AUTOMOTIVE JOURNAL

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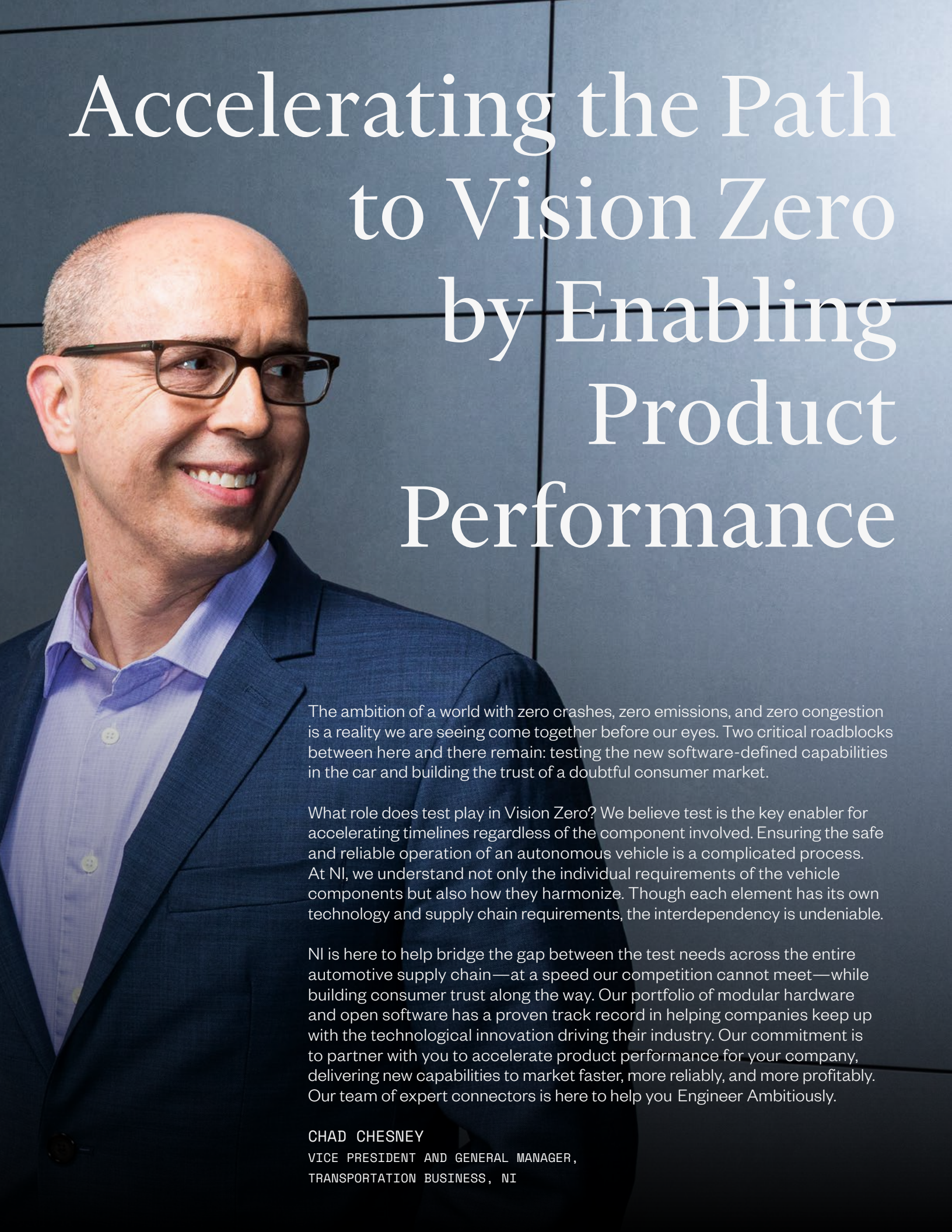
Q2 + 2021



Accelerating the Path to Vision Zero by Enabling Product Performance

The ambition of a world with zero crashes, zero emissions, and zero congestion is a reality we are seeing come together before our eyes. Two critical roadblocks between here and there remain: testing the new software-defined capabilities in the car and building the trust of a doubtful consumer market.

What role does test play in Vision Zero? We believe test is the key enabler for accelerating timelines regardless of the component involved. Ensuring the safe and reliable operation of an autonomous vehicle is a complicated process. At NI, we understand not only the individual requirements of the vehicle components but also how they harmonize. Though each element has its own technology and supply chain requirements, the interdependency is undeniable.

NI is here to help bridge the gap between the test needs across the entire automotive supply chain—at a speed our competition cannot meet—while building consumer trust along the way. Our portfolio of modular hardware and open software has a proven track record in helping companies keep up with the technological innovation driving their industry. Our commitment is to partner with you to accelerate product performance for your company, delivering new capabilities to market faster, more reliably, and more profitably. Our team of expert connectors is here to help you Engineer Ambitiously.

CHAD CHESNEY
VICE PRESIDENT AND GENERAL MANAGER,
TRANSPORTATION BUSINESS, NI

National Instruments
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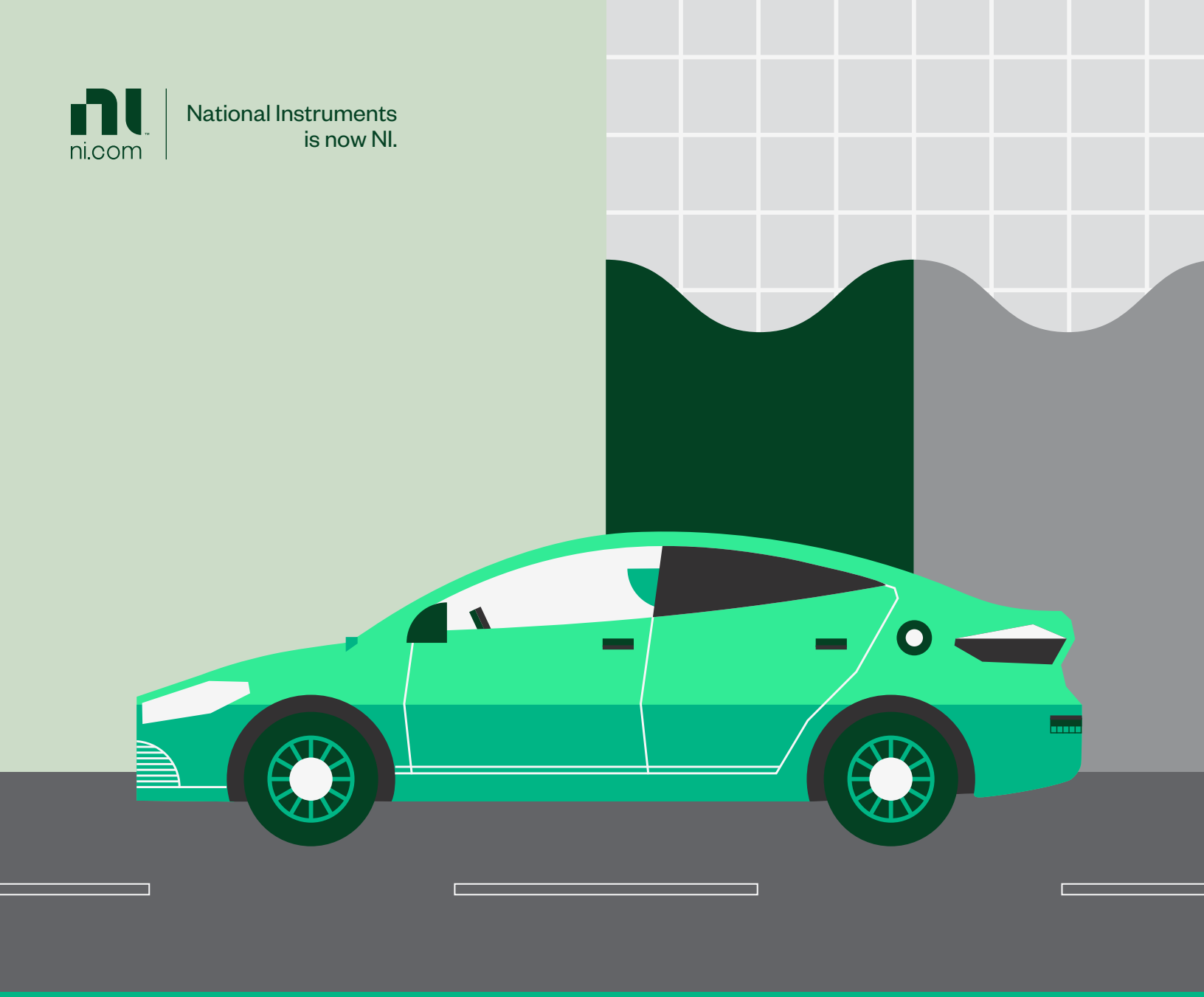

What's Between Us and Vision Zero?

As I write this, Texas is experiencing a historic winter storm. Our infrastructure is not equipped to handle this, and it shows. Due to unfortunate circumstances yesterday, I had to drive some 500 miles from Terlingua to Austin, a picturesque but harrowing expedition as we crawled through congestion on icy highways divided by medians littered with the skeletons of overturned 18-wheelers abandoned to the elements.

Throughout the 12-hour journey, I couldn't help but think of the urgency with which we need to move toward Vision Zero and the future of mobility it promises. What if transportation produced zero emissions, so the cars and trucks congesting the road weren't contributing to the climate change causing the storm we are struggling through? What if efficient rail infrastructure replaced the need for 18-wheelers sharing the road or even my personal vehicle being required for this journey? What if my car was equipped with an autonomy package I trusted to get me through the icy conditions, letting me ease my clenched grip on the wheel?

