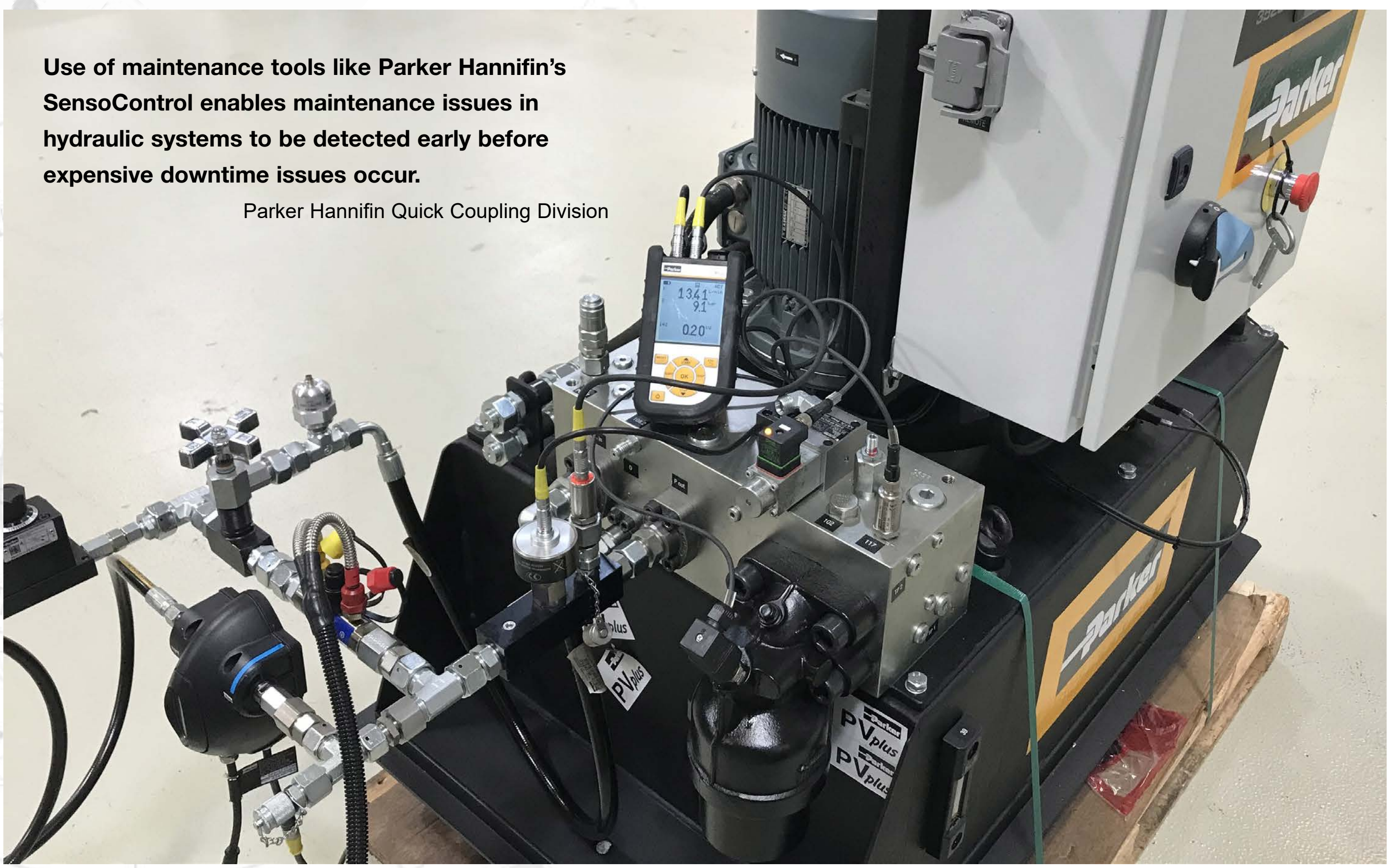
When it comes to maintenance tools, Koller said fluid power has historically been an antiquated market in terms of visibility to information and data. Many applications are in dirty environments and cost has been a factor as well, so adding preventative and predictive maintenance technologies to an operation requires a clear value proposition.

