



AUTOMOTIVE JOURNAL



The heart of the mobility revolution

is the convergence of multiple technologies, which creates both tremendous innovation and tremendous challenges. The convergence has required the automotive supply chain to take a crash course in software test, a nonlinear step function in complexity from pure hardware components. Over-the-air updates demonstrate a promising upside to reverse the steady growth in software-related vehicle issues, but that does nothing to simplify the challenge that is testing software.

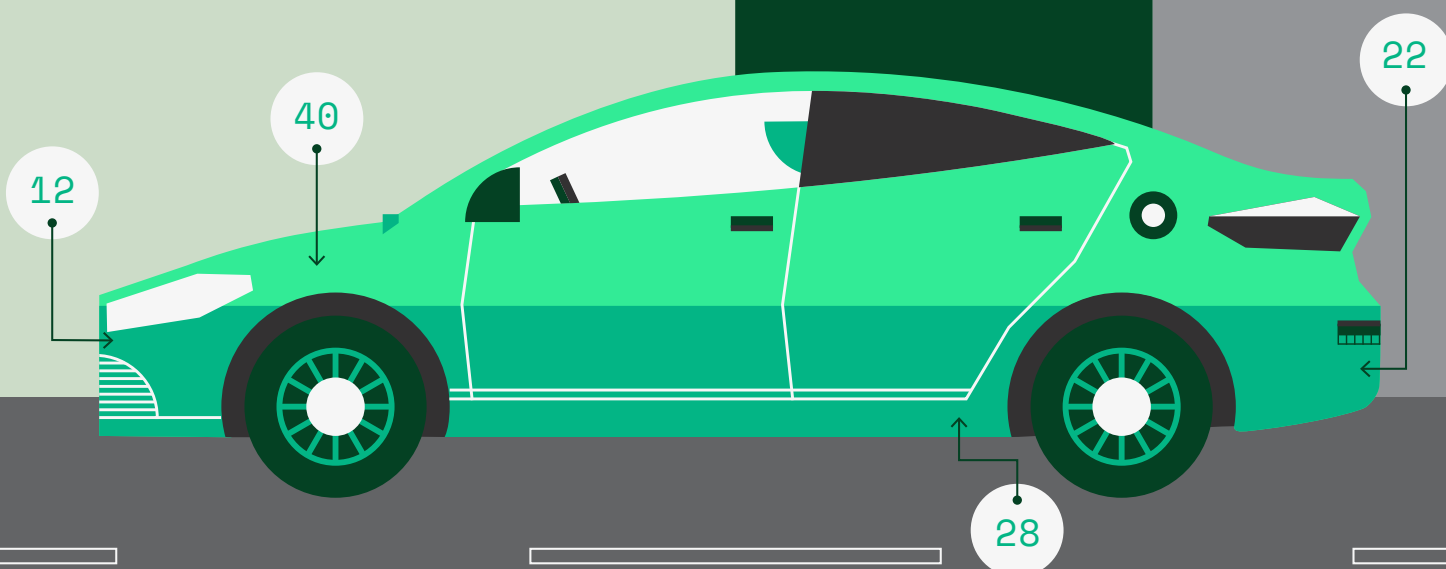
For automotive engineers, testing software behavior begins in the hardware-in-the-loop (HIL) lab. Here, the world around the software is simulated to test the software's response to various input scenarios. In this *Automotive Journal*, we'll explore the complex space where the behavior of smart, connected automotive systems is put to the test. NI's modular, software-connected automotive systems are the ideal solution for testing automotive electronics in the loop.

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Focusing on Hardware-in-the-Loop Test



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This Is the Way
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Model-Based Design and Test: This Is the Way

If a picture is worth a thousand words, a model is worth a thousand PowerPoint slides—or specification line items. As our creations grow more complex, model-based design and test is a paradigm—a way of working and thinking—that promises true understanding, clear yet detailed communication, and efficiency in engineering and operational processes.

A Way of Working and Thinking

Deep understanding is needed now more than ever as the pace of technological innovation accelerates. It's also needed as automotive design and test teams deal with integrating multiple new technologies into systems that must work well together in a wide variety of operating conditions.

The raw material for innovation and revolutionary designs is bountiful, but the risk of failure is exponentially increasing with system complexity.

Making large, complex systems requires a lot of people, strategies, and components working together effectively. As complexity grows, PowerPoint engineering no longer suffices. Designing well, with the required level of design confidence, requires

efficient communication among design teams, test teams, and stakeholders. This is where models come in.

Adherents of model-based design and test use computer-executable models as a common interface to turn raw data into information and specifications and to communicate between the stages of the development process.

Discovery and Assessment

The purposes of testing are discovery and assessment. Discovery testing helps engineers better understand their device under test (DUT) to predict and improve its behavior. Assessment testing helps decision-makers handle the costs and risks inherent in DUT deployment and operation. Hence, the job of test teams—the goal they have with their test processes—is to gain the knowledge they need to make decisions on the next steps for development, production, and deployment.

Test Processes: Begin with the End in Mind

KEEPING THIS IN MIND, GOOD TEST PROCESSES EXCEL IN PROVIDING ENGINEERS AND DECISION-MAKERS WITH INFORMATION AND INSIGHT.

FIGURE 01 outlines the major steps to extract information and insight from test processes. First, you mine the DUT for data that relates its output behavior to the stimuli applied to its inputs. Next, you refine this raw data into information that captures DUT behavior in compact and more understandable ways. Finally, engineers and decision-makers use this information to better understand DUT characteristics

and behavior and assess risk related to DUT deployment and operation.

The process works both ways. As discovery progresses and risk assessment grows more sophisticated, you need more and new information. This in turn drives changes and improvements in the mining process. This model is a useful framework in designing and classifying test architectures.

WHEN CONSIDERING THIS FRAMEWORK, NOTE THAT THE BIGGEST COST IS IN THE SETUP AND OPERATION OF THE DATA MINING EQUIPMENT BUT THE BIGGEST VALUE COMES FROM REFINING DATA INTO INFORMATION AND PROVIDING THE USER-FRIENDLY, EFFICIENT ACCESS TO AND INTERACTION WITH THIS INFORMATION.

A common shortcoming in many test tools is their sole focus on data capture and storage. Without (preferably automated) means to extract useful information and identify important events, teams often end up with a useless data “garbage heap” that leaves them disappointed in their test investments.

Mining

To mine for data, you embed a DUT in a context that models the DUT’s surroundings. Context elements can be virtual, for example, software to manipulate the DUT as well as physical

elements such as the surrounding hardware. You can emulate a DUT’s context or use its actual (real) context. For example, when the DUT is a car inverter, the electric motor that’s part of the test’s context can be either emulated or physically present on a test bench or integrated into the actual car.

In test design, you need to determine the approach that best realizes the test’s context. Traditional test architectures often embed the DUT in an emulated context. You add the DUT to a testbed that applies stimuli and measures responses. This is a proven approach that you can use to create test conditions at will, but it can be expensive and unscalable.

Consider alternative approaches like a design-for-test paradigm for which you design DUTs with built-in capabilities to data mine during regular operations. Or you can use a simulation-based test paradigm with models to test in the much cheaper virtual domain earlier in the development process.

Alternative test paradigms aim to optimize or reorganize the cost structure of test processes. Traditional test approaches often incur significant capital investment in “mining equipment” and operations. Alternative mining strategies may significantly lower capital tied up in test and, as such, prove disruptive for the industry.

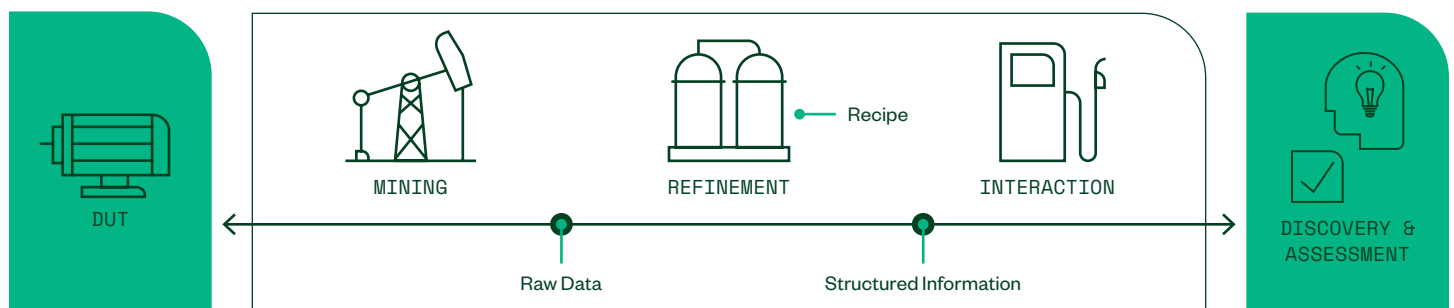


FIGURE 01

Test processes amount to mining your device under test for data and turning that into information that engineers and decision-makers can use in discovery and risk assessment.

Refining

Once you mine your data, you need to “refine” it into useful information. Models play an essential role in making sense of raw test data. They store past experience in a way that helps predict future behavior. Models are templates for compressing DUT measurement data and predicting DUT behavior.

STATED DIFFERENTLY, MODELS ARE TRANSFERABLE REPRESENTATIONS OF KNOWLEDGE AND EXPECTATION. FOR THIS REASON, THEY HAVE BEEN LABELED AS DIGITAL TWINS, THAT IS, THE DIGITAL COUNTERPART TO PHYSICAL SYSTEMS AND THE DATA STREAMS THEY PRODUCE.

Good models improve understanding and reduce uncertainty to help make DUT behavior predictable. In the context of test processes, the design of suitable model topologies is part of the discovery process. Model identification and evaluation (simulation) help you assess the consequences of DUT deployment in a given context.

Interacting

By nature, models (digital twins) are a great way to summarize test results and capture DUT information across platforms. This makes them useful for improving communication within large organizations where different departments often use different platforms and toolchains.

By providing implementations of the same set of model equations in these different environments, teams can exchange information in a coherent and executable manner. For example, the test team may use model implementations on FPGAs to conduct real-time evaluation and model parameter fitting. The systems design team may then “download” the model and parameter set as a CPU-based functional mockup unit implementation for use in offline system-level simulations. This approach produces fewer errors than exchanging information via text and spreadsheet.

This Is the Way

Model-based design and test is a way your team can keep pace with increasing DUT complexity and aggressive program schedules. Adopting this way of working and thinking yields powerful and far-reaching results that can transform organizations and turn test into a competitive advantage.

Digital twins are computer-executable models that help connect the different parts of processes and organizations. They summarize and communicate requirements, expectations, and measurement results in an executable manner.

