Virtual Test Driving and Digital Twins:
Accelerating the Shift to Software-Defined Vehicles

Tampere Automotive & Vehicle Technology Cluster's International Networking Event

November 26, 2025

Carl Squire – Managing Director, IPG Automotive USA, Inc.

David Howarth – Director, Global Software Strategy

Ben Duprey – Product Owner, Vehicle Dynamics and Modeling

Ben Duprey – Simulation Technical Specialist | Product Owner, Vehicle Dynamics and Modeling

Organizations

- IPG Automotive, Inc. (2022 – present)
- Mechanical Simulation Corporation (2010 – 2021)
- Continental Corporation (2004 – 2006)
- Honda R&D Americas, Inc. (2003)
- Saleen, Inc. (2001)

Professional Society Activity

- SAE (20+ years)
- ComVec (2008 - present)
- Vehicle Dynamics Standards Committee (2011 – present; Currently serving as Chair)
- Associate Editor, Journal of Commercial Vehicles (2016 - present)
- Truck & Bus Vehicle Dynamics Modeling and Simulation Task Force (2023 – present)

Education

- Virginia Tech – MS (2006 – 2009)
  - Thesis - “A New Fuzzy Logic Based Stability Index Using Predictive Vehicle Modeling and GPS Data.”
- RIT – BS, Mechanical Engineering (1999 – 2004)
  - FSAE – Continental Best-in-Class Brake System Award (2004)

Publications (SAE)

- ComVec – 4 technical papers
- Guest Editor - Fundamentals of Vehicle Dynamics, Revised Edition

Publications (non-SAE)

- Manuscript Review - Algorithms for Decision Making (Mykel J. Kochenderfer, Ph.D., MIT Press, 2022)

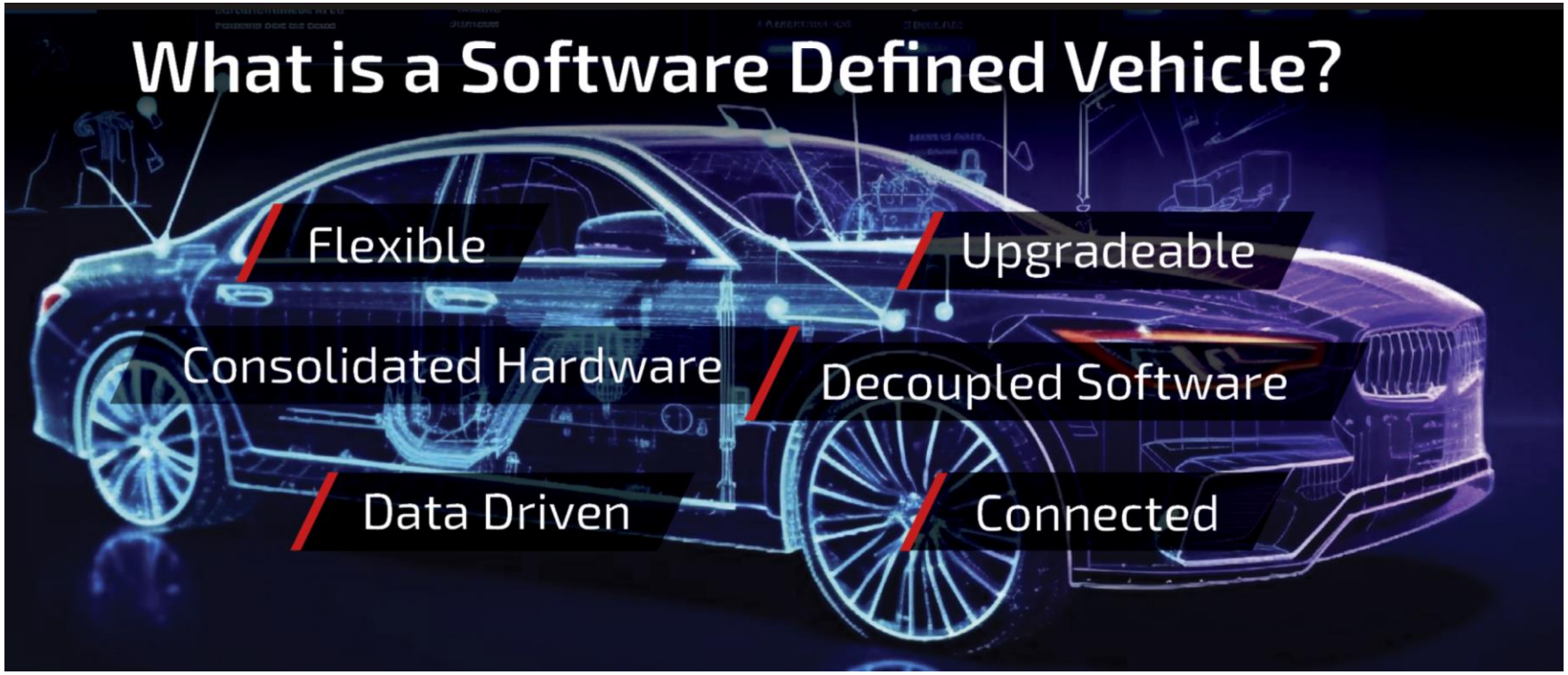
Research Interests / Activities

- Fuzzy Logic
- Game Theory
- Decision Making Under Uncertainty

Presentation Outline

- Software-defined Vehicles, Virtual ECUs, and Shift-left topics
- Application – Rapid Software Validation
- IPG CarMaker and the Virtual Vehicle Prototype

Software-Defined Vehicles (SDV)



SONATUS

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Software-Defined Vehicles (SDV)

- **What is an SDV?**
  - A car whose primary functions and features are managed and enhanced through software.
  - OTA – Allows for updates, new features, and customization.
  - Features – No longer tied to fixed hardware.