"At the end of the day the end customer has to use it, and it has to be meaningful for them," he said.

His colleague Emily Santoni, Product Sales Manager at Parker Hannifin's Quick Coupling Division, agrees that people need to see the value proposition of using preventative and predictive maintenance technology.

She offered the example of pressure spikes in a hydraulic system which can cause expensive downstream issues if not detected early. If a pressure spike occurs, it can lead to seal wash out which then negatively impacts the pump system and filters. "These can be very expensive, time consuming, [and] labor-intensive problems," she said.

But by investing in maintenance tools, it is possible to identify these issues early and determine how to fix them. In addition, tools like SensoControl enable users to read and export data without being in the immediate vicinity of a machine, giving them "safer, faster, better information," she said.



Use of maintenance tools like Parker Hannifin's SensoControl enables maintenance issues in hydraulic systems to be detected early before expensive downtime issues occur.
Parker Hannifin Quick Coupling Division

Santoni said speaking to the customer and making sure they understand the value of such products is important.

Machine Learning and AI Improving Analysis Capabilities

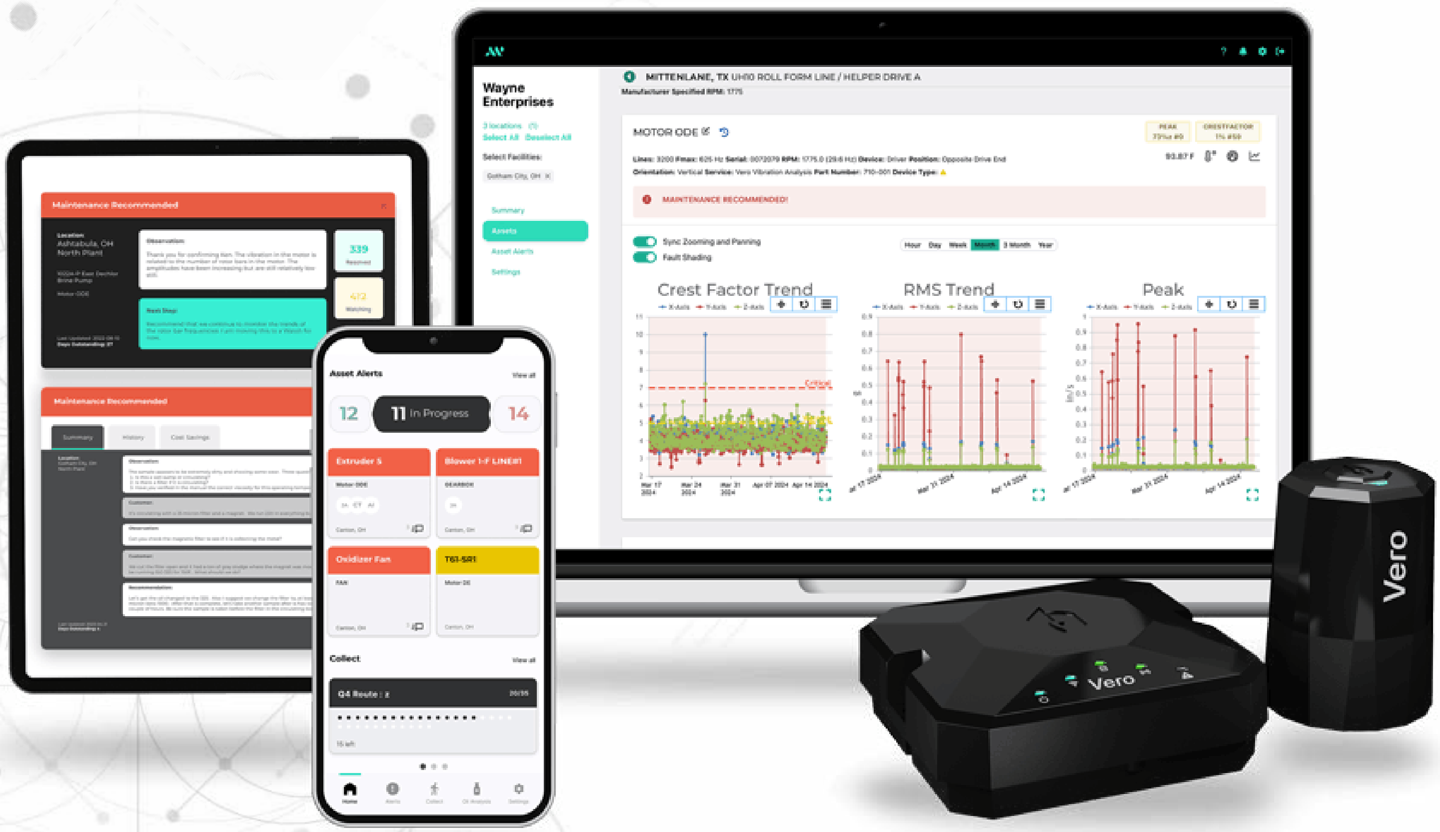
Data analysis has been a relatively manual process for many years. However, Dudas said implementing machine learning and artificial intelligence (AI) tools into maintenance systems can help improve analysis.