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| R&D TESTING | VERIFICATION AND VALIDATION | AUTOMATED PRODUCTION TESTING | DEPLOYMENT TESTING |
|---|--|--|---|
| Learns and validates the DUT model topology by comparing results from simulated (virtual) and physical testing. | Extracts DUT model parameters for larger amounts of DUTs, thereby learning model statistics. | Extracts model parameters for each DUT, thereby checking whether DUT parameters are within the expected range. | Involves DUT condition monitoring and large-scale DUT data mining, which use model topology refinement and parameter knowledge. |



The Evolution of Test Methodology in Automotive Validation

For decades, the V diagram has been the de facto approach to design and validation.

As automakers design new vehicles to be connected, autonomous, shared, and electric (CASE), the need for stricter test requirements amid increased complexity to ensure uncompromising safety is shifting a portion of the design and test toward the left side of the V diagram. This shift is driven by the large amount of software running in the vehicles, the high number of use cases and unknowns to be tested, and the push for the continuous software updates needed in the vehicles.

Looking at the V diagram from a test perspective, you can better understand the opportunities and challenges presented by the shift to the left.

V Diagram Variants in Automotive

Vehicles have a mechanical past but a software future, and automotive companies are “front loading” development and test to face that challenge by increasing the utilization of virtual prototypes (FIGURE 01).

Though their V diagram approaches vary, many companies are turning to simulation and lab techniques to increase test coverage while running safer, faster, and more repeatable tests. This optimizes the cost, time, and coverage of the still necessary road tests.

As experience and research demonstrate, conducting more tests in simulation and lab environments leads to:

- Increased test coverage since more test cases can be performed in less time
- Improved reliability by testing more fault cases
- Reduced cost through high automation and lower total cost of test
- More repeatable tests for better characterization of products and improved traceability

But shifting left to rebalance the number of tests implemented in each environment (simulation, lab, road test) remains a daunting endeavor that companies are still addressing.

Challenges of Making the Shift

There is no right way to make the shift, but there is a common set of challenges with complex interrelations generally among people, processes, and technology.

Each of these deserves attention when making a holistic assessment before defining a test strategy. This article focuses on test technology, from model-, software-, hardware-, vehicle-, and driver-in-the-loop test to real-world test.

By focusing on the design and test portions of the V diagram (virtual versus lab versus physical) (FIGURE 02), you can find opportunities to make the shift. First, you need to consider the variables involved, depending on the test environment (FIGURE 03), and how they impact your confidence in moving to real-world trials while covering as much test as possible.

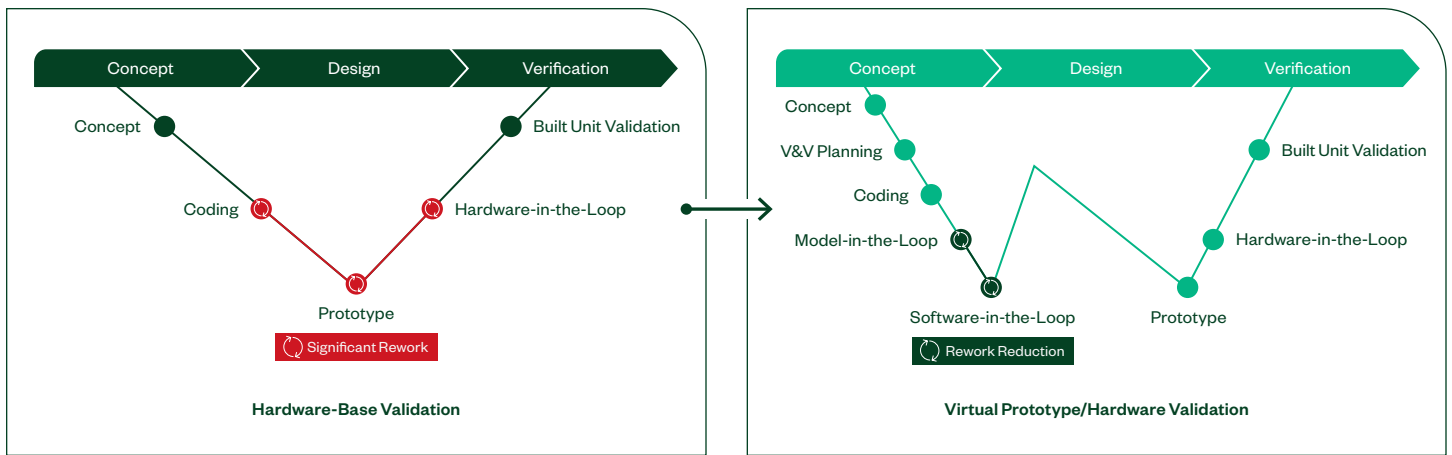


FIGURE 01

Reducing rework and front-loading development require software and data toolchains that enable fast test iterations.

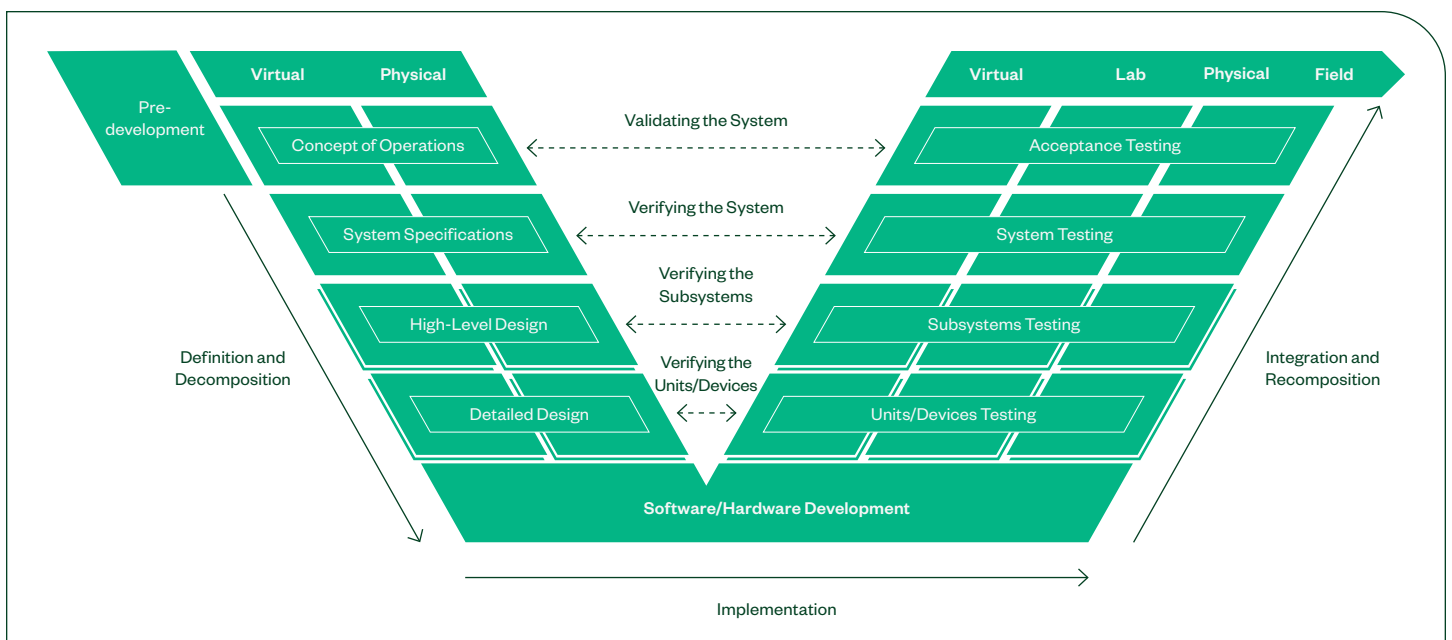


FIGURE 02

The V diagram can be expanded to show where the test happens to help identify opportunities for shifting left.

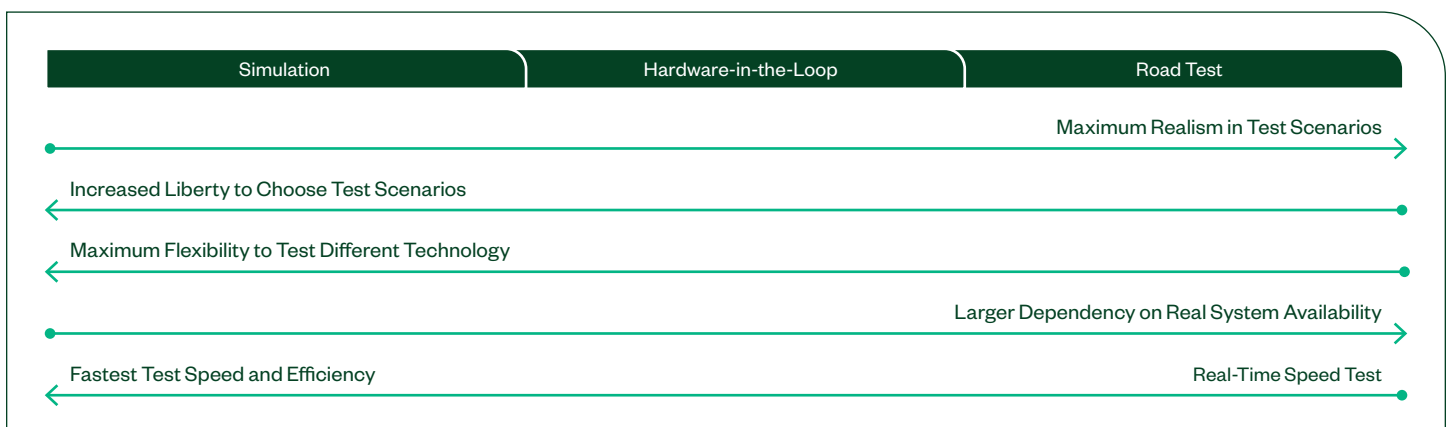


FIGURE 03

This continuum shows the trade-offs and benefits of testing at different stages [©WMG, The University of Warwick, 2018].

The following three tips can help you use technology to make the shift.

01 Test component reuse

Reusing test components minimizes rework between different stages and enables a more integrated design and test process. With appropriate test software like VeriStand, you can apply test modules across different in-the-loop stages from component to integration test.

Examples like Volvo's on page 28 in this journal demonstrate how open test architectures allow you to reuse test cases, equipment, and engineering development to future-proof test systems and meet delivery deadlines and quality standards.