- **Software, rather than hardware, is the driver for functions and connectivity**
  - Software-defined Development
  - Upgradeable over time
  - Modern software architectures and cloud-based services
    - Vehicle – Both a sender and receiver of data

Software Warranty Costs are Crushing the Industry

Automotive News Europe
https://europe.autonews.com › v... · Diese Seite übersetzen
Volvo EX30 electric SUV recalled due to software issue
10.06.2024 — **Volvo** is recalling the full-electric EX30 due to a software issue. The issue affects all of the almost 72,000 EX

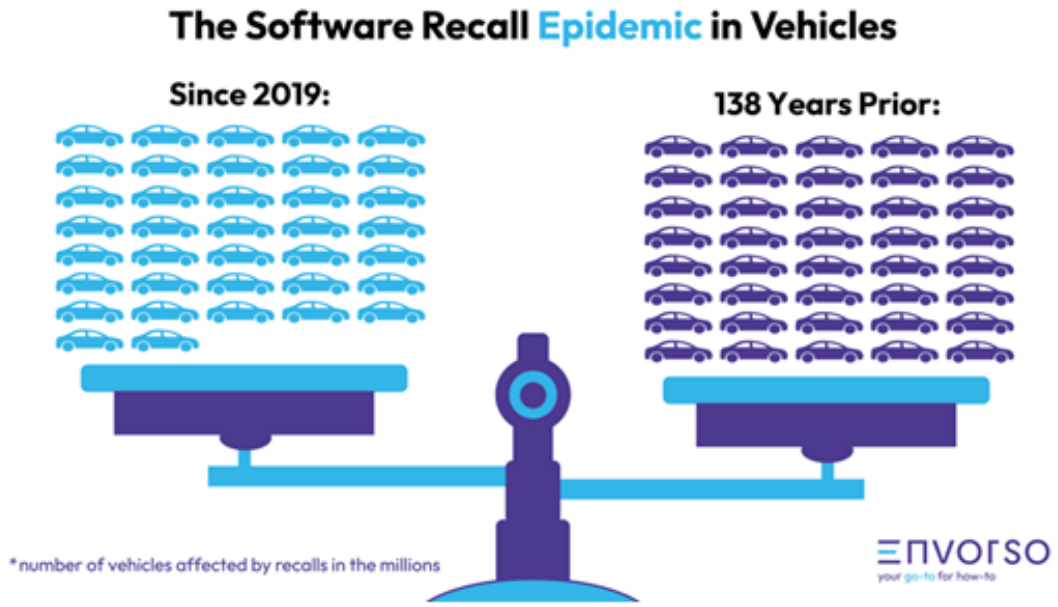
AP News
https://apnews.com › article › cr... · Diese Seite übersetzen
General Motors' autonomous vehicle unit recalls cars for ...
08.11.2023 — General Motors' autonomous vehicle unit **recalls cars** for **software** update after dragging a pedestrian ... We **do** this to deliver personalized ...

The Reiff Law Firm
https://www.reifflawfirm.com › f... · Diese Seite übersetzen
Ford Recalls More Than 430000 Cars Due to Software Defect
The **software** glitch at issue in this **recall** is one that will prevent the **car** or truck's engine from shutting off. That is, eve

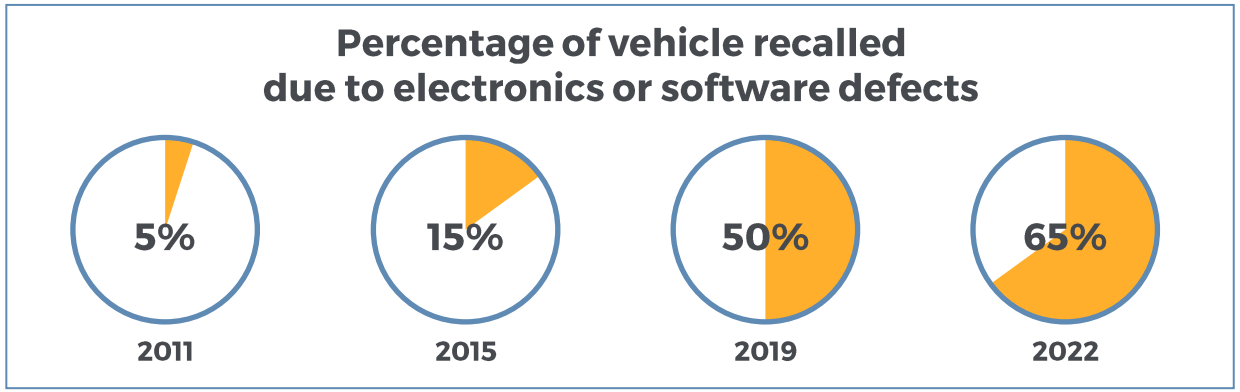
The Columbian https://www.columbian.com › News › Business
Stellantis recalls 1.5M Ram trucks to fix software bug that ...
Sep 8, 2024 — Stellantis is recalling **nearly 1.5 million Ram pickup trucks** worldwide to fix a software problem that can disable the electronic stability control system.