With these tools, it could be possible to reliably tell maintenance teams when it's time to change a motor to get 90% of the lifespan out of it, he said. Automatically creating a schedule for when to replace components based on the urgency of doing so could also be possible.

In conjunction, purchasing teams can be notified when a hydraulic motor is at 50% of its lifespan so spare parts can be ordered in a timely manner. This also reduces the number of spare parts that need to be kept on hand and thus the costs associated with storing and ordering them.

"We see this could ultimately change the landscape of predictive maintenance," he said.

To help its customers be more proactive with their maintenance, AssetWatch offers an oil analysis program in which dedicated engineers analyze data as soon as they receive it and provide feedback to customers on any issues they may detect. The company told *Power & Motion* it is able to compile this data, set thresholds and alarm limits, and contact customers immediately with the best recommendations or next steps if any of those are surpassed.



Use of artificial intelligence in maintenance tools, such as those available from AssetWatch, can help improve accuracy of data collection and analysis as well as ease of use for customers. AssetWatch

AssetWatch said it uses artificial intelligence (AI) and humans working together to find speedy and accurate resolutions for its customers. Its oil analysis program can be used to test for particle contamination, wear metals, viscosity, acid, water and more, all of which can negatively impact the performance of a hydraulic system. The company noted its oil analysis capabilities can be combined with its Vero continuous monitoring technology which sends vibration and temperature data for further performance information to aid maintenance, and that the technology can be used with both hydraulic and pneumatic systems.

READ MORE about the Vero technology in the article "How to Deliver Continuous Power to a Wireless World."

Use of machine learning and AI will help to create more digital, easy-to-use interfaces which Koller and Santoni noted preventative and predictive maintenance technologies are moving toward. This will help to provide a better value proposition for end users by making information easy to collect and interpret, enabling them to quickly address maintenance issues.

As the fluid power industry and its customer markets continue to experience a generational shift in which personnel with years of experience are retiring and the younger generations coming in do not yet have that industry knowledge, tools capable of helping to easily detect and address maintenance issues will be critical.

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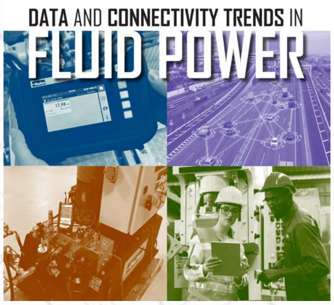

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CHAPTER 4:

How Connected and Software-Defined Vehicles are Reshaping System Architectures

SARA JENSEN, Executive Editor, *Power & Motion*

As vehicles become increasingly connected and software driven, there are opportunities to create more streamlined system architectures.

Advancements in vehicle technology over the past decade have led to increased levels of connectivity and the inclusion of more software-enabled features. Much of this is driven by the desire to create more efficient and automated vehicles of all types – from passenger cars to heavy-duty trucks to construction equipment.

Research firm IDTechEx is forecasting annual revenue for connected and software-defined vehicles will be worth over $700 billion by 2034 as manufacturers continue to invest in these technologies.

Connected and software-defined vehicles (SDVs) bring opportunities for new system architectures, many of which can be simplified compared to previous designs. James Falkiner, Technology Analyst at IDTechEx, wrote in a summary of the firm's market report on connected and SDVs that older internal combustion engine powered vehicles often included numerous components and kilometers of wiring.