We are not there yet, but that vision of zero emissions, zero collisions, and zero congestion is at least in sight. The FIGURE 01 timeline shows how far our industry has come over the last decade, which is certainly worth pausing to celebrate. However, this next decade is going to require great advancements in ACES—autonomous, connected, electric, and shared mobility—vehicle technologies that are the backbone of achieving Vision Zero. This decade is all about taking the brilliant IP developed in research labs across the world and making it a reality, which means standing up to the test of government regulation, production ramp-up, and public perception. We believe that testing is not just crucial; it will be the game changer in the ACES advancements of the next decade. Testing will be how we ensure safety, inspire confidence, and validate the impact of these innovations.

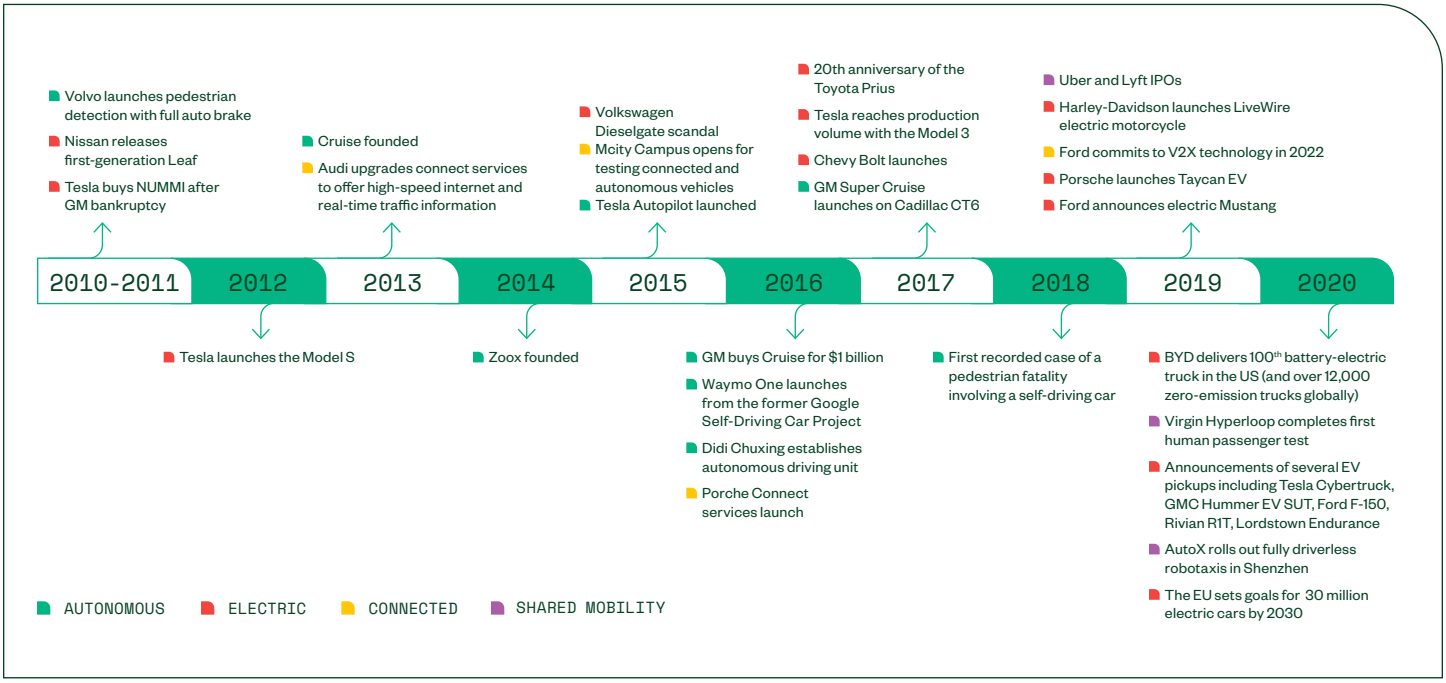

FIGURE 01

The 2010s saw significant advancements for the automotive industry.

Autonomous

With Level 2+ vehicles on the road today, developing, testing, and producing Level 3 and above automobiles will be the challenge of this decade. We believe government regulation and simulation technologies will be two key enablers of this technology.

In February 2021, Germany's Minister of Transportation submitted a draft for legislation to regulate up to Level 4 autonomous driving (Bridie Schmidt, *The Driven*, February 11, 2021). If it passes the German Federal Parliament and Council, Germany will join the ranks of countries such as Singapore, the Netherlands, the UK, and Finland in building strong policy and legislative frameworks for the development and test of autonomous vehicles (AVs). This is exciting because as we move further up the levels of driving automation to Level 4, at which point cars can steer, accelerate, brake, and navigate without a driver, government regulation can play a large role in easing the burden on AV sensing and planning. Legislation is also essential to allow AVs to be tested on public roads and ensure consistency in road quality and markings to ease the burden on AV algorithms.

By providing technical standards for AVs and uniform test methods, this regulation allows automotive companies to focus on the technology itself. The latter is a state we currently see many teams in—developing test requirements and standards in parallel to product design. Though NI has the expertise to help and solutions to recommend in this space, we believe stronger government recommendations, especially if they are consistent globally, will lead to more rapid innovation.

Once these requirements are created, the task is nowhere near complete. The sheer volume of driving scenarios that need to be validated is overwhelming and would be impossible without simulation. BMW reports that 95% of all test miles are driven on a virtual, simulated basis (BMW, "The Road to Autonomous Driving," May 14, 2020). The fidelity of this simulation is essential to make sure that those 5% of miles driven on the road are used for fine-tuning instead of detecting major faults.

The simulation and test of sensors and algorithms have a larger role to play than just validating the technology. Instilling public trust in AVs is going to be a big hurdle to success. We have a long way to go before the public is ready for broad adoption; 20% of Americans studied by the Partners for Automated Vehicle Education (PAVE) believe AVs will never be safe (PAVE Poll 2020). Similarly, only 35% of Japanese consumers desire a fully self-driving AV, with 79% believing that they will never be safe (Seth Lambert and Nicole Kareta, *MES Insights*, October 14, 2020). However, there is hope, as the PAVE Poll 2020 revealed that 60% of Americans would trust AVs more if they understood the technology more. This means that the more we can share about the vehicles, how they work, and how rigorously they were tested, the more consumer acceptance we can build.

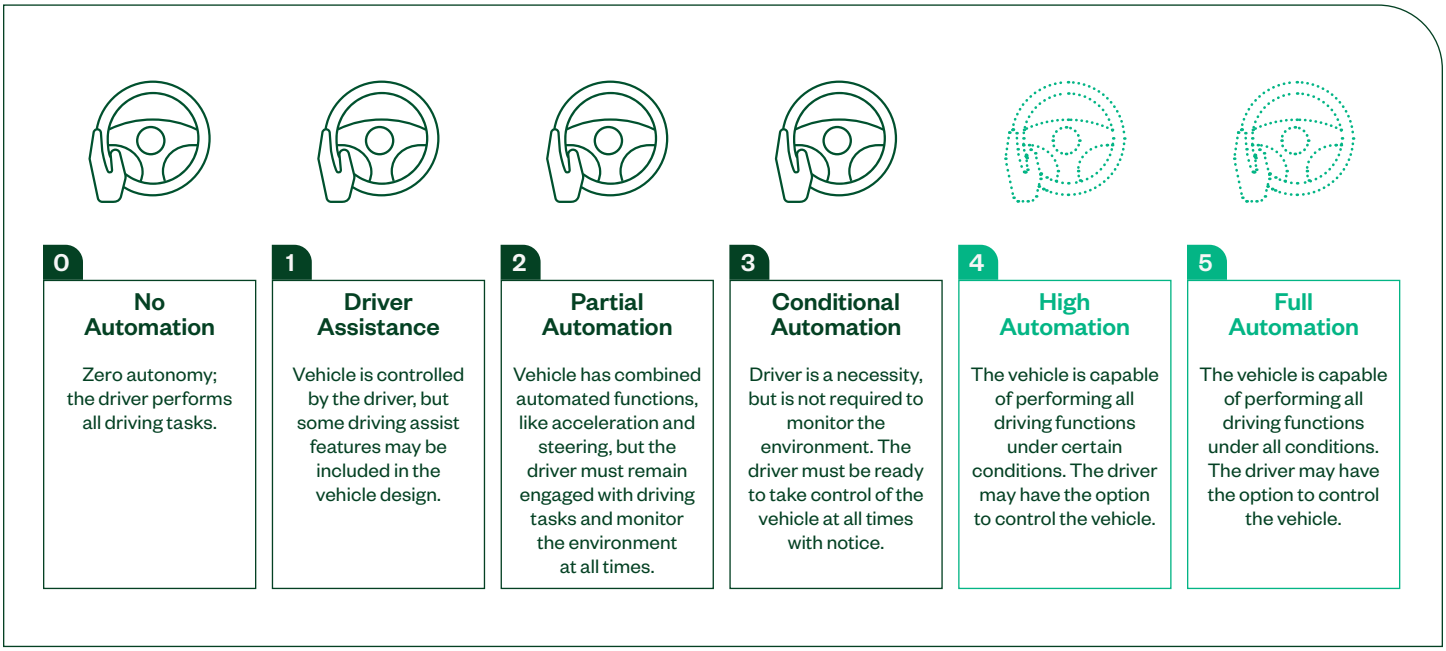

FIGURE 02

The Society for Automotive Engineers defines these five levels of driving automation.

Connected

AVs benefit greatly from the ability to communicate with surrounding vehicles, pedestrians, and city infrastructure. Vehicle to anything (V2X) communication offers the promise of decreased congestion, because we can optimize road capacity, and increased safety as vehicles communicate intent to each other. However, we need to solve infrastructure, standardization, and data privacy challenges to make progress toward this connectivity in the next decade.