02 Better use of your data

Test data has exploded, and you need to use it to:

- Better understand test coverage through a wider, multiangle, multiprocess view of the test in all environments
- Implement better simulation and statistical modeling
- Automate test case generation and eliminate unnecessary test reruns
- Mitigate the risk of eventual failures (or recalls)
- Enable the use of artificial intelligence, machine learning, and other data-centric technologies

Finally, you can use data as the bridge of communication between groups to improve decision-making and collaboration.

03 An understanding of where you are today

As with any journey, you need to know where your testing starts just as much as where it leads. The concept is simple: move away from reworking in the red zone shown in [\(FIGURE 04\)](#).

Making the shift requires you to be self-critical, multidisciplinary, and data-driven, which is challenging to say the least. But a common first step is to consider where you are in the testing scenario balance by asking yourself the following question:

HOW MANY OF YOUR TEST SCENARIOS FALL UNDER SIMULATION, HIL, REPLAY, AND ROAD TEST?

More than likely, you can shift more tests to simulation and HIL to progress faster through the stages of development and test.

A Structured Approach for Success

You must consider the cost of inaction. Without a structured approach featuring a clear strategy, you risk following the same patterns and generating the same results. By first examining your existing process, determining areas of optimization and key performance indicators, and strategically deciding which ones to tackle first, the chances of long-term success increase with each step.

With NI's test methodology, technology, and consulting teams, you can improve your testing, from implementing the very first step to realizing the vision that will eventually make the autonomous vehicle a reality.

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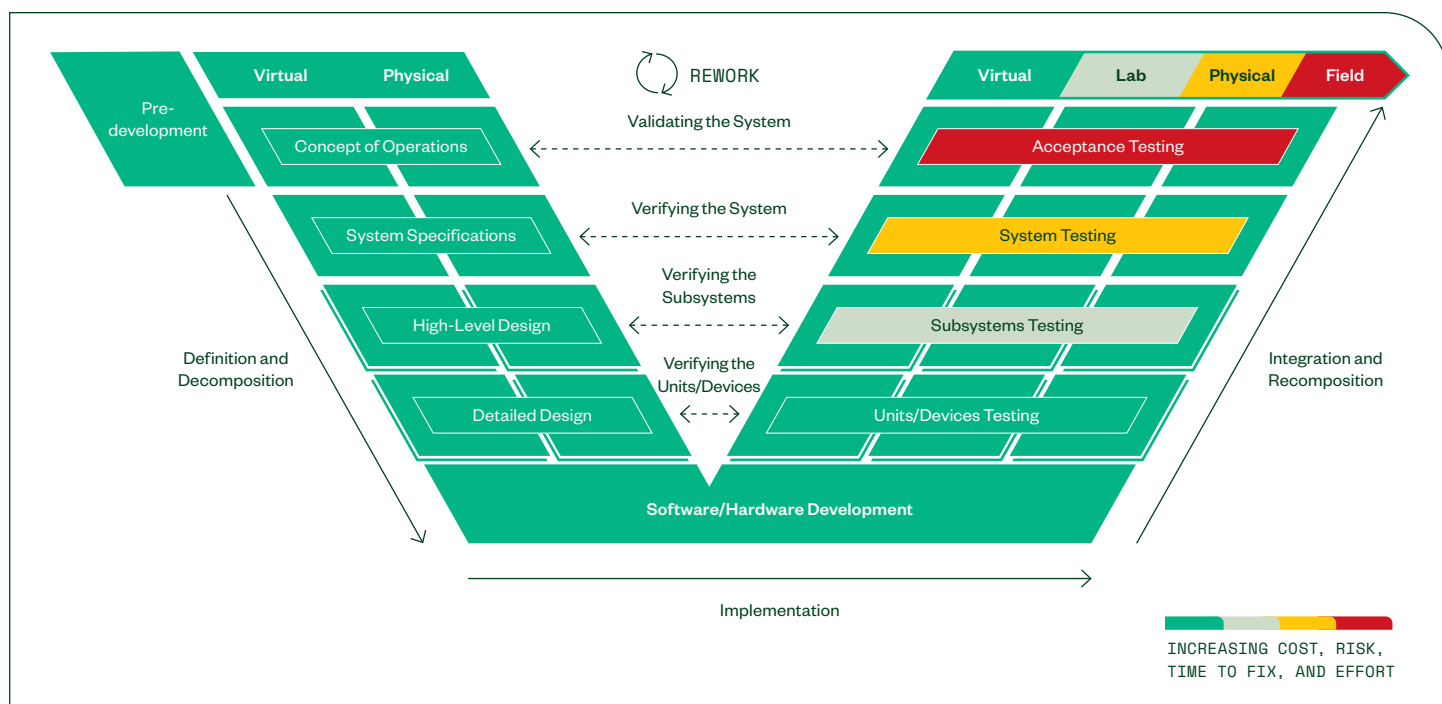
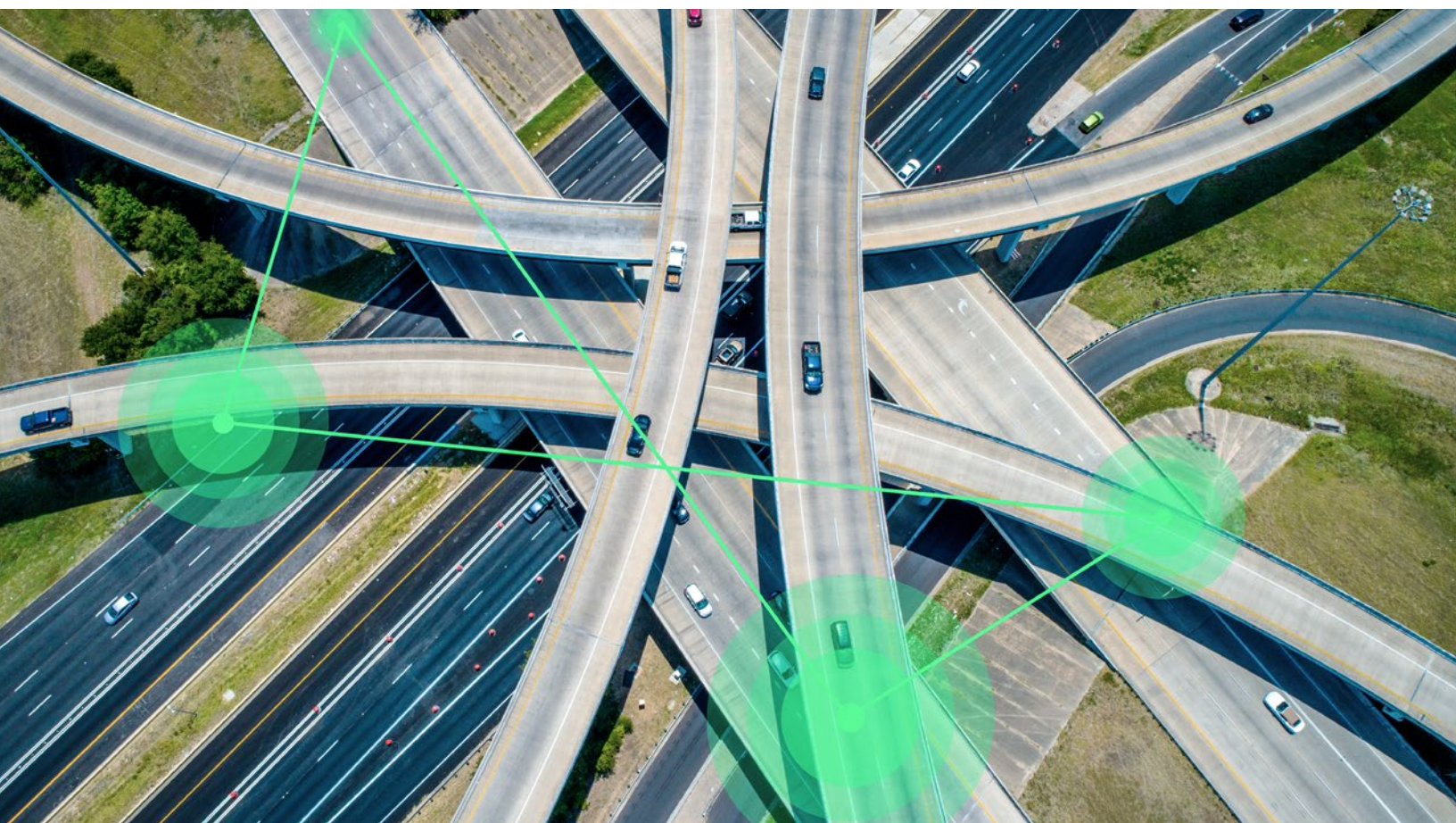


FIGURE 04

Rework at different stages can place you in the red zone, where the waste of time and resources grows disproportionately.



Sensor Fusion HIL for ADAS Test

Validating controllers for advanced driver assistance systems (ADAS) and autonomous vehicles (AVs) requires integrating multiple tools for everything from simulation to sensor data recording and replaying. To achieve the levels of reliability and safety needed with shorter time frames and limited budgets, the industry is quickly moving its test efforts toward simulation and lab scenarios. For this to have an impact, all tools need to work together across the V diagram. A unified toolchain for interoperability with environmental simulation tools, data recording and replaying systems, and future ADAS sensors streamlines the development of hardware-in-the-loop (HIL) test systems to increase coverage and reliability.

Customer Needs

01

Confidently integrate hardware I/O with environmental simulation tools like IPG CarMaker, ANSYS VRXPERIENCE, Vires VTD, Simcenter Prescan by Siemens, or monoDrive.

02

Synchronously generate I/O signals to interface with the ADAS controller. With tight control over timing, you can test faults like frame delays or phase coherency.

03

Maintain flexibility for future I/O requirements as systems continue to add more cameras, radar, and I/O types like lidar.

The NI Solution

01

VeriStand real-time test software integrates with a wide variety of third-party environmental simulation tools, so you can choose the tools that work best for your test.