Morocco World N...
https://www.moroccoworldnews.com › ... · Diese Seite übersetzen
Tesla Recalls 1.6 Million Electric Vehicles Due to Software ...
05.01.2024 — Tesla, one of the world's biggest and most storied electric **car** manufacturers, has announced its decision to recall 1.6 million electric

CarInsurance.org
https://www.carinsurance.org
Honda Announces Massive Recall of 1.5 Million Cars
Jun 25, 2024 — To update the **software** on your **Honda** CR-V or any affected **Honda** vehicle, you should wait to be contacted by **Honda** if your vehicle is included in ...



Source: ENVORSO



Source: Synopsys

Key Factors Driving the Issue

Software and system complexity are growing rapidly

(ADAS, SDV, HMI, electrification, etc.)

Traditional testing - Too much time to find and fix bugs quickly

Vehicle System HILs
Complex, expensive, not scalable

Track Testing
Time-consuming, expensive, limited scope

Test Coverage
Lack of scenario testing and vehicle correlation throughout process

Debugging / Retest
Frequently requires several weeks

Result - Significant defects make it to production

Silicon Valley Innovation: Workflow!

Silicon Valley software companies (e.g. Google, Amazon) solved a similar challenge 15 years ago

- Complexity drove a reduction in software quality & reliability
- Important lesson - Workflow concept of **Rapid Software Validation**
  - Software changes from all developers integrated together and tested in hours
  - Bugs are found while software changes are still fresh in developers' minds
    … enables rapid rework
- Discussions frequently involve the idea "it's cheaper to find bugs earlier than later"
  - While helpful (8 weeks reduced to 2 weeks), it does not fully solve the problem
    … Use the Silicon Valley mindset instead …

"Test **It** before You Forget **It**"

Test all S/W changes together in hours to yield significant improvements in S/W quality

Use Silicon Valley Innovation to Improve Auto S/W Quality

WORKFLOW

vECU on SIL | **Rapid HIL** | **VIL V&V**

IPG Automotive has developed **rapid validation** workflows to apply these principles to **existing** controls-based software development

- Three Stages integrated into one CI/CD workflow
- Rapid cycle time (hours for each stage)
- Extensive test coverage

VIRTUAL VEHICLE PROTOTYPE

Using the CarMaker virtual vehicle prototype in each stage simplifies test setup and execution

- Integrate all dependent electronic controls
  - Built-in RestBus simulation
- Correlate vehicle test results at every stage
  - Prove simulation matches physical testing

Focus - Automated S/W V&V Testing

RAPID SOFTWARE VALIDATION STRATEGIC STAGES

vECU on SIL | **Rapid HIL** | **VIL V&V**

… not S/W Development Applications

MIL

Component & Sub-System HILs

Driving Simulators

Test Beds

VIL

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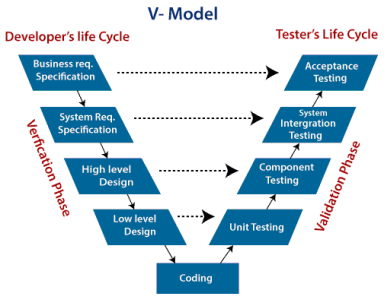
“As Is” Automotive Approach



Bugs found!

Many bugs get to production

Multiple weeks

Feature Development (MiL or S/W)

Feature Validation (SIL)

Embedded Software Build (for Physical ECU)