The industry has standardized on cellular V2X as an access layer technology for intelligent transport systems due to its coverage, capacity, reliability, and low latency. 5G networks are already in development, but their sophistication and reach vary greatly, which is another challenge that will need to be addressed. In addition, fully realizing V2X requires infrastructure investment in sensor networks and roadside equipment. This investment also may be challenging because of the delay we will see before the full benefits. We will need a certain threshold of vehicles on the road to be equipped with V2X technology before the broader benefits of less congestion and more safety are realized.

Interoperability is essential to make sure a myriad of devices can successfully communicate with each other. Organizations such as 3GPP and 5GAA are leading the way here, bringing device and infrastructure vendors together to test standards and implementation. Simulation is again an enabling technology because tests require complex simulation of the "everything" in vehicle to everything to be realistic.

Finally, data security and sharing are also challenges to tackle. The very openness and interoperability that provide V2X its value can be its downfall because of privacy breaches and even hacking. This is not helped by the fact that countries and even states differ significantly on their data protection laws, with some countries requiring constant reporting of AV locations, while others require anonymization of all data. AVs will need to adapt to the data privacy and reporting requirements of their local jurisdictions or be geofenced, limiting usability. Cybersecurity is a new area of testing for most automakers, so it will require new test technologies and IT expertise to ensure security. This is essential because safety is on the line.

Electrified

Electric vehicles (EVs) and, maybe more importantly, automakers' commitments to developing EVs have come a long way in the last decade. GM aired a 2021 Super Bowl ad about its commitment to release 30 new EVs by 2025. This is a refreshing evolution from early 2010s headlines marked by major automakers' resistance to mainstream EVs. These headlines labeled EVs as a niche solution

for the particularly eco-friendly minority and still treated Tesla as a wishful startup. To capitalize on this momentum and move toward widespread EV adoption in this decade, we need to reduce battery manufacturing costs and ease range anxiety concerns with the development of charging infrastructure.

Several questions remain regarding the most efficient way to develop mass market EVs. To meet emissions requirements, should automakers focus on hybrid vehicles in the short term and postpone EV development, or completely focus on EV right now? How do we minimize emissions across the full vehicle life cycle from manufacturing to obsolescence? What alternative fuel source is best? As the car's power source changes, does the entire vehicle architecture have to change? Or is it possible to create a plug-and-play system that reuses existing designs? Similarly, does every company involved in the EV space need to create the complete vehicle? Or, through partnerships, can we segment to conquer and divide, so we can get to market faster?

The magic price for battery packs is less than $100 USD per kilowatt. At that threshold, automakers should be able to sell mass market EVs at the same price and margin as combustion vehicles. Promising progress has already been made toward this, with the first prices below this threshold reported for e-buses in China in December 2020. The average battery electric vehicle (BEV) pack prices hit $126/kWh, an 89% drop from their $1,100/kWh price tag in 2010 (BloombergNEF, December 16, 2020). Increased volume, new chemistries, and optimized production are the keys to achieve this milestone.

Production ramp-up is a challenge under any circumstance, but it may be particularly challenging to many of the EV startups without automotive manufacturing backgrounds. In a February interview, Elon Musk spoke candidly about the challenges with maintaining product quality during Tesla's production ramp-up, which is certainly a story likely to be repeated as more EV production lines and automotive disruptors start to produce at scale. Batteries specifically present production difficulties because of the many safety-critical elements that need to be tested throughout the battery creation and assembly process. High-performance test equipment can increase production line speed without compromising product quality. Additionally, test systems with built-in data management can funnel manufacturing insights back into R&D to improve product performance, which helps create designs that lend themselves to easier production and simplified test that can win at scale.

Shared Mobility

Though certainly being developed in parallel, shared mobility largely relies on the success of the aforementioned technologies. This future likely involves fleets of autonomous, electric vehicles connected to apps and infrastructure that provide mobility as a service. As such, we believe partnerships are essential for success. The industry is reflecting this, with the number of partnerships between automotive companies, research institutions, and governments increasing by the year. Similarly, traditional automakers are shifting part of their business toward mobility service provision. For example, MOIA by the Volkswagen group created a digital ecosystem for ridepooling. This area also benefits immensely from the field of data analytics for fleet maintenance and user experience.

Test as an Accelerator

Investment in test is a key accelerator for the ACES technologies that will make Vision Zero a reality. Test is the enabler of product performance. Automakers can use it to effectively simulate the right scenarios to validate product designs, ramp up production while maintaining product quality, and, perhaps most importantly, convince consumers to trust and adopt the technologies that will get us to zero emissions, zero congestion, and zero collisions.

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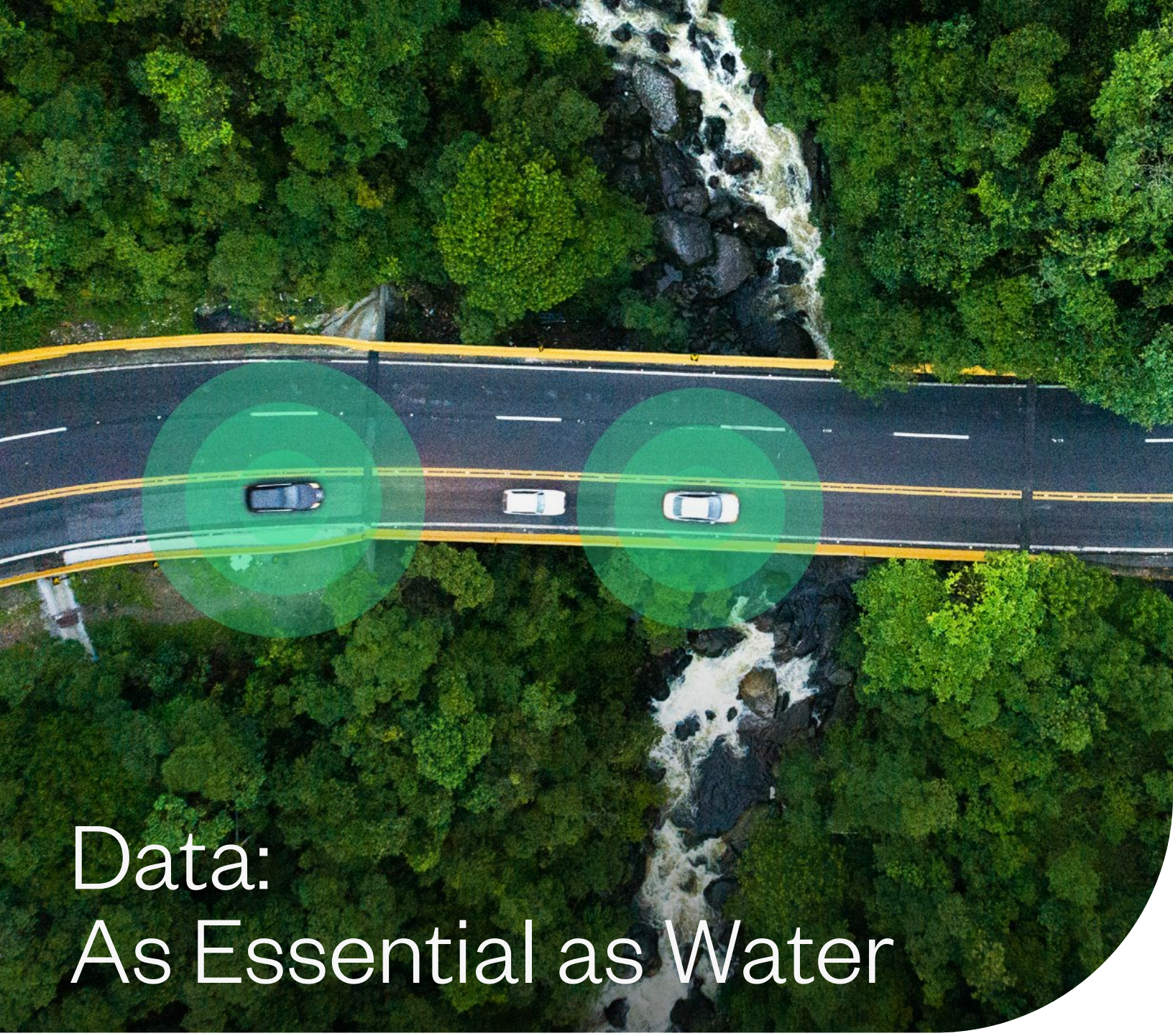

Data: As Essential as Water

Data analytics is a critical enabling technology in bringing Vision Zero to fruition. Data has proven to be transformational for business, but what does it mean to harness the power of analytics in the quest toward an autonomous future?

The recent winter storm that swept across the US, and the perils of that storm in Texas, helped me better understand the role that data plays. For days, millions of people struggled without electricity and running water in their homes. The cold subsided and the sun swept across the state, but much was left to learn about how we receive those services. We're so used to having these resources that we don't always stop to think about how they get from one place to another. For example, I learned that in Austin, Texas, a certain volume of water is required to reach appropriate pressure, but Mexico City has multiple critical pumping stages because the water comes from over 300 km away.

The work of these utilities can help us understand the role and value of analytics with an analogy: data analytics is like your water utility.

We rely on our local water utility to capture water from many different sources, treat it and distribute it. Likewise, we expect data analytics tools, such as NI's SystemLink™ and OptimalPlus (O+) software, to grab data from many sources and make it accessible to us to draw value from it.

STEP 01: Grab the Water

We can easily imagine all the different types of water the utility manages: rain water, sewage, natural sources, and so on. Depending on that type, different processing would be needed to avoid polluting the water by mixing it prematurely. Once the water is caught properly, it is brought to processing facilities.

Like water, data is inconsistent, everywhere, and usually fragmented. Think databases, CSV files, MESs, hard drives, cloud services, data lakes, and anywhere data is stored. We don't want to pollute or mix the data without preparing it, so we use data analytics software on all our data sources for pulling the data together in a single, accessible, contiguous source that is independent from the original data sources and raw formatting.