However, he stated that the new era of vehicles can be more centralized, connected and convenient, bringing benefits to consumers and OEMs. For those in the fluid power and electric motion control markets serving various vehicle sectors, it is important to understand these new system architecture needs as it will influence their future designs as well.

What is a Software-Defined Vehicle?

Falkiner described SDV as that in which the software within a vehicle affects the user experience in some way. As the number of software-based features increases, the vehicle becomes more software-defined. These can include over-the-air updates, already a common feature in the trucking industry, or the ability to watch movies on the go.

Software-enabled features, such as autonomous driving functions, will become more common as development of software-defined vehicles continues to increase.

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A constant cellular connection is typically required for these vehicles as well as large touchscreens and a powerful central computing system which is connected to various components and systems within the vehicle.

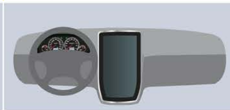
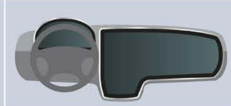
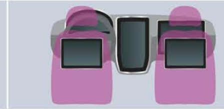
In his summary, Falkiner noted that most vehicles introduced to the market over the past 5-10 years can be considered software-defined as they likely include some semblance of software-enabled features. During IDTechEx's analysis of the SDV market, it gained a deeper understanding of the various types; it created an SDV Level Guide to compare the various types available to help provide a better look at current and future designs.

The guide compares software and software-critical hardware by looking at a vehicle's connectivity level, compute power, type of displays and software systems (see figure below). With each increasing level of software-enabled capabilities comes inclusion of more advanced technologies and higher levels of connectivity.

CAN-Based Systems Enable Connectivity and Streamlined Designs

The drive toward further connectivity between systems and vehicles "is allowing us access to far more data on devices than we previously had," said DJ O'Konek, Engineering Manager at Nott Co., during the National Fluid Power Association's (NFPA) December 2023 Fluid Power Industrial Consortium (FPIC) quarterly technology conference focused on connected systems and machines.

Use of CAN-based systems, including for hydraulics and pneumatics, has played a key role in enabling ever higher levels of connectivity and data collection. Many components for these systems feature integrated controllers, sensors and additional products to collect data. "This has created a lot of advantages in developing streamlined systems by simpli-

	Current					Future
IDTechEx Research	'Non-SDV' SDV Level 0	'Basic' SDV Level 1	'Modern' SDV Level 2	'Advanced' SDV Level 3	'Cutting Edge' SDV Level 4	'Futuristic' SDV Level 5
Cockpit						
Connection	None	3G/4G	4G	4G	5G	5G/*6G*
Display	Non-touch	Small display (non-touch or touch)	Medium-sized Touchscreen	Large Touchscreen	Multiple large touchscreens	Touchscreens for all passengers
Central Compute	No central compute	Central compute with some updates possible over Wi-Fi or connecting a phone	Central Compute with some components connected and updateable via OTA update	Central Compute with key components (engine/electric motor and battery) connected and updateable via OTA update	Central Compute with all components connected and updateable via OTA update	Central Compute with all components connected and updateable via OTA update
In-vehicle payments	None	None	App-based	In-vehicle possible	In-vehicle with biometric identification	In-vehicle with biometric identification for each passenger
Software Apps	None	1st party apps only (e.g. a generic 'Sports' App)	App store with some 3rd party apps (e.g,. Google Maps)	App store with many 3rd party apps (e.g. YouTube, Angry Birds)	App store with many 3rd party apps (e.g. (Google Play Store)	Multiple app stores (e.g., Steam & Google Play store)
Autonomy	Level 0	Level 1	Level 1/ Level 2	Level 2	Level 3	Level 3/4+

IDTechEx has outlined the various levels of software-defined vehicles which are defined by how much connectivity they offer and amount of software-defined features within the vehicle. IDTechEx

fying the wiring since you can just have the CAN wires and power wires going out to those devices and the onboard CAN controllers can manage those devices," he explained.

This design also provides distributed intelligence throughout the system, removing reliance on a primary controller, he said. Instead, decisions on how a component or portion of the system should operate can be made locally at each device.