02

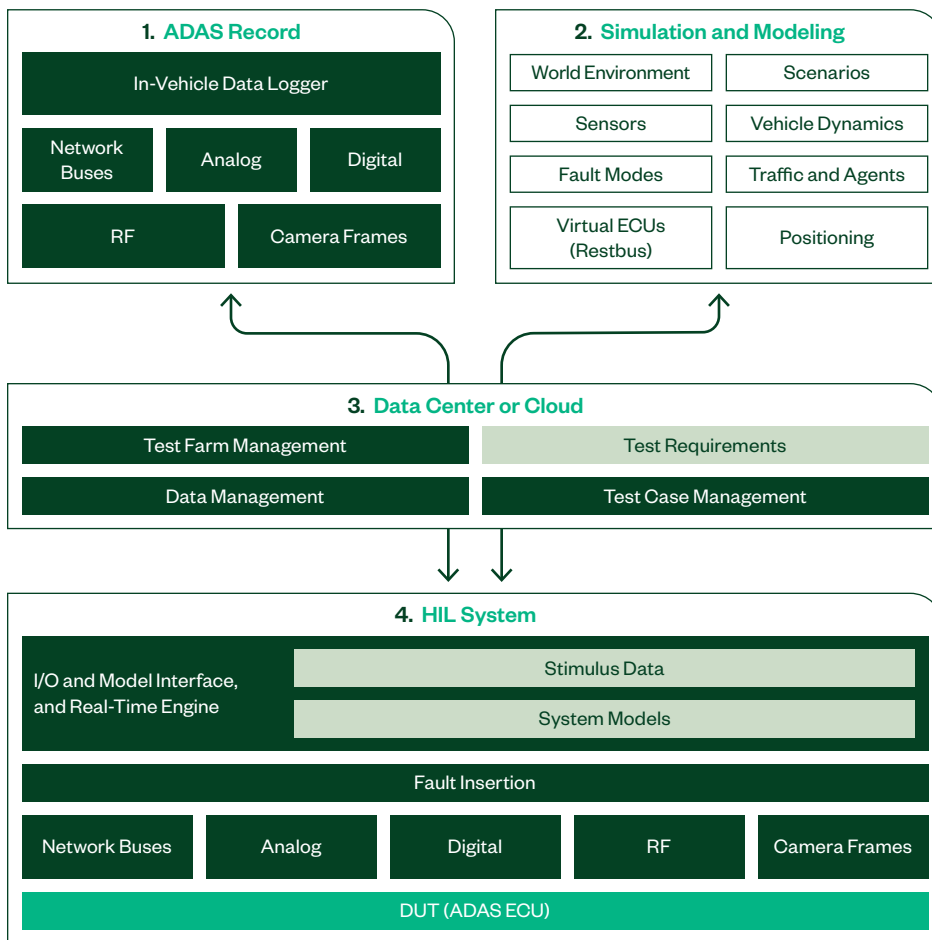
NI PXI modular hardware generates over-the-air radar signals, camera signals, vehicle bus traffic, and general-purpose I/O and offers hardware and software faulting capabilities and nanosecond synchronization and timing control.

03

NI's open software and PXI performance for timing and streaming enable raw sensor data recording and replaying, fault injection, and faster execution of new test scenarios.

THE NI ADVANTAGE

- Develop faster by leveraging work across design and validation through NI's toolchain.
- Maximize test coverage by integrating simulation from your choice of modeling software and injecting signals from different sources as you move from simulation to lab.
- Grow with your requirements by using NI's breadth of I/O to change camera interfaces, inject bitstream faults, test radar sensors, or add new sensor types without significant costs, development time, or hardware changes.



Hyundai Autron Performs ADAS Validation Tests Using NI Technologies

83% FASTER

Hardware and Software Integration

30% REDUCTION

in Maintenance Costs

System Components

01 High-Bandwidth Data Recording

Record synchronized raw data from ADAS sensors with high fidelity and in high volumes, and stream it to local or cloud-based storage for replay.

02 Simulation and Modeling

Connect NI's software to your choice of specialized simulation and modeling software to increase test cases and scenarios during HIL validation of ADAS engine control units (ECUs).

03 Data Center or Cloud

Upload, store, and retrieve test data, requirements, cases, and system information directly to a local data center or cloud service for managing your test.

04 HIL System

Connect any I/O you need from NI's broad portfolio to your ADAS ECUs, and complete the ADAS HIL integration from cloud to pin.



MathWorks and NI Tools for Model-Based Design and Test

At some point in the development process, you must actually make the thing you are designing. You must implement your design in the real world, which requires transitioning from design tools and simulation to physical testing on prototypes and then production-intent hardware running deployed embedded software. Efficiently transitioning between the simulated domain and the physical domain—between the design world and the test world—is critical to ensure increasingly complex products function as intended.

MathWorks and NI Model-Based Design and Test Workflow

MathWorks and NI are collaborating on model-based workflows to eliminate barriers and facilitate that efficient transition between design and test. We are integrating MathWorks tools for design and modeling like Simulink®, Simscape™, Powertrain Blockset™, and Vehicle Dynamics Blockset™ with NI software and hardware for I/O-connected simulation like LabVIEW, LabVIEW FPGA, VeriStand, CompactRIO, and PXI. An integrated design and test workflow gives teams a way to move test earlier in the product development process and increase the speed and frequency of product iterations. This ultimately leads to improved product quality and lower total program spending.

A traditional linear development process is siloed, with walls between steps of the process and the design domains. Problems first show up in the integration and test phase because that is the first time systems are integrated. The result is that errors are found late, which makes them expensive to fix.

With Model-Based Design, you model system components to simulate the pieces of your system for exploring the design space with an integrated system model. You can evaluate your integrated system much earlier in the design process, where catching problems is cheaper and iterating on designs can happen much faster. Simulation provides a method to incorporate test and verification at every step along the design process.

Model-Based Design for Electric Vehicle Powertrain Test

One application area where Model-Based Design is needed is electric vehicle (EV) powertrain design. The electrification of the powertrain presents a variety of hybrid vehicle design possibilities. Model-Based Design is necessary to evaluate all the possible design permutations. By simulating components, you can compare vehicle architectures through virtual design studies without the time-consuming and expensive process of building prototypes for each possible design.

“Complementary MathWorks and NI strengths can help you work on applications like EV powertrain design where you must run complex models extremely fast to simulate behavior accurately. Leveraging models from the design phase extends the advantages of Model-Based Design into test workflows.”

Paul Barnard
Marketing Director, Design Automation at MathWorks

Design Studies with the Powertrain Blockset

MathWorks developed the Powertrain Blockset as an extension of Simulink to lower the barrier to entry for powertrain and vehicle

system modeling. For companies that are starting to build system models, Powertrain Blockset provides an open and documented framework that includes good plant and controller models designed to work with hardware-in-the-loop test systems. You can use the Powertrain Blockset's library of blocks and prebuilt reference applications to augment your existing system models.

Follow this general design flow:

01

Select a reference application as a starting point

02

Customize the plant model by parameterizing the components, customizing existing subsystems, and adding your own subsystem variants

03

If required, customize the controller models to test your controller

04

Integrate your controller to be tested

05

Perform closed-loop system testing using model-in-the-loop, software-in-the-loop, and hardware-in-the-loop testing methodologies

Transitioning to Test: Closing the Loop in Real Time

While performing that last step, closed-loop system testing, you can take advantage of an integrated workflow between MathWorks and NI tools. Once your controller and plant models are ready to test, you need to integrate them into a system that can close the loop in real time to give accurate simulation results. This is especially true when testing models featuring high-speed dynamic behavior like that of a traction inverter and motor.

You can implement and run MathWorks models on NI systems in a few different ways: with desktop simulation, on a development computer at slow to medium speeds on a real-time controller, or with hard determinism at very fast speeds on an FPGA.

Where you decide to run the model depends on the complexity of the model and the amount of simulation fidelity you need. Vehicle dynamics and controller models can often run on the real-time controller, whereas motor and power electronics models must typically run on an FPGA to get high enough simulation fidelity to characterize performance with useful accuracy.

You can also connect models running on the real-time controller with models running on the FPGA and synchronize them with I/O to perform hardware-in-the-loop testing. In this case, you incorporate the real controller running embedded software and exercise it by inserting faults on the I/O lines and communication bus.

By using the combined MathWorks and NI toolchains to implement a model-based workflow, you can improve and accelerate testing for complex applications like EV powertrain test.

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A futuristic car interior is shown from the driver's perspective. A hand holds a magazine in the foreground, which features a green car and various headlines. The background shows a road with a digital overlay of a car's sensor range. A list of features is displayed in the upper right, and a 'Self-Driving' label is in the center. The dashboard and steering wheel are visible, along with a digital display on the right side of the dashboard.

/Autonomous
/Sensing
/Communication
/Battery
/Navigation
/Mirrorless
/Ecology

Self-Driving

By working together, Amazon Web Services, Dell Technologies, and NI can provide a tested, hybrid approach to ADAS/AD development so engineers can leverage the best of all solutions: the flexibility and scalability of cloud-based services, the performance of on-premises infrastructure, and the accuracy of HIL testing.

Hybrid Cloud Hardware-in-the-Loop Autonomous Driving Simulation

Delivering an autonomous vehicle to market is an incredibly complex task that requires the careful orchestration of many moving parts. Capturing sensor data is only the beginning, and testing the final solution is but one critical stage. An entire flow must be developed, with massive quantities of data at its core.

By working together, Amazon Web Services (AWS), Dell Technologies, and NI can provide a tested, hybrid approach to advanced driver assistance systems (ADAS)/autonomous driving (AD) development so engineers can leverage the best of all solutions: the flexibility and scalability of cloud-based services, the performance of on-premises infrastructure, and the accuracy of hardware-in-the-loop (HIL) testing. With this new hybrid cloud HIL architecture, customers avoid the challenges caused by poorly selected tools and mismatched and/or underpowered infrastructure components.

AWS for Automotive

AWS's nearly unlimited storage, compute capacity, and support for deep learning frameworks allow for the collection, ingestion, storage, and analysis of autonomous vehicle data to facilitate full-scale autonomous vehicle development. Deep learning frameworks such as Apache MXNet, TensorFlow, and PyTorch accelerate your algorithm training and testing. AWS IoT Greengrass provides edge computing with machine learning inference capabilities for the real-time processing of local rules and events in the vehicle while minimizing the cost of transmitting data to the cloud.

NI PXI Hardware

HIL testing is a key step for any ADAS/AD design flow. Whether streaming synthetic sensor data generated on-the-fly or sensor data from the real world, HIL testing requires custom, physical hardware that is not available on traditional public clouds.

Recorded field data from ADAS sensors can be replayed in the lab to simulate driving and increase test repeatability and test coverage. Real, recorded data is better for testing because 3D-rendered scenes can be misinterpreted by algorithms designed for the real world. Timing in replay applications is critical, and NI replay systems provide extremely accurate timing and synchronization to ensure your perception algorithms receive sensor data just as it occurred in the real world.

You can integrate scene-generation tools with hardware I/O to play back simulated scenarios for validating the sensor fusion and decision-making algorithms on ADAS controllers. Scene generation from all the leading environmental simulation software tools increases test coverage because scenarios can be created to meet specific test requirements. With the open software architecture, you can use the best simulation tool for the application.