STEP 02: Clean the Water

Sewage water would certainly require more treatment than water from natural springs, so it takes longer to mix them together and purify them to a standard level.

After data has been pulled together, data analytics software processes it to translate it into a single, common, consistent source. As part of this, some data that's not numerical runs through a parser to make it numerical, for example, when the data is a photo of a radar module assembly, or a snapshot frame from an advanced driver assistance systems (ADAS) camera.

STEP 03: Deliver the Water to the Faucet

Once the water is purified, it must be distributed with enough pressure from the plant to the places it needs to be: from water tanks, underground pipelines, and in-house pipes all the way to a faucet, shower head, or washing machine.

After the data analytics software has prepared or "purified" the data by making it consistent, keeping it together, and correlating it properly, the fun part starts: delivering it to the source where it's needed. In business terms, this means impacting the bottom line through the insights that come from the data.

We recognize how that "bottom line" changes. Just like a faucet represents a different use case than a shower head for the same water, a process engineer needs something different from the test engineer, or the sustaining group.

NI's data analytics software automatically delivers the data that each of them needs, to the outlet where they need it, so they can detect problems faster.

What Does This All Mean?

Modern cars are increasingly equipped with radar sensors for safety functions like autonomous emergency braking or blind spot monitoring. One of the tests that those radars undergo assesses their ability to determine an object's distance precisely.

Let's say we expect the measured distance from the radar under test to follow a Gaussian curve with the center at 25 m, and all variation in a distribution to stay within a couple of centimeters. To make sure this happens, we sample results every few days, look at the data, and make sure the curve is plotting as expected. If something fails and the distribution moves, we pay a cost associated with retesting, reworking, downtime of the test equipment, and so on. The cost depends on the root cause, but we've lost time regardless. With NI's data analytics software, we can automatically run that analysis every few minutes and immediately alert the right people of any problem such as the skewing of that curve. By raising this alert at the right moment, we can act sooner and plan better for whatever downtime we need.

In this example, members of the test engineering group defined the measured distance plot as their "faucet," or their use case. Just like a shower and washing machine are connected to different faucets, other or multiple data "faucets" may be programmed from all the available product, process, supply chain, and test equipment data to provide the following in real time:

- Scrap
- Yield
- Test time
- Asset utilization
- Process efficiency and capacity
- Adaptive manufacturing
- Artificial intelligence and machine learning enablement
- Predictive maintenance

In other words, you receive insights about your product and the test equipment in real time with NI's data analytics software.

NI's product-centric approach offers advanced data analytics in real time.

What about Vision Zero?

This example is applicable to any manufacturing process, so how does data analytics extend to help us reach Vision Zero? In ACES, the S stands not only for shared mobility but also for services.

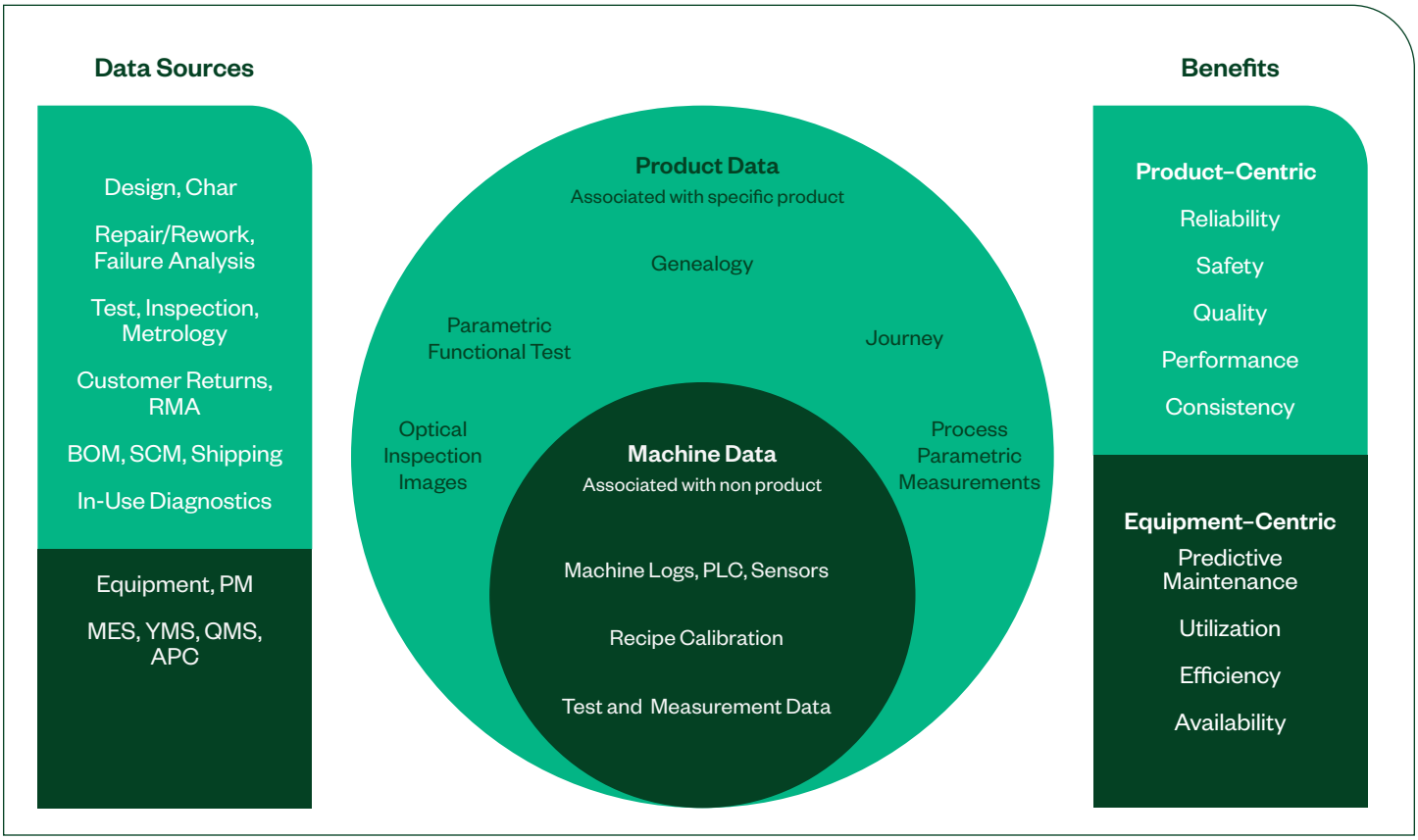

FIGURE 01
NI's product-centric approach offers advanced data analytics in real time.

This is where data analytics is the main enabler: the market around mobility. Companies in virtually all markets can tap into this new consumer behavior that mobility will generate. For example, car insurance companies will very accurately and dynamically adjust rates not on your answers and history but on your actual mobility behaviors. Most of us reduced our driving significantly after we started working from home, but we seldom saw that improving the premiums we pay for insurance. What if we could get a service that's always available and customized, like owning a car, but without the cost of ownership? Data analytics can make that dream of mobility happen.

Closer to Vision Zero

As we work toward Vision Zero, conducting smarter test and smarter manufacturing through data analytics has a positive impact on all relevant variables, including time to market, time to results, total cost of ownership, risk reduction, and liability reduction. Specifically, consider that liabilities in the autonomous future look vastly different from those in the ADAS or semi-autonomous present. Though this is not the only technology that will get us there, NI strongly believes that through the right analysis of impact and commitment to change, implementing the NI data analytics solution is not a gamble on data analytics. It is a solid step toward making data work for you to drive insights.

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Konrad and NI Team Up to Better Serve Auto Companies

Chances are, you've heard or read from me that no one company can solve all the technical challenges across mobility. One of the many ways that an industry landscape changes is through partnerships—opportunities to defy math and make 1 + 1 = 3. I had the pleasure of chatting with Michael Konrad, CEO of Konrad Technologies, to learn more about a strategic agreement announced between Konrad Technologies and NI, and the benefits automotive companies will see from it.

JEFF PHILLIPS: KONRAD HAS BEEN WORKING IN THE AUTOMOTIVE SPACE FOR 25 YEARS. HOW WOULD YOU DESCRIBE THE VALUE THAT YOU'RE ABLE TO DELIVER TO YOUR CUSTOMERS?

Michael Konrad: By working internationally with OEMs and Tier 1s in multiple spaces like consumer electronics, mil/aero, and automotive, Konrad understands the market needs in several different application areas. For example, from our automotive projects, we have developed knowledge in validation and verification test as well as the mass production test of sensors and electronic control units (ECUs) in high volume. And from our consumer electronics projects, we now have deep expertise in high-throughput camera test applications. At Konrad Technologies, these experiences and expertise are combined into challenging and innovative projects to support our customers' new test needs for multisensor advanced driver assisted systems (ADAS) and autonomous vehicle (AV) test applications on a global scale.

JP: WHAT DO YOU THINK IS THE BIGGEST CHALLENGE BETWEEN NOW AND SEEING AVS AT SCALE?

MK: Konrad Technologies is one of the leading suppliers of sensor fusion test benches and hardware-in-the-loop (HIL) systems. The simulation of the street environment in the lab to validate ADAS and ADAS sensors is one of the biggest challenges for AV mass deployment. Testing the behavior of an AV on the street requires complex test and simulation systems, a lot of time, and the ability to address inconsistencies for repeatability tests. So, the goal is to design the in-lab simulation tests to resemble as closely as possible the real environment in order to test the sensors as they would work in the real world. Due to the complexity of those systems, Konrad Technologies is also partnering with other domain experts and market leaders to create high-performance simulation test systems to address this challenge.

JEFFREY PHILLIPS
HEAD OF AUTOMOTIVE MARKETING, NI

JP: KONRAD TECHNOLOGIES RECENTLY SIGNED A STRATEGIC AGREEMENT WITH NI. CAN YOU ELABORATE ON THE AGREEMENT?