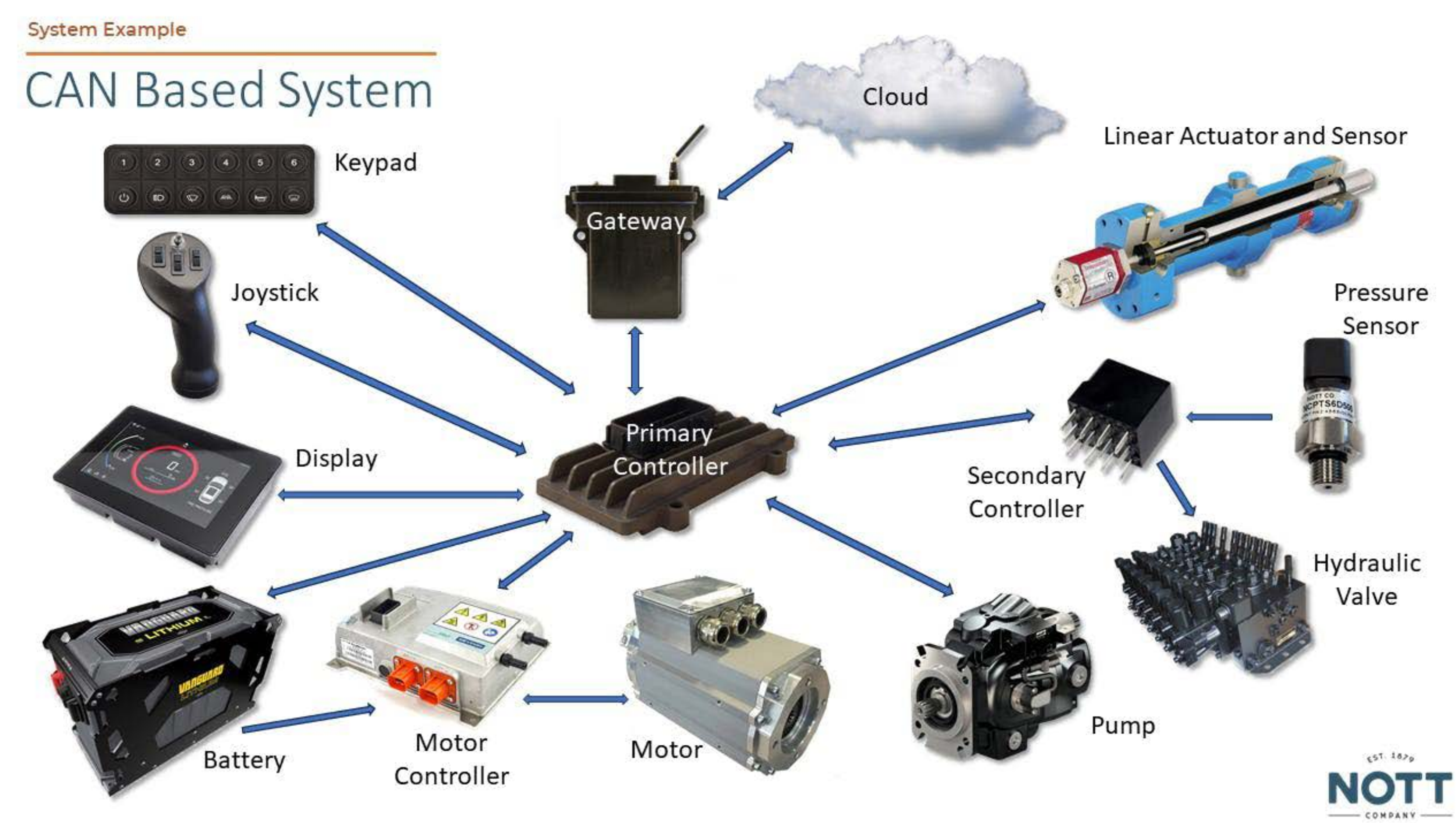
The increased amount of data accessibility which is possible with CAN-based systems is allowing the creation of far more efficient systems, said O'Konek. "We can monitor all [performance] parameters far closer [to the component] than we used to," he said.