Integrate: ECU
- Feature
- Comm-IO
- CANdb
- Diagnostics

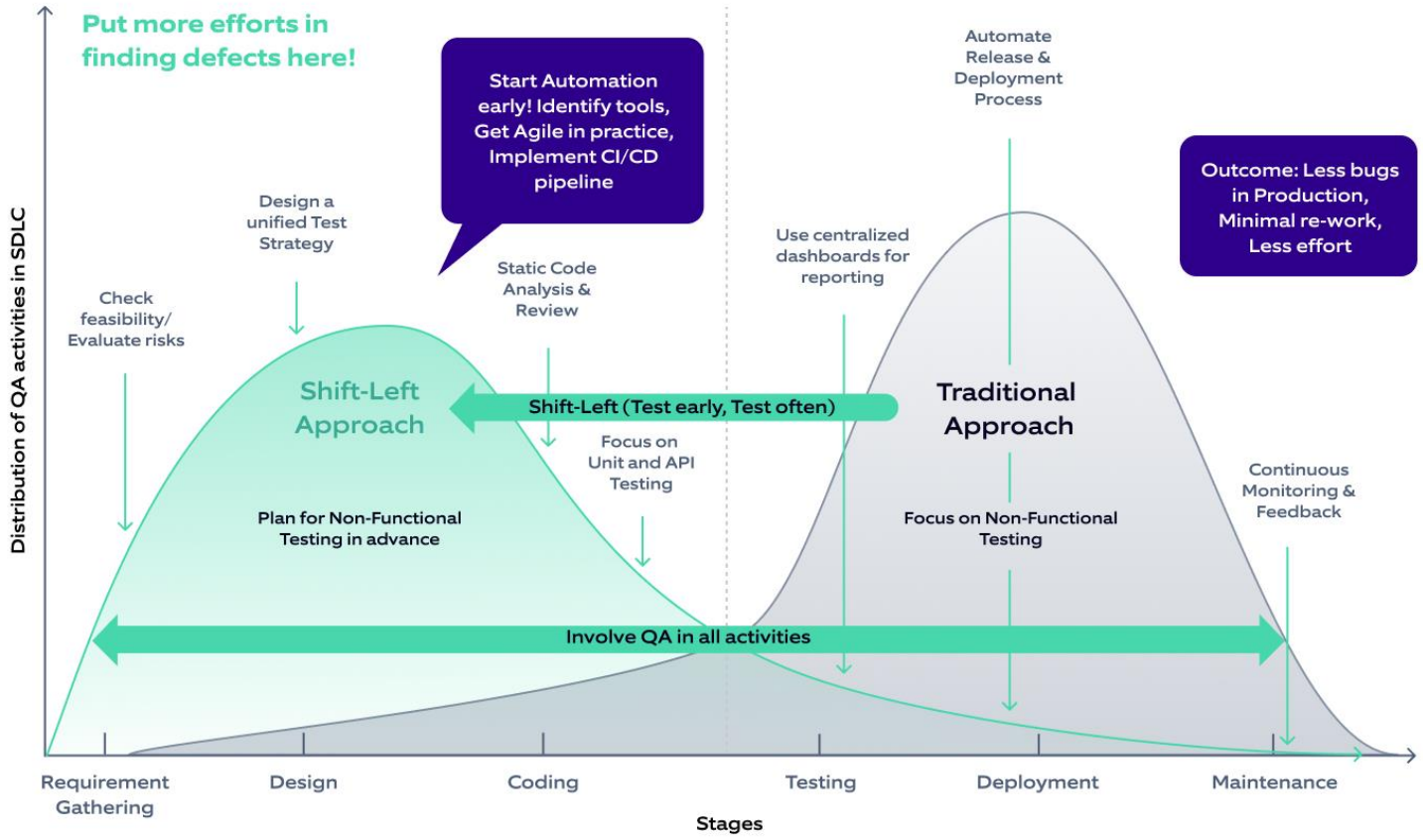
Embedded Software Validation (HiL)

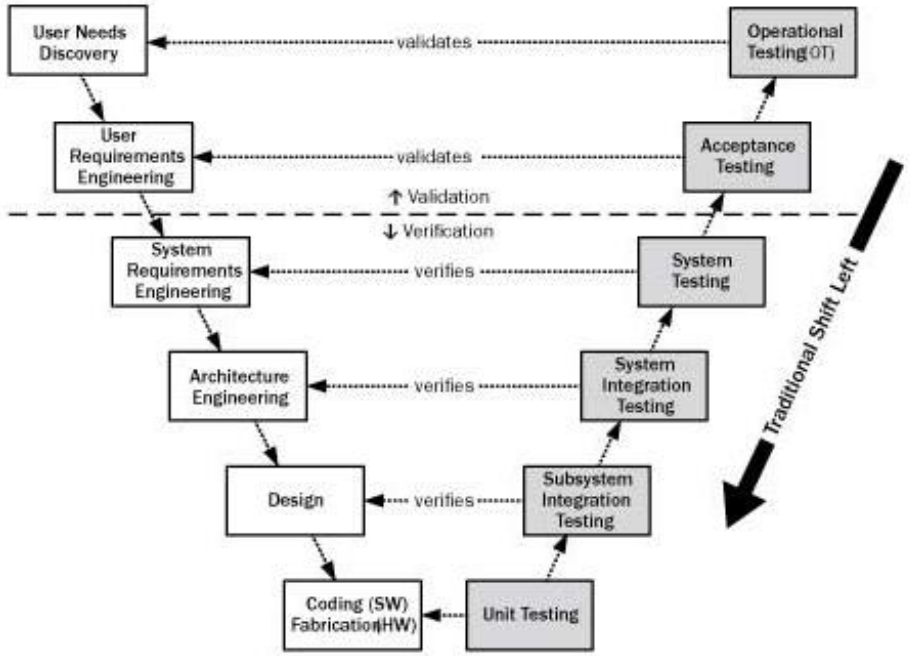
Physical Vehicle Validation (Test Track)

Prolonged Loop Time: Tempo of code changes outpaces ability of these test systems to debug

Vehicle System HIL Complexity: Unrealistic to add new HIL systems given cost and complexity