MK: The agreement will help focus NI's and Konrad's resources to accelerate the development and distribution of complex validation and manufacturing systems for ADAS and ADAS sensors. NI provides a good platform, PXI, to be used in our systems, while Konrad is experienced and effective at developing the necessary specific software and hardware to be integrated in complete turnkey solutions. Finally, we will be able to deliver complex systems based on standard tools and components for the automotive market.

JP: LET'S PUT OURSELVES IN OUR CUSTOMERS' SHOES. WHAT DOES THE STRATEGIC AGREEMENT MEAN FOR THE INNOVATIVE COMPANIES BUILDING AVS THROUGHOUT THE SUPPLY CHAIN?

MK: From the customers' point of view, the AV companies will get a more standardized testing toolchain that can be used for testing over the whole product life cycle, from the product development to the product incorporation in the car to the test of the car performance itself. Using the same toolchain enables customers to accelerate their development processes by taking advantage of the synergies between the stages of the product life cycle.

The strategic alignment between Konrad Technologies and NI is one of the many examples of NI being an expert connector in our industry. NI recognizes the inherent strengths of our ecosystem and knows how to combine our resources to create a better solution. Together, Konrad and NI can apply that same creative problem-solving mentality to help customers transform test into a strategic advantage for their companies.

MICHAEL KONRAD
CEO, KONRAD TECHNOLOGIES

Unlocking the Potential of a Vision Zero Future with Redefined Body and Chassis Testing

As vehicles become increasingly automated, connected, and electrified, their body and chassis systems are being transformed to maintain interfunctionality and meet users' changing demands. The complexity and number of electronic control units (ECUs) within vehicles continue to grow—from active suspension, brake by wire, and emergency steering, to seat control and rearview mirror ECUs integrated with infotainment systems, to passive safety systems like airbags or seat belts.

Because of this, body and chassis components are expected to help achieve Vision Zero: zero emissions, zero collisions, zero congestion. They are the tools that will help us improve vehicle safety, and how we test them is crucial to achieving the Vision Zero goal faster.

Customer Needs

01

Engineers need a fast, accurate, and automated way to systematically test functionality while eliminating potential points of failure before production starts. With NI's open, flexible hardware-in-the-loop (HIL) solutions, you have the power to easily customize the test system to fit your specific needs. Using a modular architecture, you can easily upgrade the solution with added functionality to future-proof your test systems and meet the requirements of the most demanding embedded software test applications.

NI Solution

01

Minimize cost and ensure reliability with HIL simulation, which reduces the need for costly real-world tests.

02

Maximize system reuse with a flexible test solution designed to be extended and customized to meet your changing requirements.

03

Reduce your development time and enjoy quick ramp-up by taking advantage of customized solutions through NI's robust HIL partner ecosystem.

NI ADVANTAGE:

- Powerful real-time controllers provide high-performance modular instrumentation and a broad range of I/O modules connected directly to the FPGA for testing with higher fidelity through high speed.
- NI switch, load, and signal conditioning (SLSC) devices help you simplify devices under test by standardizing connectivity and providing a modular approach to signal conditioning, fault insertion, and other test needs.
- NI VeriStand configuration-based test software helps you configure I/O channels, create test sequences, and import real-time models with associated stimulus profiles to conduct automated system integration testing.