Additional safety can be built into a system as well because there are more controllers integrated into it. "We can have dedicated controls going on locally and have a redundant supervisory controller in the system," he explained.

There is also the possibility of adding error checking to the data and monitoring the outputs of most of the controllers being used within the system to see if any faults occur when connecting to the physical devices. This helps to ensure optimized performance and action to be taken faster should an issue be detected.

Creation of intelligent devices with integrated controllers, sensors, etc., is becoming common practice within the fluid power and other vehicle component sectors. Using linear actuators as an example, O'Konek said the more intelligent options now allow monitoring of rotation, torque, displacement, current draw, and linear force. "By having access to these pieces of information, we can control the force going into that [actuator's] operation to optimize for efficiency or to overcome specific limits," he said.

READ MORE - Sensors and Software in Motion Control: Key Benefits to Consider



A depiction of the various fluid power and electronic components included in today's CAN-based systems. Nott Co.

System Architectures Must Evolve to Meet Data Processing Needs

With the continued development of connected and software-defined vehicles will come the need to rethink system architectures, due in part to the vast amounts of data processed by these vehicles.

As data processing needs will greatly increase with these vehicles, Matt Via, Vice President of Sales and Marketing at HED Inc., said during the FPIC conference that OEMs will likely move toward use of zonal system architecture configurations. This will not only aid with data processing needs but also enable vehicle manufacturers to reduce the number of components required in a vehicle and thus the costs associated with producing it.

Typically, OEMs utilize a domain architecture in which vehicle controls are organized around functions and all inputs and outputs that are part of that function are wired back to that location he said. This requires at least four CANbuses to be used to move data across the vehicle. And as data needs continue to increase, so will the number of CANbuses.

Use of the Ethernet communication protocol instead could help meet future data processing needs without adding more components to already space-constrained vehicles. This will require a reorganization of how functions are distributed from functions to locations on the vehicle, said Via, leading to an evolution from domain to zonal architectures.

"With [this] change, an Ethernet backbone is set up around the vehicle allowing controllers to share data between them. Within each zone, LAN and CAN, which are more optimized for lower speeds and lower data rate applications, are used to collect data from sensors while zonal gateways then use the Ethernet backbone to transfer aggregated data back and forth for data processing," he explained.

"The evolution from the domain to the zonal architecture will start with the alignment of the body domain, incorporating power distribution and central computing," he continued. "Over time, more and more domains around the vehicle [will be] added all using the same backbone."

Using a zonal configuration not only benefits increased data processing needs but also allows for simplification and shortening of wire harnesses, reducing space claim and production costs. Additionally, Via said that in a zonal configuration, "the software layers become more contained, allowing components to simply transfer raw data and remove multiple locations for software configurations, meaning less locations to maintain software."