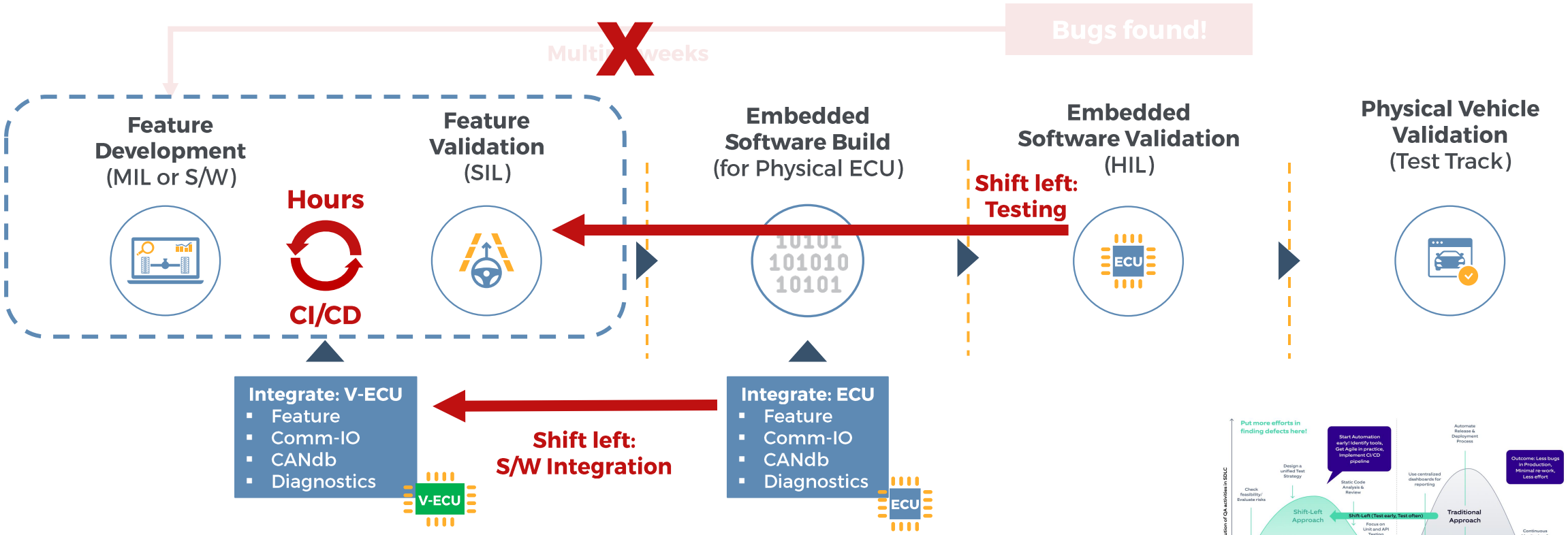
Test early and Test often - “Shift left”