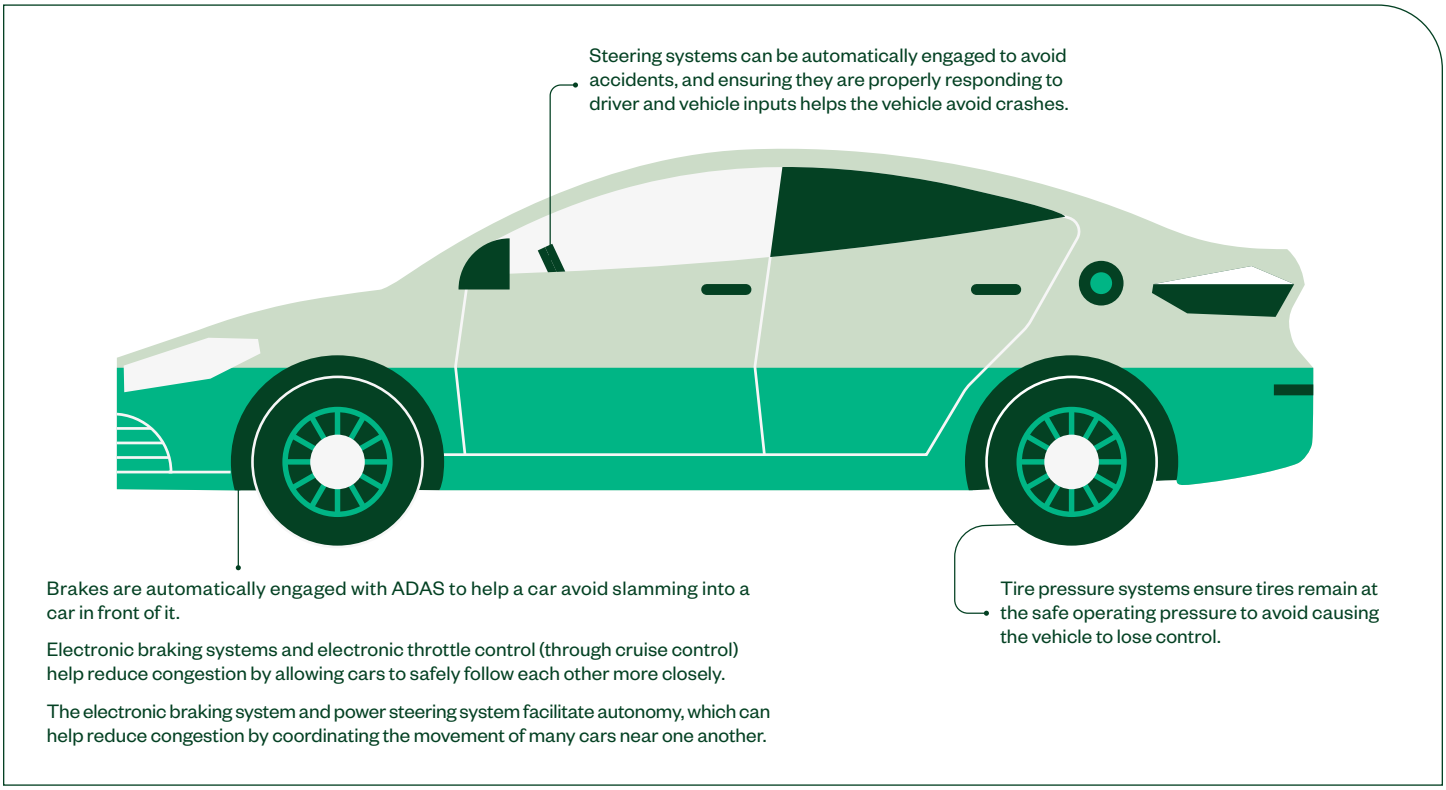


FIGURE 01

The Role of the Body and Chassis System in Vision Zero

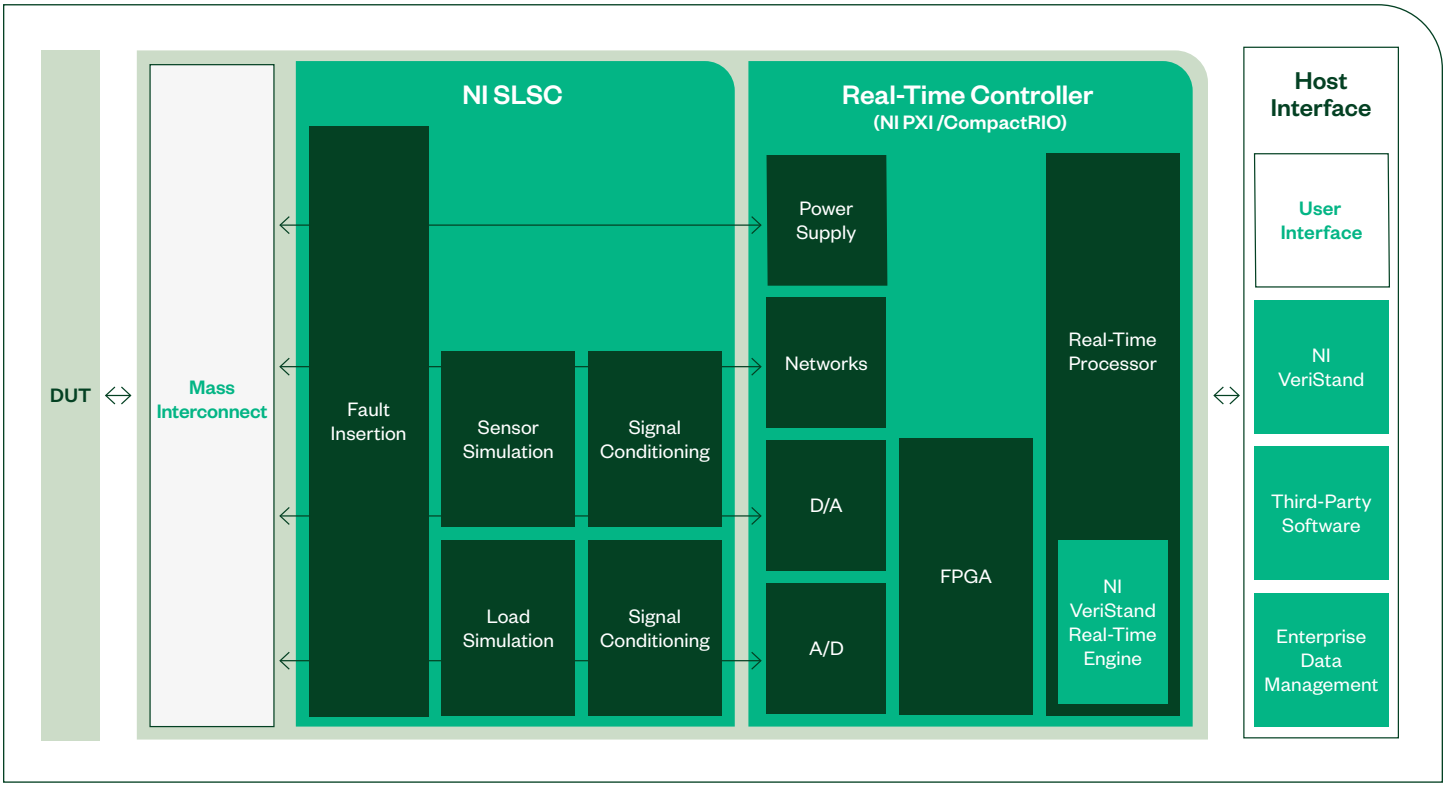
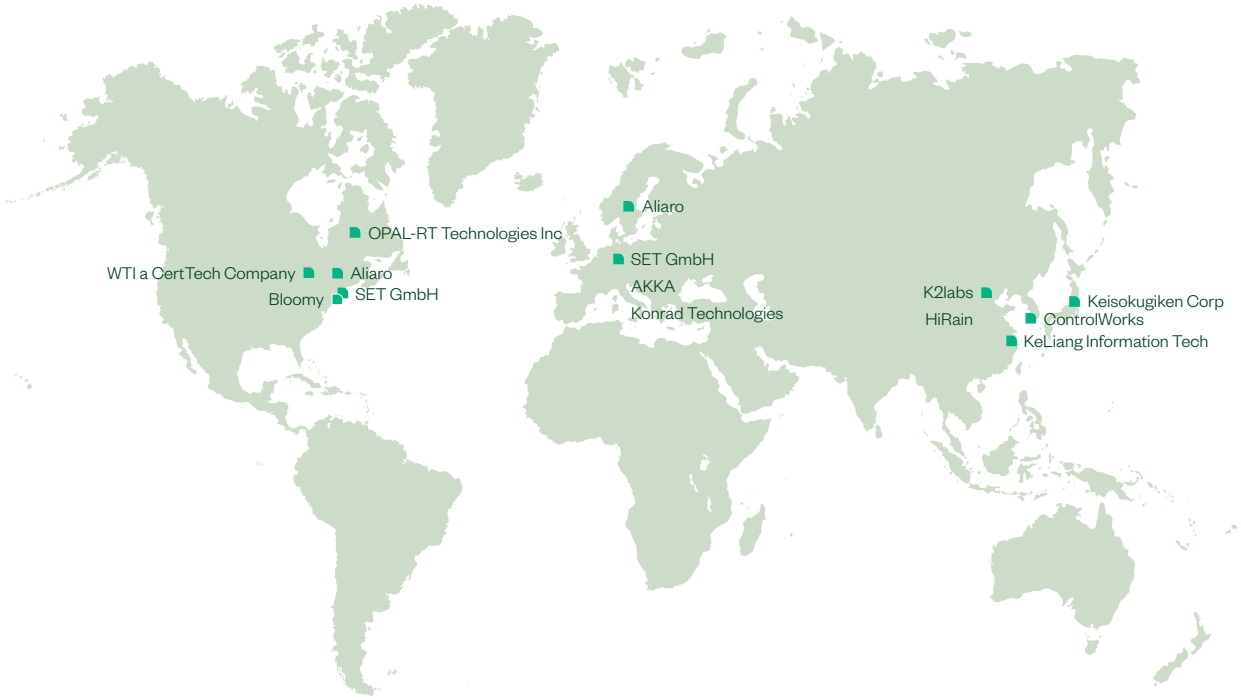


FIGURE 02

A body and chassis HIL system built on NI components offers the ultimate in flexibility by incorporating on modular, off-the-shelf components.

NI Partner Advantage

Working with automotive HIL specialty NI Partners can help you reduce development costs and time with full support and delivery. NI Partners can create a customizable solution using your expertise, your exact application requirements, and their experience to build a flexible turnkey solution based on NI tools. These systems are built to integrate into your existing workflow while giving you the flexibility to adapt to future requirements.



AN NI PARTNER IS A BUSINESS ENTITY INDEPENDENT FROM NI AND HAS NO AGENCY, PARTNERSHIP, OR JOINT-VENTURE RELATIONSHIP WITH NI.

"By using NI's highly adaptable platform, we were able to scale from the electric parking brake HIL tester to the durability tester that helped a global automotive brake manufacturer substantially reduce its nonrecurring engineering costs."

Todd VanGilder
Senior Vice President of Business Development, WTI a CertTech Company

Working Together to Accelerate the Path to V2X

We sat down with Jason Conley, executive director of OmniAir Consortium, and Kitt Farrar, business development manager at NI, to discuss delivering vehicle-to-everything (V2X) technology and applications to the market.

NI: WHAT IS V2X?

Jason Conley: V2X refers to a short-range wireless communications system that allows cars to share safety, road hazard, and traffic information. This system is based on both Dedicated Short Range Communications (DSRC) and Cellular-V2X (C-V2X) technologies. The National Highway Traffic Safety Administration (NHTSA) estimates that full deployment of V2X can eliminate or reduce the severity of up to 80% of non-impaired crashes, saving thousands of lives each year.

NI: WHAT IS THE OMNIAIR CONSORTIUM AND HOW DOES IT CONTRIBUTE TO DELIVERING THIS TECHNOLOGY TO MARKET?

JC: OmniAir is the leading industry association promoting interoperability and certification for intelligent transportation systems, tolling, and connected vehicles. It offers independent, third-party testing through a network of accredited test labs. OmniAir certification ensures that devices meet industry standards and minimal interoperability and security requirements.

NI: HOW IS NI INVOLVED IN V2X TEST AND CERTIFICATION?

Kitt Farrar: NI's tools empower engineers to test across different layers, from physical to protocol layers and from day 1 standards to custom scenarios. NI also helps engineers test across technologies, such as 802.11p, LTE, and 5G, and across regional variants without the hassle and cost of changing hardware because the hardware is defined by software. NI's role is like unlocking all degrees of freedom in V2X test to achieve compliance, time-to-market, and cost expectations.

NI: WHAT CURRENT CHALLENGES ARE OMNIAIR AND MEMBER COMPANIES EXAMINING? HOW IS NI PLANNING TO ASSIST?

JC: OmniAir is immediately focused on rolling out the world's first comprehensive testing and certification program for C-V2X. NI, together with NI Partner S.E.A., is meeting a critical need for a portable radio packet capture (sniffer) tool for testing C-V2X radios. This tool, which is expected to be used by both test laboratories and deploying agencies, will be showcased at the upcoming OmniAir Michigan Plugfest.

KF: In addition to the sniffer-logger we're working on for OmniAir with S.E.A., we are enabling V2X test with 5G New Radio even before chipsets are widely available. We're also providing a platform for automotive companies to test their C-V2X devices for congestion loading,

KITT FARRAR
BUSINESS DEVELOPMENT MANAGER, NI

channel emulation, hardware-in-the-loop, RF conformance, and more.

NI: WHAT OPPORTUNITIES ARE THERE TO PLUG INTO THE V2X ECOSYSTEM IN 2021?

JC: OmniAir offers its members the opportunity to get involved in one of our six active working groups, which are exploring everything from cybersecurity to V2X application testing. We are also planning a series of webinars and workshops as well as our Plugfests to bring together leading device manufacturers, OEMs, engineering firms, test labs, and test equipment manufacturers for a week of lab and field testing. The OmniAir Michigan Plugfest is June 14–18 (omniair.org/events).

KF: V2X still has a long way to go, and organizations must work together globally toward standardization, implementation, and adoption. Working with OmniAir greatly helps accelerate the realization of V2X, both in defining and advancing the standards as well as working out the kinks like only a Plugfest can do. I look forward to being part of the great progress in V2X that I predict for 2021.

> We are excited to welcome NI as the newest OmniAir member. NI is a recognized global leader in testing solutions. Their deep expertise in V2X and automotive testing will help OmniAir advance its certification programs for connected vehicles.
>
> **Jason Conley**
> Executive Director, OmniAir Consortium

JASON CONLEY
EXECUTIVE DIRECTOR, OMNIAIR CONSORTIUM

“High-performance modular instruments allow us to do test-bench-based development of future vehicular fail-operational low-voltage power systems. Through communication with selected measurement and control components, the system under test can be stressed electrically with an automated validation test process. Highly dynamic and accurate measurements are immediately evaluated. Results from these physical tests help us to significantly improve our models deployed in our digital twin.”

Martin Baumann
Simulation Electrical Power Supply, BMW

Challenge

Vehicle electrification and automation greatly impact safety-relevant and functional power system requirements because interferences to those can cause fatalities. Critical situations should be discovered in the early concept phase through simulation. Countermeasures such as harness redesign, component modifications, and anti-interference solutions can be derived. Virtual designs reduce development time and preserve financial resources, but they also require a close measurement feedback loop to validate the models against the real physical systems and system-inherent retroactive effects.

Solution

The BMW Group designed and developed a digital twin for low-voltage vehicular power systems. With a newly defined validation approach and the development of a system-level physical and digital twin, highly dynamic processes can be simulated and emulated to fully stress the low-voltage power system and therefore identify weaknesses quickly, which reduces development time and costs.

Designing and Developing a Digital Twin for Low-Voltage Vehicular Power Systems

Digital Twin Methodology

A digital twin is a virtual replica of the physical twin, which represents a physical asset (object, system, device, process, product, service, and so on). This includes modeling and simulating its functionality and behaviors. A tight connection between the digital and physical twins is required to make sure that the virtual replica can mimic the physical effects as closely as possible. Real-time data and sensor measurements play a critical role in establishing and evolving the digital twin because data and measurements are key to compare and fine-tune the modeling and simulation aspects of the digital twin.