Dell EMC PowerScale Network-Attached Storage

PowerScale is an ADAS development-proven, enterprise network-attached storage solution that bridges the gap between the public cloud and on-premises HIL testing. Architected for massive concurrency and low latency, PowerScale is ideal for performance-critical, timing-sensitive ADAS workloads including sensor data streaming to HIL test rigs.

PowerScale is powered by the PowerScale OneFS operating system, which offers DataIQ technology for managing ADAS sensor data including worldwide data tracking and movement to/from Amazon S3 buckets. With ADAS development, change is inevitable, and as vehicle operation approaches full autonomy, performance requirements become even less predictable. With this reality in mind, Dell Technologies architected PowerScale to grow seamlessly with your project, in capacity and performance, and provide the flexibility you need to maximize your return on investment.

AWS, Dell Technologies, and NI Benefits

To successfully develop ADAS, you need solutions that can scale to address exponentially growing sensor data and you need the compute requirements to leverage that data. This starts inside the car and extends through to the data center, whether on-premises or in the cloud, where infrastructure must support massively parallel, concurrent data ingest; artificial intelligence, machine learning, and deep learning; and model-in-the-loop, software-in-the-loop, and hardware-in-the-loop workloads.

HIL hardware platforms are particularly sensitive to infrastructure. Even a single dropped frame of data, or data not accurately synchronized to the microsecond, is unacceptable. With the AWS, Dell Technologies, and NI partnership, you can work confidently knowing that your infrastructure—including HIL hardware—was architected to meet these stringent requirements.



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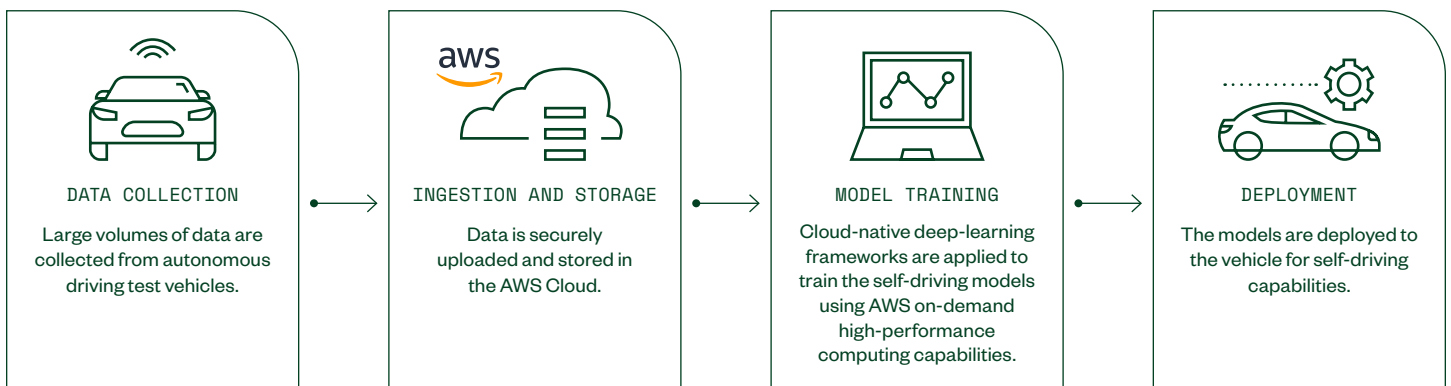


FIGURE 01

This full suite of services from AWS supports ADAS/AD on the public cloud.

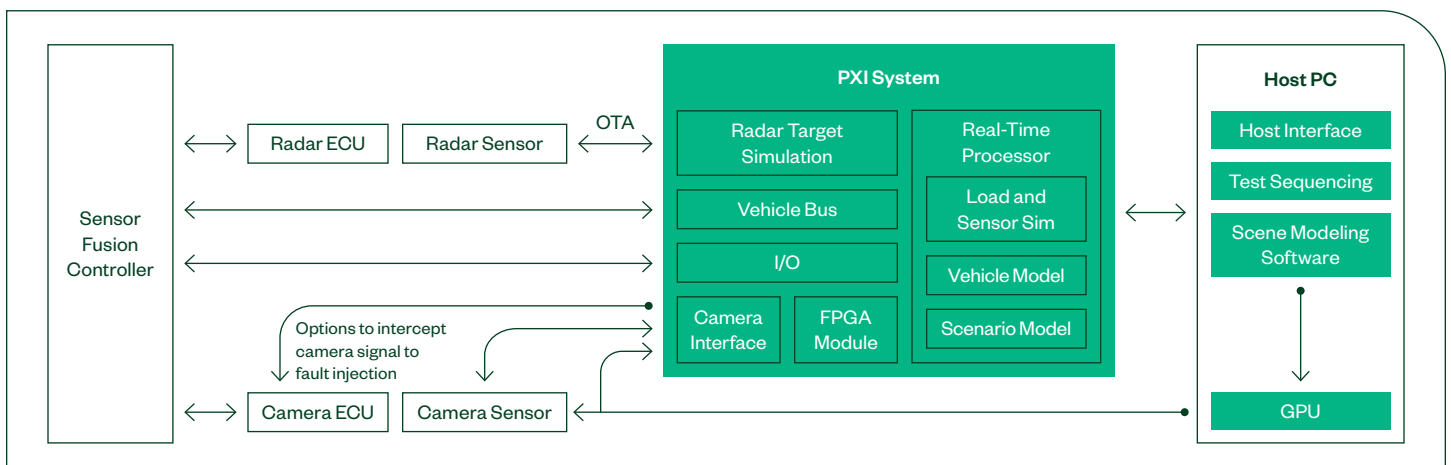


FIGURE 02

Test active safety systems with the PXI HIL system architecture.



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- Short lead time due to automated HiL design process
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- Verification & validation of automotive components
- Real-time simulation and test
- Fault injection according to ISO 26262
- COTS based open architecture
- Standardized signal conditioning with NI SLSC
- Reduction of overall risk & Total Cost of Test
- Control & evaluation of vehicle busses (CAN, LIN, FlexRay, BroadR-Reach)



“We can design, build, and configure a complex HIL test system that covers customer-specific needs in less than 10 weeks thanks to NI technologies such as PXI, SLSC, and VeriStand.”

Ondřej Hála

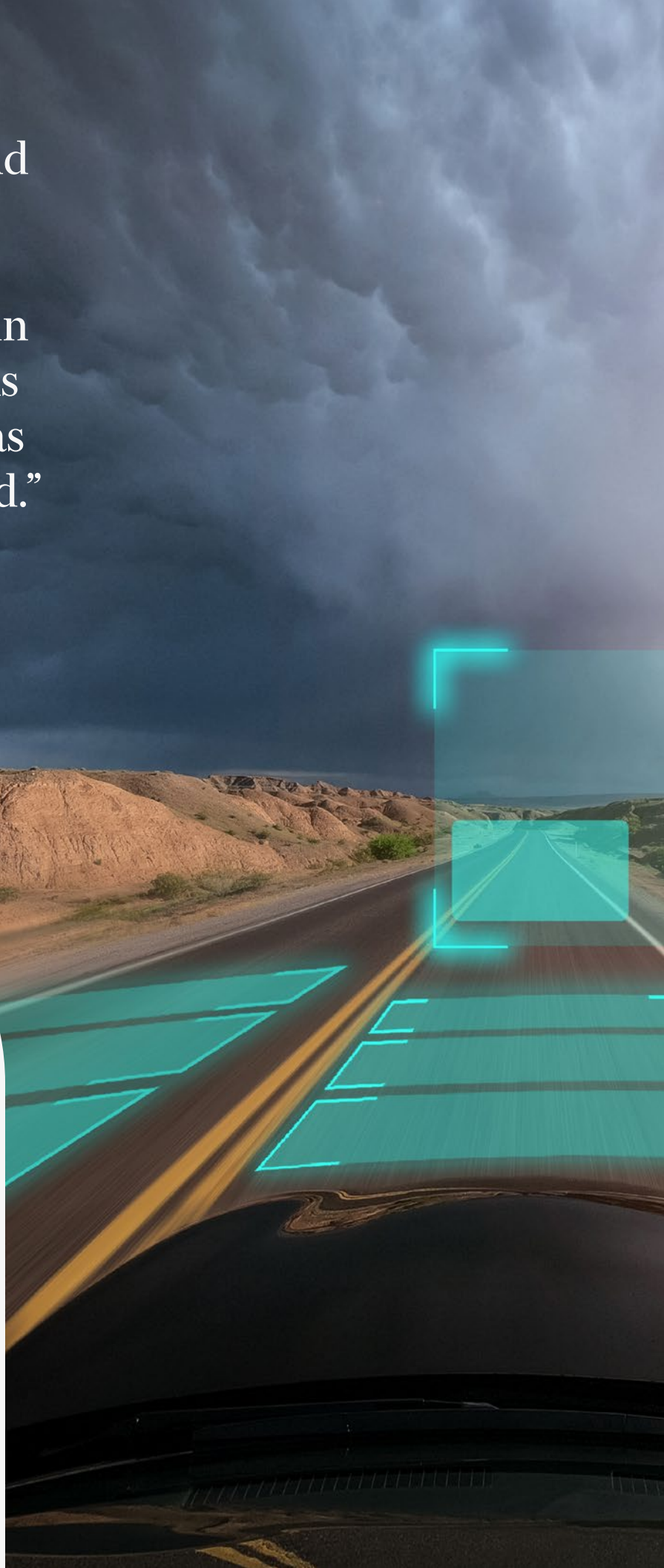
Team Leader, STI and TME,
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Challenge

AKKA needed to design and deliver a hardware-in-the-loop (HIL) test system to fulfill project-specific customer requirements within tight time and cost constraints.

Solution

We based our HIL test system on NI adaptable technologies: PXI hardware is used as the real-time computer with configurable I/O slots to make the measurements; a switch, load, and signal conditioning (SLSC) chassis provides signal conditioning and a fail insertion unit (FIU); and VeriStand manages the electronic control unit (ECU) HIL functional testing. We can extend this core tester with third-party or customer modules to create turnkey solutions that meet a wide range of customer requirements.



Building a Future-Proof HIL Test System for a Tier 1 Automotive Supplier

AKKA is an integration services provider specializing in HIL test system design, building, commission, and maintenance.

Project Specification

Representatives from a leading Tier 1 automotive supplier approached us to discuss a new generation of HIL test stations. Their device under test (DUT) was an ECU to control a car braking system's advanced safety functionality.

The customer sought a turnkey HIL solution that could be customized in-house because its previous HIL test solution, which lacked global support, offered limited flexibility and obsolescence management. Already obsolete, the previous HIL solution contained closed IP blocks that prevented modifications by either the customer or an alternative service provider.

Test Platform Design

We built the new architecture using NI technologies that featured fast delivery (less than 10 weeks) and future expandability.