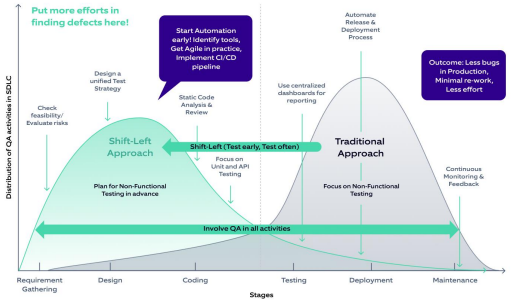




Rapid Migration of Existing Workflows

vECU on SIL | Rapid HIL | VIL V&V



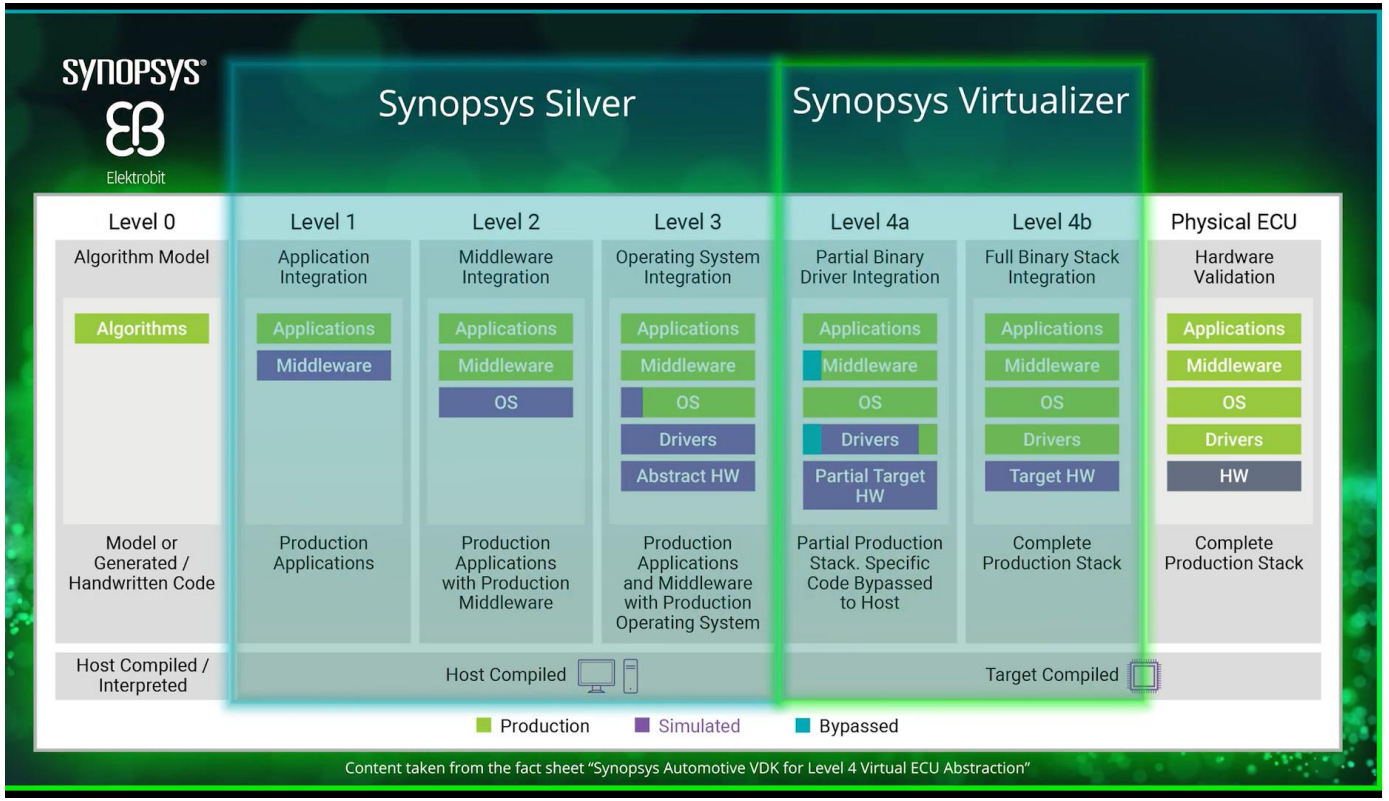


Speed: Run many tests in parallel on the Cloud

Coverage: Scenario tests, message tests, static code tests, diagnostic tests, fault-insertion

Virtual Prototyping using Virtual ECUs

- **Ensure accurate ECU behavior in virtual environments**
  - Levels 1 – 3 – Software-in-the-Loop (SIL): Run software on your host
  - Level 4 – Representation of virtual hardware



Rapid Migration of Existing Workflows: vECU on SIL

Use two different vECUs to achieve both **Speed** and **Coverage** for “layered integration” testing

Speed: Level-1 vECU for fast testing of many scenarios

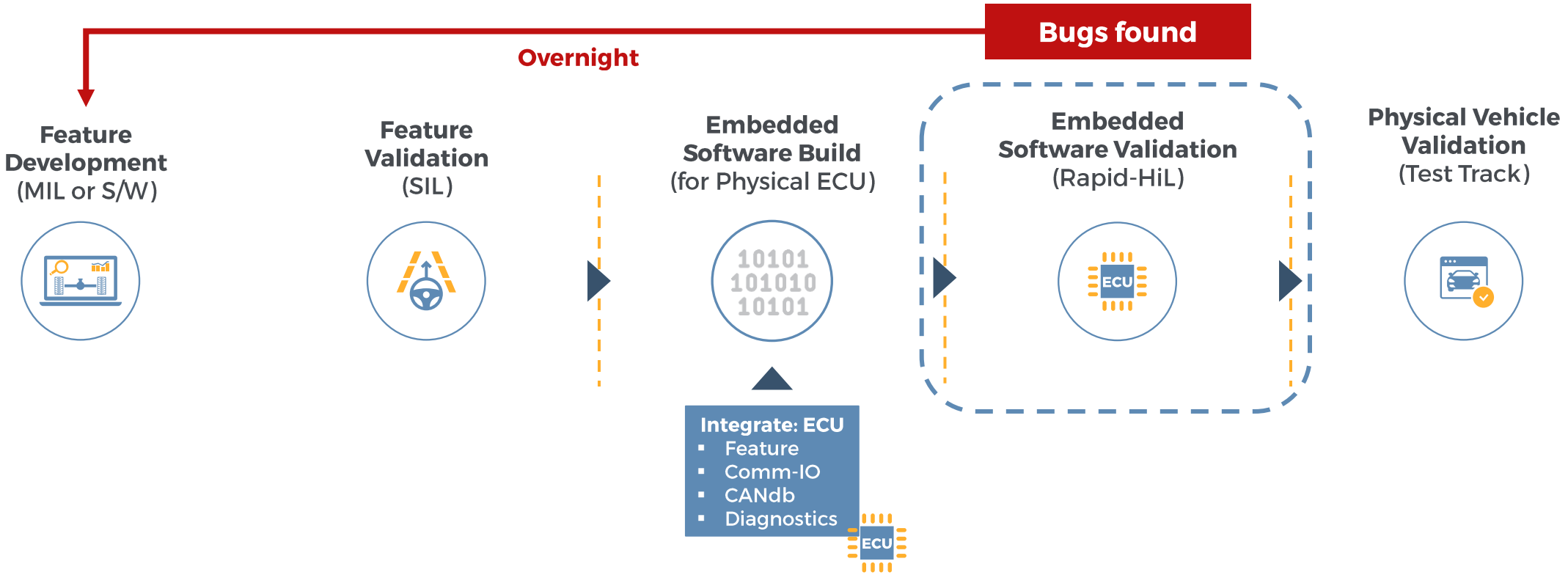
- Test function behavior for feature developers
- Simplicity and scalability (FMU “signals”)
- Fast completion of significant quantity of scenario-based tests on the cloud