Solution Requirements

BMW's ultimate goal is to shift the development of the low-voltage power system toward a virtual approach, thus making it a digital twin. Therefore, accurate models are needed for those components connected to the power system influencing its behavior. Safety-relevant components ranging across multiple Automotive Safety Integrity Levels (ASILs) include brakes, steering, windshield wipers, headlights, central electronic control units (ECUs), and sensors for object recognition purposes (advanced driver assistance systems, or ADAS). High-power components such as power electronic driven machines, audio boosters, fans, and amplifiers impact the power system's voltage stability. Hence, precise models are needed for the power supply and wiring harness. As a first step, BMW improved these models by characterizing the physical components on a component-level test bench. Then they recorded electrical behaviors through road testing and replaying those phenomena back in the lab. Finally, BMW developed a system-level test bench as a physical twin within the lab (see FIGURE 01) to validate the results of the digital twin against reality. By injecting the recorded electrical waveforms from road testing into the power system of the physical and digital twins, BMW can further optimize the simulation. The physical twin also includes simulation and emulation technology to mimic real driving, startup, and malfunction behavior by injecting interferences.

Before BMW implemented this multistage model characterization and validation process including the previously mentioned system-level validation test bench, virtual development had successfully provided valid results for long-term processes such as driving cycles. Initial improvement steps were taken by implementing a first test bench for a low-voltage vehicular power system using adequate loads[1] but no highly dynamic effects and interferences.

With further developments on functional safety, particularly focusing on highly automated vehicles (HAVs) ranging up to fully automated vehicles (FAVs), fail-safe functionalities and fail-operational functionalities have become more crucial. At the same time, these safety features and the already existing non-safety-critical devices and subsystems (for example, HVAC) are all connected to the same energy (voltage) source. This can lead to a severe impact on safety-relevant components as well as comfort systems. With the newly defined validation approach and the development of a system-level physical and digital twin, these highly dynamic processes can be simulated and emulated to fully stress the low-voltage power system and therefore identify weaknesses quickly, which prompts designing and implementing appropriate countermeasures.

Approach

The previously mentioned requirements can be met with a high-performance modular instrument that is capable of high-accuracy measurements and process elaboration at high speeds. A modular design supports customizable test applications. NI's real-time PXI system meets these requirements. The instrument acts as the central test system and main connection to guarantee a seamless integration of all necessary measurement and control capabilities needed to fully orchestrate (time, trigger, sync) the whole system-level validation test bench.

The PXI hardware is controlled with engineering software products including LabVIEW and VeriStand. Besides that, the measurement system architecture allows for preserving existing investments in

third-party tools and equipment through full integration into the whole setup (for example, Vector CANoe for Restbus Simulation). This software-connected PXI-based test system has become an all-in-one solution to address communication bus simulation, measurements, and control of third-party devices, such as electronic loads, sources, and in-house-developed prototypes, as well as logical interfaces to the safety environment including safety switches, relays, circuit breakers, and so on (see FIGURE 02). The established measurement setup enables the development of highly automated test sequences, which leads to never-before-achieved repeatability within the whole validation workflow.

The predecessor of the current system was developed as a joint project between the Technical University of Munich and BMW,[1] so BMW has had a lot of positive experiences with high-performance modular instruments, which can be reused. Modular instruments also address demanding requirements such as high-frequency measurements (>3 MS/s), communication with third-party products, test automation capabilities, and automatic report generation of results. Additionally, the software toolchain is comprehensive, allowing for straightforward test solutions for both experts and students.

Furthermore, the modular and scalable design of the PXI system enables expansion and adjustments of measurement and control capabilities at any point in time, so the setup is optimized to meet future challenges and requirements easily and cost-effectively. Simple yet powerful details like standardized connection concepts such as the SCB-68 Terminal Block and SH96 connectors and cables allow for straightforward system upgrades to enhance the performance when necessary.

The models used are either acquired directly from the component suppliers or developed by BMW itself. Simulation tools and programming languages used include the MathWorks MATLAB® and Simulink® software, Plexim PLECS, Python, Modelica Dymola, and others. Homegrown models are typically generated through system identification methods and/or designed by acquiring current and power profiles from each component to perform a proper device characterization.[2] This, again, includes measuring back high-dynamic current pulses and fault-injection behavior.[3] Signals used to stress test the system range from 0 kHz to 150 kHz. The acquired profiles are then imported into the simulation as lookup tables to further fine-tune and improve the existing models.

Results and Benefits

This new approach to validate the low-voltage power system, including both physical and virtual testing techniques, has enabled BMW to design completely new models by leveraging a new model development methodology. It is now possible to find new defects earlier in the overall design and development process, which reduces development time and cost because engineers can fast track to an initial higher quality prototype. The data and insights generated can be shared with suppliers and internal stakeholders at BMW to further improve their models. Some of the models used are running 95% faster now,[4] while interferences to the power system in the range of 10 kHz to 100 kHz have been reduced by 75% due to stability countermeasures made to the previously mentioned physical-to-digital design flow.[5] Moreover, the new and improved models already achieve a less than 5% deviation compared with the real-world component in the up to 150 kHz frequency range. Because of this, BMW feels confident it is on track to achieve 20% faster development cycles, leading to shorter times to market through digital design, as predicted by research initiatives such as the PANDA project.[6]

Outlook

A complete system simulation model still needs to be validated because only parts of the system have been fully validated. System optimization concepts will be physically implemented and compared with the simulation results. Furthermore, time-overlapping pulse injections will be implemented in the future to fully understand and diagnose cross interference. Last but not least, a Network Analyzer will be integrated to acquire online transfer functions and execute impedance measurements.

[1] M. WINTER, A. RENNER, J. TAUBE, AND H.-G. HERZOG, "GENERATORPRÜFSTAND MIT GEKOPPELTER GENERATOREMULATION ZUR VERWENDUNG AN EINEM BORDNETZPRÜFSTAND," 2016.

[2] M. BAUMANN, T. BREM, S. SCHWIMMBECK, C. WEISSINGER, AND H.-G. HERZOG, "IMPEDANCE-BASED MODELING OF AN AUTOMOTIVE ELECTRIC POWER STEERING," 2020.

[3] M. BAUMANN, C. WEISSINGER, AND H.-G. HERZOG, "AUTOMOTIVE POWER SYSTEM MODEL VALIDATION USING IMPULSE RESPONSE ANALYSIS," 2020.

[4] M. BAUMANN, B. HAJ ALI, C. WEISSINGER, AND H.-G. HERZOG, "EFFICIENT SMALL-SIGNAL ALGORITHM FOR HIGH DYNAMIC PHASE-SHIFTED FULL-BRIDGE CONVERTERS," 2020.

[5] M. BAUMANN, A. SHOAR ABOUZARI, C. WEISSINGER, B. GUSTAVSEN, AND H.-G. HERZOG, "PASSIVE FILTER DESIGN ALGORITHM FOR TRANSIENT STABILIZATION OF AUTOMOTIVE POWER SYSTEMS," 2021.

[6] A. BOUSCAYROL AND W. VAN DORP, "EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME: PANDA."