Defining Communication Protocols

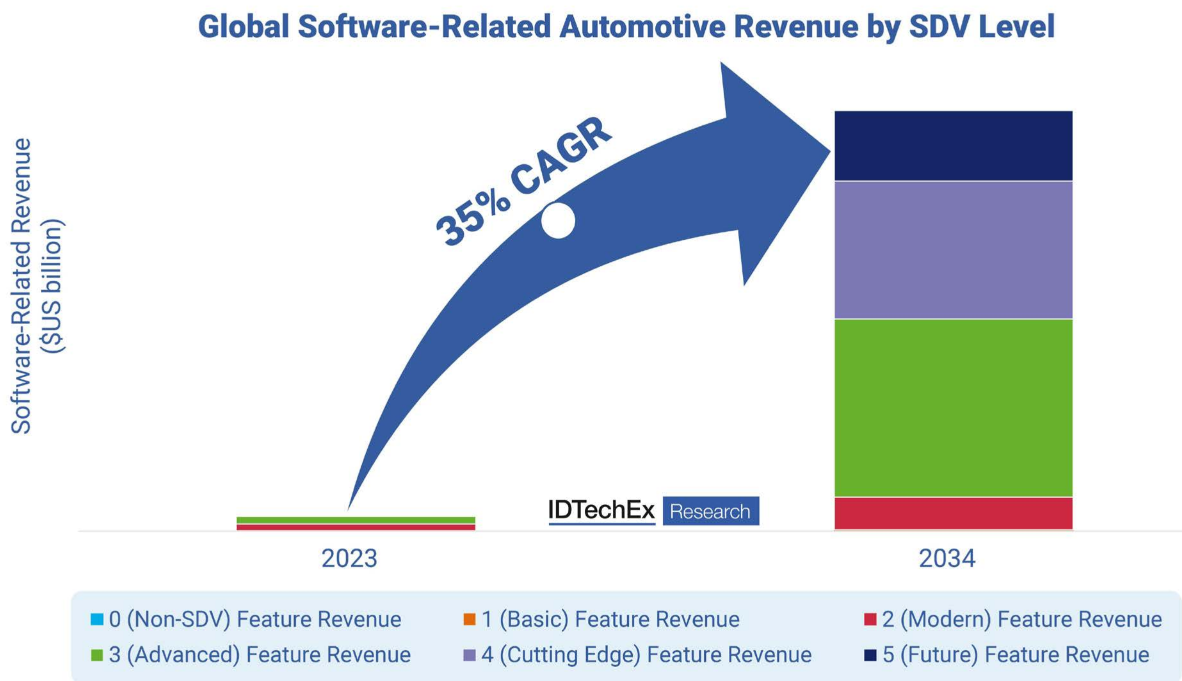
As referenced throughout this article, there are various protocols used within vehicles and mobile machines to transmit data and enable the creation of smart, connected systems. Following are definitions for these protocols to help ensure a better understanding of industry terminology.

LAN = local area network, a computer network which connects computers within a limited area.

Ethernet = a wired computer networking technology that can be part of local area networks.

CANbus = controller area network used in vehicles of various types to allow communication between controllers and devices.

Software-defined vehicles, such as that displayed by ZF at the 2021 IAA Show, present the opportunity to simplify system architectures which offers cost and installation benefits to OEMs. VanderWolfImages | Dreamstime.com



As more software-enabled features are added to vehicles in the coming years, there will be increasing revenue potential for automotive OEMs. IDTechEx

All of this can help to create more simplified vehicle architectures which reduce production costs for OEMs and potential maintenance issues for end users – fewer components mean fewer failure points.

READ MORE - A Shift Toward Compact Hydraulic Systems

Future Market Opportunities for SDV

IDTechEx the software-defined vehicle market is an emerging one with many OEMs in the automotive industry determining how to proceed with monetizing the features available in these vehicles as well as how they want to enable these features.

Per IDTechEx, OEMs such as Ford, Tesla and BMW are already generating revenue from software features such as connectivity, real-time traffic information and heated steering wheels. Meanwhile, there are also automotive manufacturers still utilizing limited or sluggish onboard compute technologies and unoptimized software which is limiting the revenue potential they could see from more advanced, SVD designs.

According to Via, SVD will present revenue opportunities for OEMs in the heavy-duty equipment market as well. The ability to provide over-the-air updates in these vehicles over their lifespan will allow OEMs to build constant value for vehicles in the field, he said. The ability to fix issues with over-the-air programming can increase uptime, providing a key differentiator for early adopters of this capability.

With the amount of data collected by SVD, it will also be possible for machine manufacturers to get a better understanding of actual vehicle usage which can be used to design better machines.

“Software is the future in vehicles that will drive changes to architectures and expand how connectivity is used in the vehicle,” said Via.

He went on to say that in the future, SVD will also accelerate the pace at which data on vehicles is created, as well as the opportunities that can be created from data. It will provide OEMs with the chance to build customer value on existing vehicles, increase satisfaction, and lower warranty rates. As such, it will be important for manufacturers to focus on desired outcomes from the vast amount of data collected. “Users of data want to get an outcome that produces a better result, otherwise it’s noise and expense,” he said.

Therefore, it will be important for OEMs to utilize an outcome driven framework when developing their SVD. “Start with the outcome, not the data, and determine what is needed to deliver that outcome.”

Given the many opportunities possibilities SVD can provide automotive and heavy-duty vehicle manufacturers, IDTechEx is forecasting a 35% compound annual growth rate (CAGR) for software-related revenue through 2034.

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