Coverage: Level-3 vECU for “layered” integration testing

- Test Production-Intent integration of:
  Feature + Base Software + CANdB + diagnostics
- Test Vehicle System integration of:
  vECU (SUT) + dependent vECUs on virtual CAN bus
- Test bus messages and scenarios

Rapid Migration of Existing Workflows

vECU on SIL | Rapid HIL | VIL V&V



Speed: Massively increase throughput using scalable, low-cost Rapid-HIL farm

Coverage: Scenario tests, Message tests, Static code tests, Diagnostic tests, Fault-insertion

Rapid Migration of Existing Workflows

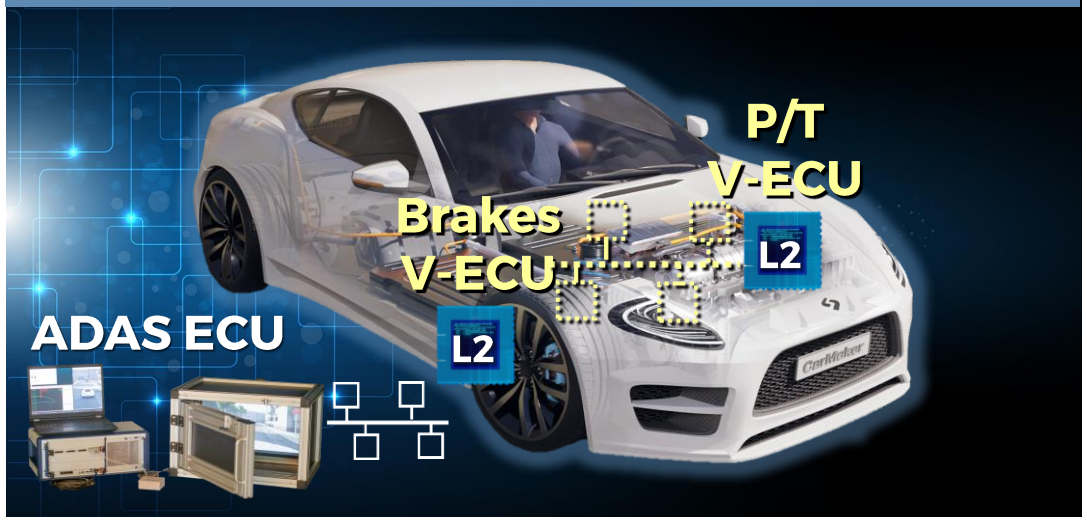
vECU on SIL | Rapid HIL | VIL V&V

ECUs in vehicle system HIL

Challenge of current Vehicle System HILs

- Vehicle physical ECUs connected on big “bread-board”
- ECU software version management at test bench
  - Restbus managed at the bench
  - Restbus and ECU network issues result in debugging on the bench, reducing uptime