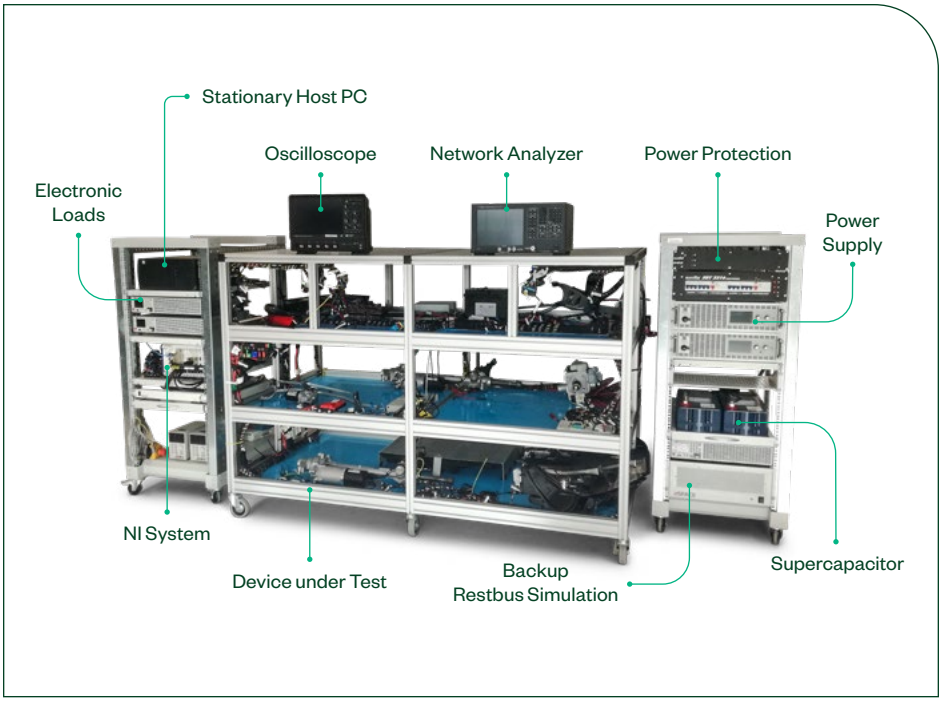


FIGURE 01
System-Level Validation Test Bench

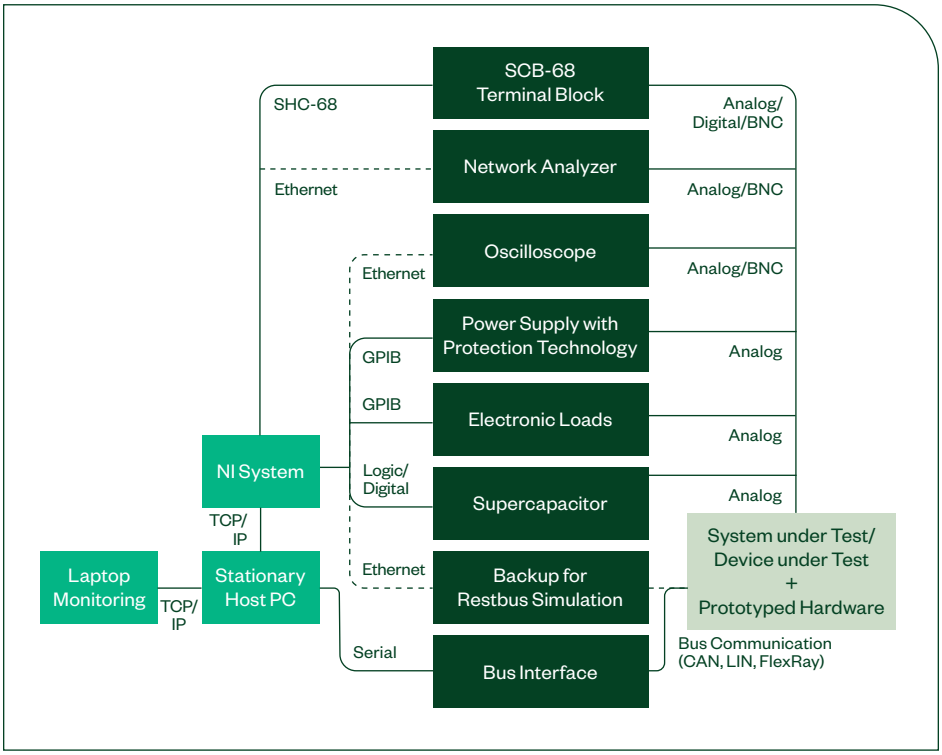


FIGURE 02
System-Level Validation Test Bench: Measurement and Control Architecture

Company:
BMW AG
MUNICH, GERMANY

Industry:
AUTOMOTIVE, RESEARCH

Application Area:
MULTIDOMAIN VALIDATION

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NI PRODUCTS USED:
- PXI System
- FPGA-based Multifunction I/O
- VeriStand
- LabVIEW

Leading the Way with the Force of Our Partners

Wireless technology drives significant improvements in vehicle safety, comfort, and user experience to influence how drivers, passengers, and vehicles see, think about, and react to external circumstances.

As telematics modules converge with infotainment systems, test complexity increases along with the need to effectively integrate these capabilities. This is because test systems must cover new wireless standards, increase throughput, support multiple devices under test that usually require other tests.

Customer Needs

01
Test flexibility and long-term support

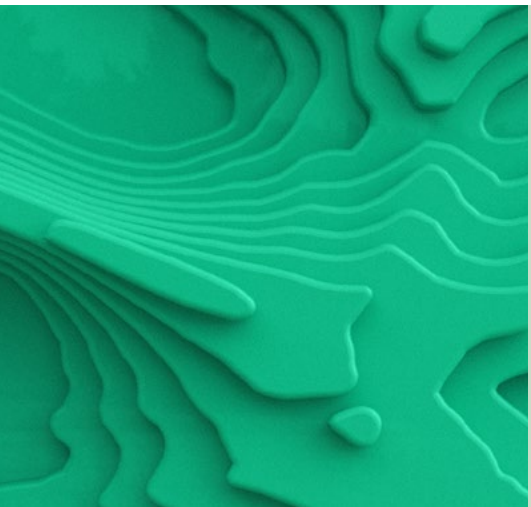
02
System scalability with cost-effectiveness

03
Short time to test across validation and production

NI Solution

01
We can make a difference using the right technology in today's vehicles to provide greater safety and efficiency, but we cannot do it alone.

NI, along with our telematics and infotainment partner solutions, can help you reduce development costs and time by providing full support to you while helping the automotive industry achieve the broader vision of creating safe mobility for all.



"Vision Zero is not a race to be won alone, and our partners can help you achieve your goals and overcome your challenges faster by ensuring quality, reducing risk, and shortening your development time with best-in-class solutions."

Kyle Ulrich
Senior Director, Partner and Digital Strategy, NI

RF Base Station Emulator by Noffz Telematics and Infotainment Test

- Save test time with parallel user equipment (UE) connection because multiple UEs can go through environmental exercising and other endurance testing at once.
- Minimize cost with full 2G/3G/4G/5G protocol stack support with increased flexibility at a fraction of the price of traditional callbox solutions.
- Quickly adapt to changing specs with minimal system changes with software-defined architecture and modular hardware.

Universal Wireless Tester by Noffz Telematics Control Unit Test

- Minimize downtime through automatic relinking between test adapters and transceivers, continuing production in case of component failure.
- Reduce test time through parallel DUT testing, automatic RF port routing, and automatic resource sharing.
- Reduce total cost of test through a faster test time, high port count, DUT control, signal conditioning integrated in the RF switch, and system scalability to 5G NR, 802.11ax, and 6 GHz Wireless.

StellaNGC by M3 Systems GNSS Test

- Create scenarios using an intuitive user interface.
- Achieve easy integration with multiple APIs and data flow that fits your application.
- Use a single software suite and compatible hardware for both simulation and record/playback.

Wireless Test eXtended by Alfamation Telematics and Wireless Test

- Use a single platform for multistandard, multi-DUT testing.
- Achieve unparalleled modularity in terms of number of supported ports and scalability.
- Take advantage of flexible fixturing and configurable switching for local and remote tests.
- Use software with a starting configuration, a command line interface (CLI) to update settings, and a future-proof architecture based on NI drivers.
- Optimize system integration through the Alfamation experience.

AST-1000 by Averna Infotainment RF Record and Playback Test

- Enable global deployment with a single, standard test platform that offers simple calibration, maintenance, and support.
- Adapt to changing requirements with support for additional RF/non-RF signals, protocols, and communication buses.
- Maximize test coverage with modular instrumentation that supports RF signal record and replay and system synchronization.

National Instruments
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LYNN SARCIONE
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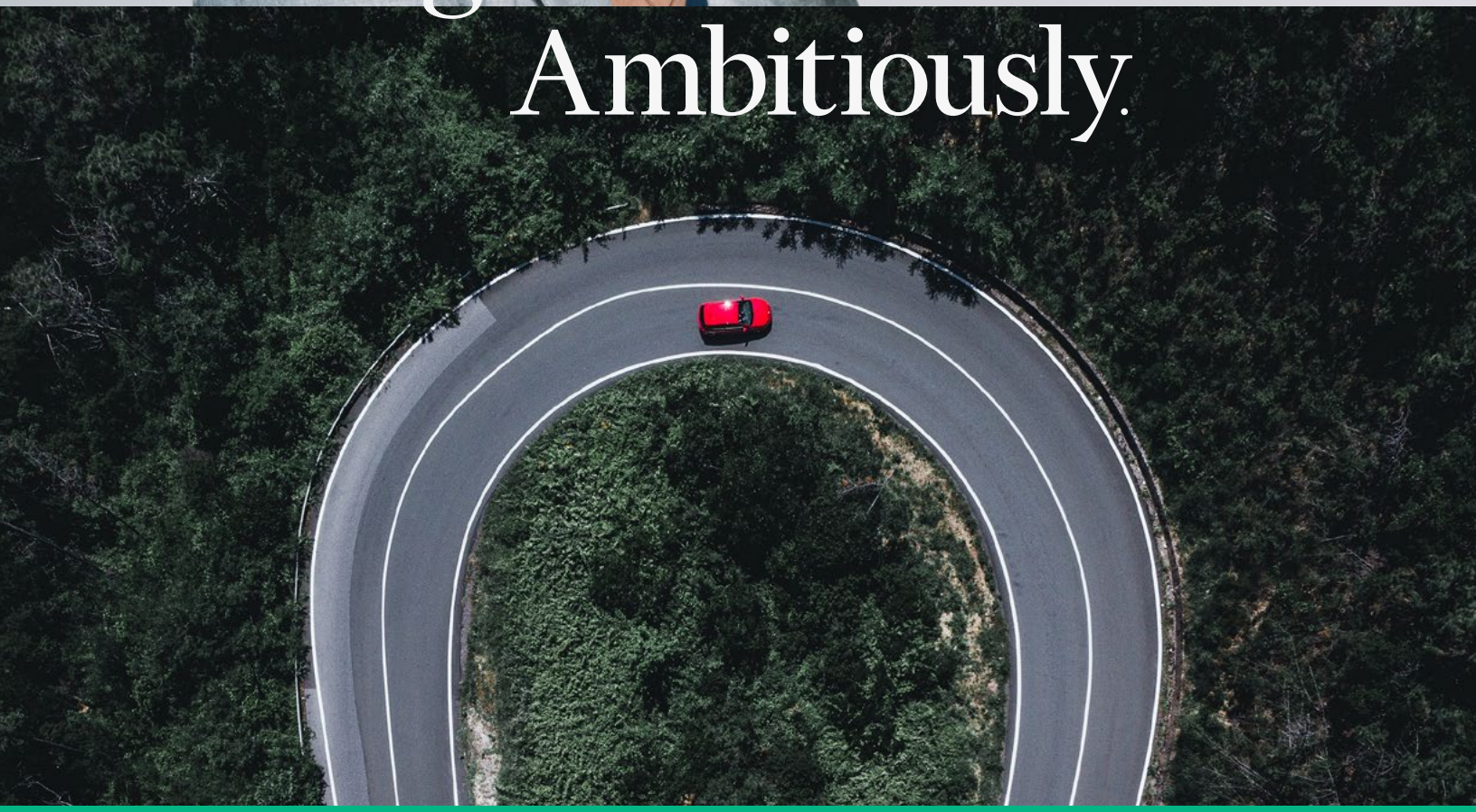

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