The new architecture's technical requirements included:

- Both analog and digital signal acquisition and generation on different voltage levels
- Standardized signal conditioning and failure injection supportable over the long term
- Automotive communication bus support, such as controller area network (CAN) or local interconnect network (LIN), and future FlexRay or Automotive Ethernet upgradability
- Peripheral ECU communication CAN restbus simulation
- A customer-specific terminal block that can connect and switch between two ECUs simultaneously
- Battery simulation power supply (0 V to 30 V, 0 A to 110 A)
- Small external device power supply (5 V and 12 V)
- The ability to measure mechanical strain on a stand containing hydraulic components



Key HIL Test System Features

The test system includes the following components.

01

NI PXI and SLSC hardware technologies:

- A block diagram signal overview
- PXI modules to provide I/O channels
- SLSC modules for automotive signal conditioning (voltage range, special wireless smart sensors)
- Failure simulation: short-to-battery, short-to-ground, open circuit at defined signal lines

02

A VeriStand real-time software environment with:

- Custom devices for power supply and third-party components
- Restbus simulation via AKKA's PROVEtech:RBS custom device
- veDYNA model vehicle dynamics simulation compatibility
- ECU-TEST framework compatibility via XIL API for test automation

03

Customization options:

- Connect two DUTs via two identical terminal blocks; the test operator can switch between two DUTs via software configuration
- Connect a customer-specific device such as RSIM, EPB, or M-Modules
- Take advantage of auxiliary voltages for customer-specific devices
- Simulate battery voltage by remotely controlled power supply with power sink
- Apply real-time simulation (models, restbus) based on VeriStand or the LabVIEW Real-Time Module
- Leverage veDYNA model compatibility
- Take advantage of ECU-TEST test automation sequencer compatibility
- Integrate customer-specific hardware module integration for sensor simulation

To meet these requirements, we decided to use off-the-shelf components as much as possible and customize only the customer-specific parts of the test system. We used NI's standard Chassis for SLSC with signal conditioning and fault insertion SLSC modules. This solution is easily extendable with third-party or customer modules. Because of the project-specific ECU connection, we designed and manufactured terminal blocks to connect all components, DUTs, loads, and other parts.

Restbus Simulation Solution

PROVEtech:RBS, by AKKA, integrates restbus simulation functionality into VeriStand with a custom device. It identifies end-to-end protection signals (AUTOSAR Profile 2) imported from a database container or ARXML database and performs the automated protective signal (message counters and cyclic redundancy check) calculation according to the standard.

Summary

Using NI PXI, SLSC, and VeriStand technologies, we quickly integrated commercially available NI, third-party, and customer-specific components. We delivered the system in less than 10 weeks, including on-site commissioning and customer staff training.

Company:

AKKA CZECH REPUBLIC S.R.O.,
DAIMLEROVA 6, CZ-301 00 PILSEN,
CZECH REPUBLIC

Industry:

AUTOMOTIVE—
ELECTRICS/ELECTRONICS SYSTEMS

Application Area:

FUNCTIONAL HIL TEST SYSTEMS

Authors:

ING. MICHAL KUBÍK, PHD
ING. ONDŘEJ HÁLA

NI PRODUCTS USED:

- PXI Chassis
- Embedded Controller
- DAQ Multifunction I/O
- R Series
- NI-XNET
- Chassis for SLSC
- VeriStand

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HARDWARE-IN-THE-LOOP

High-Fidelity HIL Simulation

Testing and validating features in advanced driver assistance systems (ADAS) and autonomous vehicles (AVs) are industry challenges. Identifying and characterizing test cases, pass/fail criteria, and test case producibility and repeatability are difficult with current tools.

Through its partnership with monoDrive, NI has introduced a new hardware-in-the-loop (HIL) simulation solution that automates these previously manual steps. You can validate the vehicle perception, planning, and control with near 100% test coverage in a completely virtual environment.

Customer Needs

01

High-fidelity simulator

02

High-performance PC cluster with NVIDIA RTX support

03

PXI, CAN, GMSL2 or FPD-Link III, Automotive Ethernet modules

04

Automotive ECU

NI + monoDrive Solution

01

monoDrive master runs vehicle plant model in hard real time on NI Linux Real-Time OS

02

Sensor simulators, running on Windows 10 with NI Linux Real-Time, are clock synchronized to the monoDrive master

03

Vehicle ECU in the loop is synchronized with NI Linux Real-Time for translating throttle, brake, and steering commands to vehicle pose state

monoDrive

monoDrive's software simulates the camera lens flare.



NI + MONODRIVE ADVANTAGE


- Improve safety of ADAS/AV features in production vehicles
- Improve time to market on new, innovative, perception-heavy features like pedestrian detection, collision avoidance, lane keeping, and traffic jam assist
- Significantly reduce validation costs by simulating more and relying on less “mule vehicle,” over-the-road testing

| KEY SPECIFICATIONS | |
|--------------------|--|
| Camera FPS | 60 Hz 4k camera |
| Camera interfaces | MIPI CSI-2, FPD-Link, GMSL, HDMI |
| Camera parameters | Exposure time, lens parameters |
| Radar | FMCW 77-79 GHz 2D and 4D (SBR) |
| Vehicle bus | CAN-FD, LIN, FlexRay, Automotive Ethernet |
| Lidar | Velodyne 16 to 128 lasers |
| Ultrasonic | Physics-based material-/size-accurate response |
| Other sensors | IMU, GPS, wheel RPM, collision, and more |

“Perception testing starts with robust environment modeling and accurate sensor models. Customers start with simulation because many test scenarios are hard to duplicate in the real world. With the NI HIL solution, customers can now validate their perception, planning, and control systems in hard real time with high-fidelity sensor models and their vehicle ECU in the loop.”

Celite Milbrandt
CEO, monoDrive



A blue Volvo car chassis is shown on a complex test rig. The car is positioned on a blue base with various mechanical components, including actuators and sensors. The driver's side door is open, revealing the interior with a steering wheel and a digital display showing '93'. The background is a blurred road, suggesting motion. The text is overlaid on the left side of the image.

“The ease of setting
up the whole
system enabled
us to deliver
world-class quality
on time and at the
right cost with
limited resources.”

Volvo Cars

Driving Dynamics Centre



Volvo Improves Ride Quality Using Open HIL Platform

The Driving Dynamics Centre at Volvo Cars defines and improves the driving experience for the latest generation of Volvo cars.

This department tweaks a vehicle's handling characteristics and defines presets that, for example, allow customers to quickly switch between driving modes like dynamic and sport. Air suspension, electronically controlled dampers, body control, and steering feedback are a few of the features that can be fine-tuned.

Volvo Cars has developed a variety of virtual test environments to validate vehicle dynamics attributes (like handling, steering, and ride) and verify vehicle motion control components (like braking, steering, and suspension). These virtual testbeds incorporate elements of software-in-the-loop (SIL), hardware-in-the-loop (HIL), and, in the case of the Dynamic Driving Simulator, driver-in-the-loop (DIL) test.

The Dynamic Driving Simulator offers the efficiency and safety of simulation whilst delivering an emotionally resonant driving experience. It allows human drivers to physically feel the models so researchers can discern their subjective experience.

The Dynamic Driving Simulator enables the Dynamic Driving Centre to:

- Test solutions in the concept development phase before the prototype vehicle is available
- Safely deliver repeatable testing of real driving situations and driver interaction
- Measure the immeasurable (great for requirement and method development, for example)
- Tune chassis characteristics, such as hard points, damper, and bushing, without using prototypes

Limitations of the Traditional Driving Simulator

To reduce time and cost, and decrease the on-road testing requirements, the simulator needed to be complemented with physical vehicle motion controllers, such as steering, brake, and suspension controllers.

These improvements would:

- Add vehicle dynamics test capabilities while maintaining subjective testing capabilities
- Enable the calibration of vehicle motion control systems in a controlled computer aided engineering environment
- Support vehicle motion control software development and verification in early phases
- Help researchers perform exploratory testing and thereby gain software test coverage
- Support continuous integration of software functional increments

Company:

VOLVO CAR CORPORATION,
DRIVING DYNAMICS CENTRE

57334, VOLVO JACOBS VAG PV14
GÖTEBORG, 405 31
SWEDEN

Industry:

AUTOMOTIVE-ELECTRICS/
ELECTRONICS SYSTEMS

Application Area:

FUNCTIONAL HIL TEST SYSTEMS

Author:

SIMON SCHOUTISSEN

NI PRODUCTS USED:

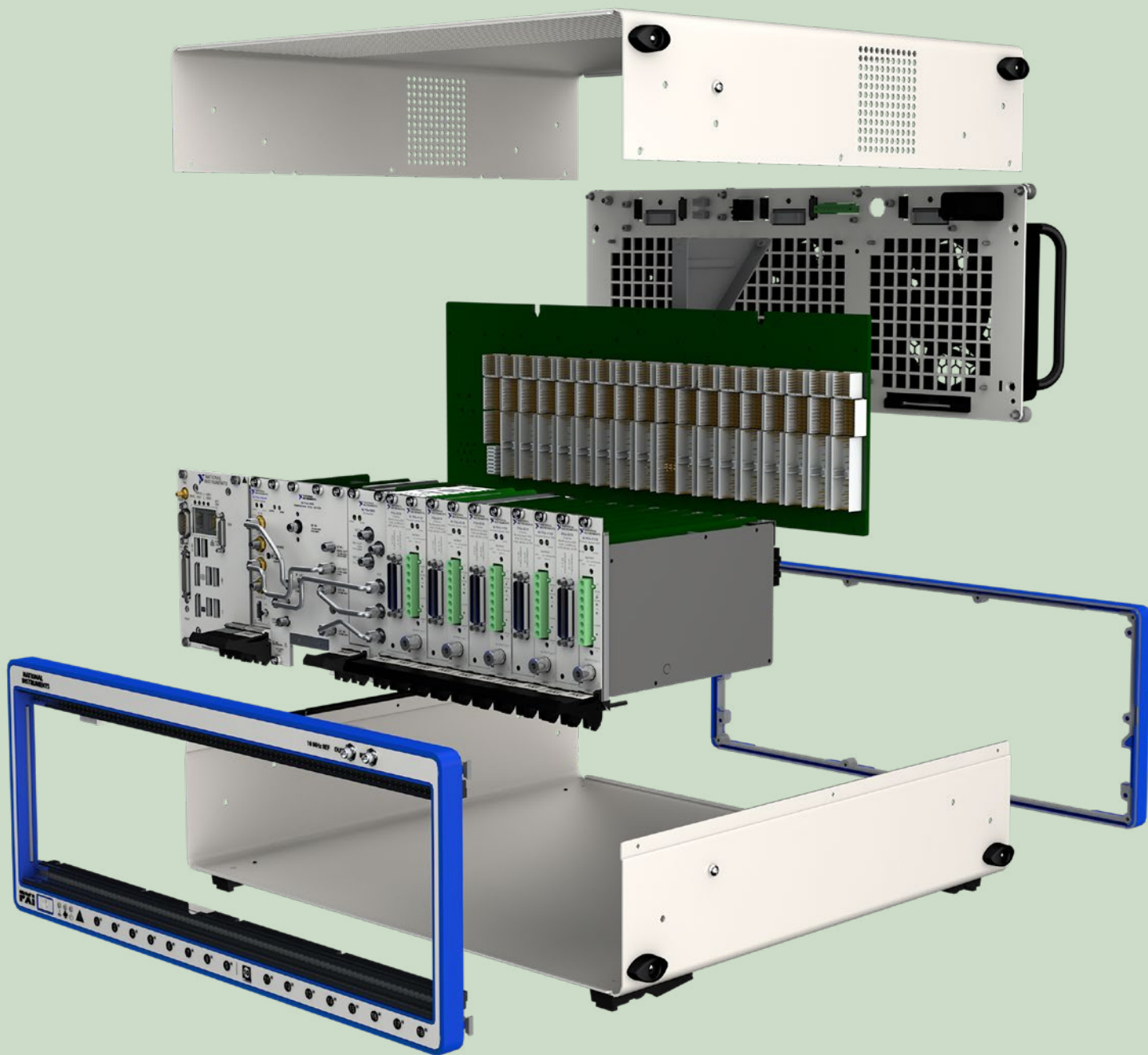
- PXI Chassis
- Embedded Controller
- DAQ Multifunction I/O
- R Series
- NI-XNET
- Chassis for SLSC
- VeriStand

Challenge

Volvo Cars needed to extend the functionality of its Dynamic Driving Simulator to encompass active vehicle components and control systems. This would reduce the need for costly, physical field tests whilst delivering more freedom to innovate in the concept phase and shortening the simulator's overall development time.

Solution

By using NI PXI hardware and VeriStand integration software for real-time test, Volvo Cars was able to integrate all the components on deadline, create a high-quality solution, and save valuable field-test time.





The extended driving simulator offers significant benefits but presents three challenges:

01

The need to develop and integrate a vehicle motion control HIL test system into the existing virtual test environment

02

The inability of HIL tests to run stand-alone with and without the Dynamic Driving Simulator

03

The need to completely validate a vehicle's systems in shorter time frames despite increasingly complex devices and rapid changes in test requirements

Strict System Requirements

Ideally, a validation system consists of the best solution from the right vendor. In reality, a complex HIL system consists of different technologies from a variety of vendors, real-time OSs, communication standards and vehicle buses, and application software. Volvo Cars needed an open and scalable platform to prevent being locked into one particular vendor.

Other requirements included:

- Modularity and flexibility to enable future expansion
- Seamless integration with the existing driving simulator
- Stand-alone operation
- Intuitive and cost-efficient design
- Support for open standards and ability to integrate hardware and software from other vendors (for example, FMI, UDP/Ethernet, EtherCAT)

The Right Solution for a Complex Challenge

NI offered a solution that fulfilled all Volvo Cars' requirements:

Real-time test execution and integration—A PXI Express controller running VeriStand on a real-time OS to leverage out-of-the-box functionality, including configurable data acquisition and logging, test sequencing, and simulation model integration.

Vehicle dynamics simulation—IPG CarMaker software, running alongside VeriStand, and off-the-shelf IPG CarMaker hardware to avoid building custom hardware. The openness of VeriStand made adding third-party software and hardware components easy and efficient.

The existing equipment at Volvo Cars needed to be integrated with the open HIL platform through an already available communication channel that allowed communicating between VeriStand and Vector CANoe systems. EtherCAT communication, available out of the box, integrated with NI I/O, Beckhoff I/O, and Kollmorgen motion devices.

After One Year

VeriStand proved to be a powerful and reliable real-time test environment. By using VeriStand in the HIL test architecture, Volvo Cars was able to:

- Work with multiple vendors
- Use the right system for the right job and reuse existing components
- Build a future-proof, flexible, and modular HIL platform
- Integrate third-party hardware and software, such as IPG CarMaker software

Lastly, the ease of setting up the whole system enabled Volvo Cars to deliver world-class quality on time and at the right cost with limited resources.

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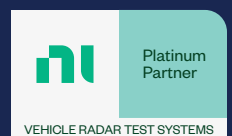
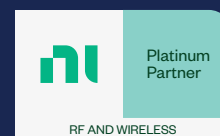
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- 1 object Side Radar Simulator (1 to 4 GHz BW)
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adasiiT
INNOVATION IN TEST





JEFFREY PHILLIPS
HEAD OF AUTOMOTIVE
MARKETING, NI



The Unintended Consequences of Technology Convergence

The main challenge with testing modern automotive systems is technology convergence. Many technologies entwined in a complex, interworking web are shaking the foundation of a century-old industry. It's intelligent sensing, energy storage, artificial intelligence, network communications, power conversion, high-performance computing, machine learning, security, and more, but let's stop there just to take a breath.

The effect of this convergence is ubiquitous both inside and outside the industry. It's so far-reaching that the vast potential of the future of mobility is causing companies worldwide to dip their toes in the water.

WE SHOULDN'T BE SURPRISED. WE'VE SEEN TECHNOLOGY CONVERGENCE DO THIS BEFORE.

The smartphone and the desktop PC were both disruptive forces that rippled across industries because of how far-reaching technology can be. Cash registers were displaced by computers and purpose-written software. Do you remember when you had a calculator? I still have my TI-86, but it's not usually in my pocket. A level, a dictionary, an encyclopedia? The list could go on.

This technology convergence is driving two changes.

First is a market spike that invites new competitors from interesting adjacencies. Cash-rich tech giants acquiring start-ups and pivoting to new market opportunities seems to be more the norm than the exception. Industry

giants come and go. The electric vehicle has already given companies like LG, Panasonic, and Samsung a foot in the door for automotive, and tech giants like Amazon, Apple, and Google have all demonstrated a leadership position in some facet of the industry.

The second change is happening behind the scenes within the product development process for the industry. As technology disrupts markets, the value of software-connected systems ultimately wins out. That increase in software adds complexity to testing a device for proper and safe functionality. This shifts the balance of investment in the traditional V diagram to the left.

WE'RE AT AN INFLECTION POINT WITH TECHNOLOGY AS AUTONOMOUS VEHICLES ARE INTRODUCED.

Code written on the device will make decisions that may endanger our lives. That uncompromising need for safety demands more investment to handle the complexity of test driven by the nature of software-connected systems. Automotive test engineers aren't testing just "the car"; they're testing the

integrated functionality of hundreds of smart, connected subsystems.

As this shift happens, test departments throughout the supply chain will be pressured to adjust their test methodologies to keep pace with the rampant changes in the technology under test.

Let's work together through the shift. Together, we can turn test into a competitive advantage that accelerates your path to market for new features. We can also improve the world around us with each wave of innovation.

Standardizing on an Architecture for Your HIL System Using SLSC

Hardware-in-the-loop (HIL) systems are nothing new; however, building them in a standardized way that encourages reuse and scalability to decrease overall development cost and shorten time to market is a complex task for hardware integrators and test engineers. Point-to-point wiring adds complexity between the measurement system and the signal conditioning on the front end.

The switch, load, and signal conditioning (SLSC) architecture provides a modular approach to using standard, commercial off-the-shelf cables between the measurement system and front end, where load management, fault insertion, and signal conditioning are handled.

The SLSC Architecture

The SLSC architecture provides standard connectivity options to reduce the need for point-to-point wiring while offering a modular approach to signal conditioning, fault insertion, sensor simulation, and more.

Each slot in the Chassis for SLSC uses a rear transition interface (RTI) to interface between the module and a measurement I/O system built on CompactRIO or PXI.

Standard, commercial off-the-shelf cables are used to connect the RTI with the measurement I/O modules to complete the signal path in the HIL system. The use of standard cables eliminates complex point-to-point wiring and expands the standard architecture from the measurement I/O system to include the SLSC front end.

Communication between the Chassis for SLSC and the HIL host computer occurs over Ethernet. Using the SLSC software API, you can set properties and send commands to the modules in the chassis.


Ecosystem

An open approach to the SLSC architecture has enabled a vast ecosystem of companies to develop application-specific modules such as Peripheral Sensor Interface 5 (PSI5), a power switch module, and capacitance simulation cards for fuel sensor emulation.

Learn more at ni.com/slsc.







CHRIS FICKLIN
CHIEF PRODUCT PLANNER,
APPLICATION SOFTWARE, NI



Connecting All the Pieces of an HIL System Using VeriStand

We sat down with Chris Ficklin, our resident hardware-in-the-loop (HIL) expert, to discuss how VeriStand connects models with hardware and provides the openness needed to integrate with a variety of commonly used tools and buses.

Kristoffer Iversen: Improving the validation workflow and standardizing on an efficient approach are valuable ways to connect software and hardware in an HIL system. How does VeriStand help accomplish this?

Chris Ficklin: One of the most important parts of an HIL system is the application software that acts like a master in the system. VeriStand is that software, connecting and mapping the system hardware to a model. It has built-in functionality such as the ability to create stimulus profiles that can run on real-time targets adhering to strict timing requirements. This enables engineers to re-create real-world conditions. Functionality like alarming, advanced logging, and interfacing with other programs

is, of course, also built in. Once a test is deployed and executing, the user can even debug efficiently by adding controls and indicators to the user interface, without having to stop the test, to view signals and gain insights into the current state versus desired state. Ultimately, VeriStand provides a configurable execution framework that improves the workflow for validation engineers.

KI: Having an open design is critical to the execution framework. How does VeriStand integrate with third-party tools and encourage reuse?

CF: Integration is critical to HIL systems. VeriStand can run compiled models that are built in a variety of modeling environments and languages. MathWorks

MATLAB® and Simulink® software is an example of a model-based engineering approach, and VeriStand maps the model to hardware. The extensibility of VeriStand enables us to have our partners build custom devices. As an example, IPG's CarMaker can be added as a custom device interacting directly with VeriStand, so changes made during the test show immediately in IPGMovie.

KI: Using custom devices is a powerful way of integrating with other hardware or tools. How can customers in the automotive industry leverage this?

CF: It again comes back to the openness of VeriStand. One example here is the restbus add-on developed by AKKA. They were able, with minimal effort, to

build their DLL into a custom device, exposing a configurable interface directly in VeriStand. This is in addition to the out-of-the-box functionality such as CAN, LIN, and FlexRay interfaces. Many models often need to be validated, and complexity is increasing fast. How do test engineers use VeriStand to connect how physical hardware maps to a model?

VeriStand has a mapping diagram that shows how channels and parameters map to the model. This visual provides instant feedback on mappings that gets broken between the model and hardware along with connections to the user interface. NI is also making it simpler to interface with our switch, load, and signal conditioning front end for routing and faulting modules. Users can preconfigure multiple routes, save them, and then call them during run time when the test executes. This reduces complexity during test development and debugging.

KI: With the openness and integration options, VeriStand acts as master of the validation test, but what options are there to increase automation?

CF: Though VeriStand is the real-time execution engine, we often see it interface with our test management software, TestStand. Openness is important to us, and, as a member of ASAM, NI has developed ASAM XIL steps that can be called from TestStand. By supporting the ASAM XIL standard, NI helps engineers reuse test sequences they have developed using that standard from other HIL systems.

KI: Thank you, Chris. So test engineers trying to standardize on an approach can gain efficiency in their workflows without losing the ability to reuse, integrate, and customize

according to their requirements. What alternatives do users have when they are looking to standardize their HIL systems?

CF: What we see the most is software developed in-house that suddenly needs to scale and support multiple testers. This is often a crossroad where test engineers struggle to find the time to continue developing because their job responsibilities increase along with the complexity and number of tests. On the other hand, we also see very closed solutions that test engineers sometimes struggle to access to make functionality changes important for them to be effective in their jobs. With VeriStand, NI gives them the best of both worlds with an execution framework that they can standardize on, reuse, and apply to make the changes they need to validate their units faster.

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Using Simulation to Improve EV Power Electronics Designs

Electric vehicle (EV) powertrain architectures vary between full battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and various series or parallel hybrid electric vehicles (HEVs), but they all use power electronics to control and convert electrical power in the system.

Power Electronics Testing Presents New Challenges

High Speed

EV power electronics are characterized by fast-switching frequencies in the range of 2 kHz to 20 kHz. The industry wants to speed up these frequencies even more using new designs based on silicon carbide and gallium nitride. Accurately modeling switching behavior requires simulation timesteps at much higher frequencies than this switching speed—often many times faster than can be accomplished in real time with a standard CPU-based simulation system.

Complex Behavior

Electric machines exhibit complex nonlinear behavior such as magnetic saturation and cogging torque. This behavior can be difficult and computationally intensive to model. You can use

linear models to test basic embedded controller functionality, but for tuning and optimization, you need to accurately represent the more complex behavior of the system.

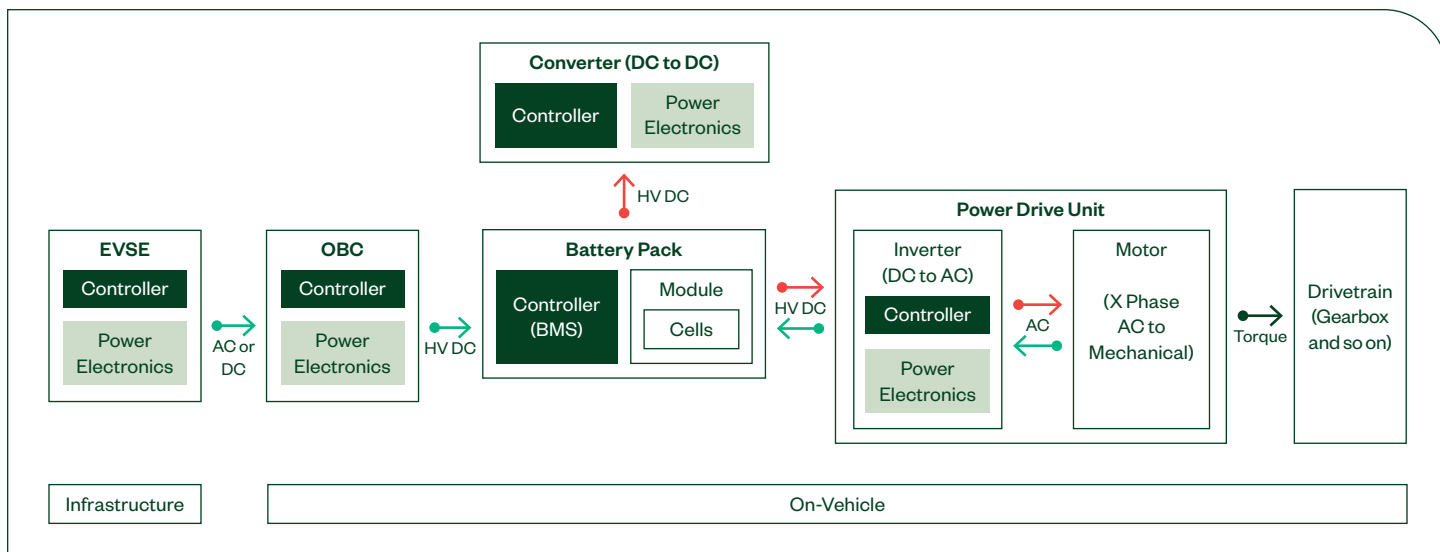
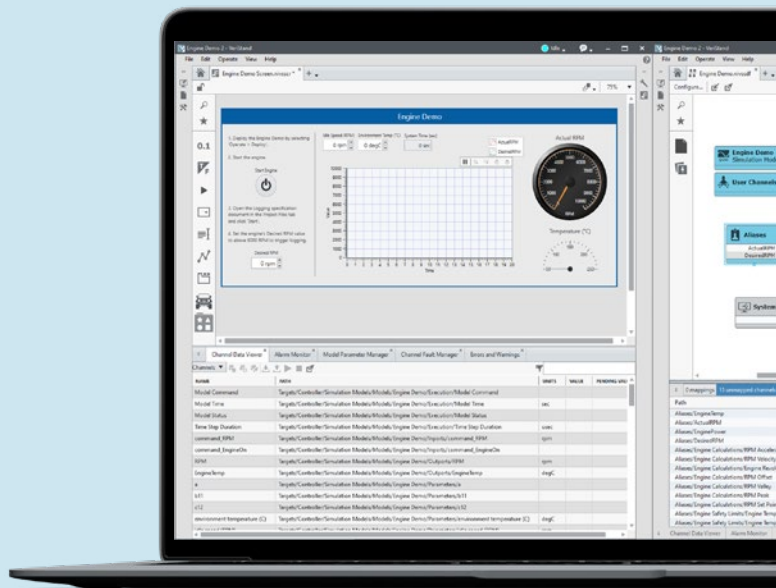
Limitations of CPU-based systems for real-time simulation have made simulation-based methodologies like model in the loop (MIL) and hardware in the loop (HIL) impractical to move earlier in the product development cycle and away from expensive and time-consuming physical test on e-dynos (motor testbenches).

Approach

Use FPGAs for High-Speed Simulation

Achieving adequate simulation speed to enable MIL and HIL testing of EV power electronics means reaching less than 1 s range for simulation periods to execute models that can represent these complex systems with adequate fidelity. Closing the control loop at these speeds requires a paradigm shift away from CPU-based systems to using FPGAs for simulating power electronics and motors.

However, FPGA-based simulation raises new difficulties. Implementing complex power electronics and motor models on FPGAs often requires specialized FPGA-programming knowledge. Also, waiting for lengthy compilations to complete can be a highly iterative process of program, compile, and test.



EV powertrain design is all about managing the flow of power and optimizing power conversion.

Solution

NI Real-Time Test Architecture + OPAL-RT Power Electronics Simulation

NI provides flexible test, measurement, and control with PXI and CompactRIO hardware. Both systems combine a real-time CPU with a user-programmable FPGA and modular I/O. They also run VeriStand software for integrating models with I/O and configuring and running real-time tests.

Both PXI and CompactRIO offer the system architecture you need to realize an FPGA-based simulation approach. With these systems, you can run sophisticated power electronics and motor models at submicrosecond loop rates to provide the simulation fidelity required to return accurate test results and move more testing earlier in the design process.

VeriStand

VeriStand is real-time test software that helps you perform real-time target-to-host communication, data logging, stimulus generation, and alarm detection and response.

VeriStand also transitions quickly from simulation-only testing to HIL testing, which helps you reuse test components such as test profiles, alarms, procedures, and analysis routines. You can remap parameters from models to hardware channels and real-world I/O. This transition saves you time when performing regression testing and helps you automate tests using test executive software such as TestStand.

VeriStand also features an open framework that you can use to create application-specific functionality through add-ons. This provides maximum flexibility in your test system.

OPAL-RT

Power Electronics Add-On for VeriStand

NI collaborates with NI Partner OPAL-RT to provide its FPGA-based Power Electronics Add-On for VeriStand. Integrated directly with VeriStand and extensible with a LabVIEW software development kit, the add-on is a powerful FPGA-based power electronics and motor simulation tool that includes the following:

- OPAL-RT's electric Hardware Solver (eHS), which is a powerful floating-point solver you can use to simulate an electric circuit on an FPGA without having to write the mathematical equations. Import models from various popular schematic editors for power electronics simulation such as MathWorks Simscape™ Electrical™ Specialized Power Systems Library, Plexim PLECS, Powersim PSIM, and NI Multisim. You can choose the eHSx64 or eHSx128 to match the complexity and size of your power electronics topology (the number of states, switches, and measurement and control signals in your system).
- Machine model solvers including permanent magnet synchronous machine and induction machine configurations as well as position feedback devices like resolvers and encoders.
- Multiple supported 2D and 3D solvers that enable tabular import of machine characteristics from finite element analysis or experimental data.
- Signal generation engines, such as sine wave, pulse width modulation (PWM), and sinusoidal PWM, built directly into the FPGA design to generate control signals for open- and/or closed-loop testing.
- The ability to change parameters during simulation using customized test scenarios and parameter sets to generate faults and automate testing without reloading or recompiling your model.

Results

With the NI and OPAL-RT solution, you can implement submicrosecond model-based simulations of power electronics and motors on an FPGA for high-accuracy MIL design studies. You can connect these models to high-performance FPGA-enabled I/O to implement high-performance HIL test systems.

With modular hardware and open software, you can tailor your test system to each specific application while maintaining a consistent test architecture between systems and over time as you upgrade to address changing test requirements. This solution helps you shift test earlier in the design process so you can find problems more quickly, optimize performance sooner, and achieve greater test coverage while shortening test times and reducing total cost of test.

Author

NATE HOLMES

POWERTRAIN TEST LEAD, NI

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