vECUs in virtual prototype

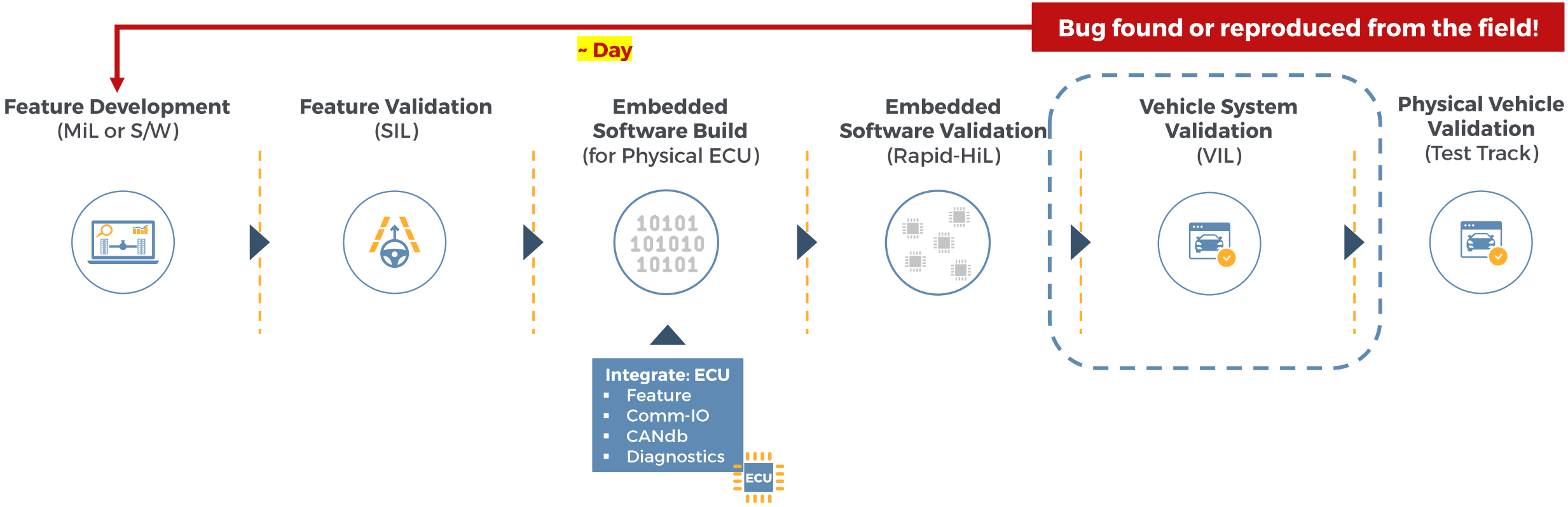


Same CarMaker virtual vehicle used with V-ECU in SIL

- Dependent ECUs virtualized and connected in virtual vehicle
- ECU version management in virtual vehicle, not bench
  - Restbus managed in virtual vehicle
  - Find bus errors at build time, not later at the bench

Rapid Migration of Existing Workflows

vECU on SIL | Rapid HIL | VIL V&V



Speed: Include VIL in CI/CD automation to generate results in one shift

Coverage: Correlate real-world results with virtual vehicle from simulation (SIL/HIL)

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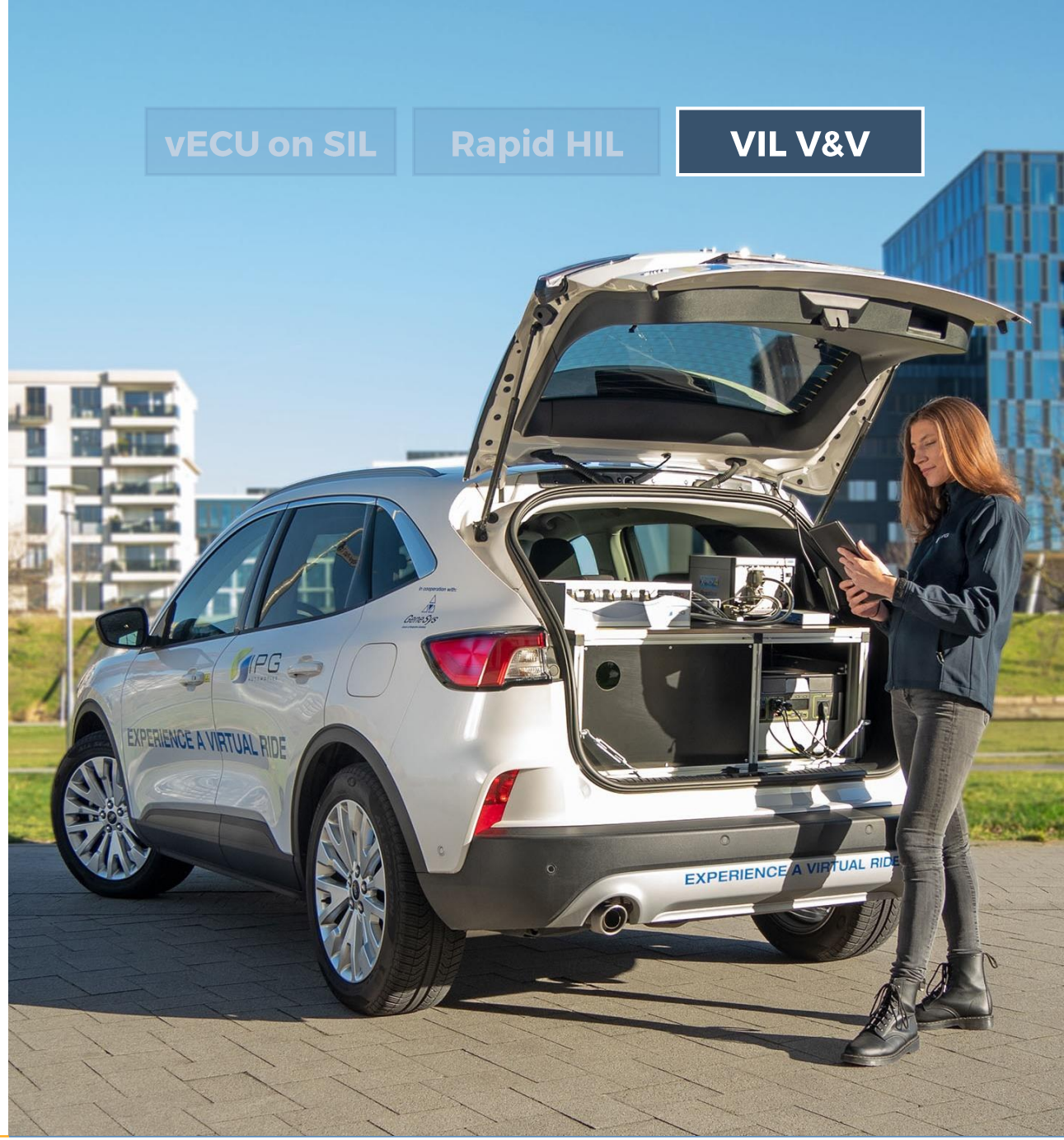
Rapid Migration of Existing Workflows: VIL Validation

Virtualization and production correlation

- Correlate the physical results from VIL with the simulation results from SIL and Rapid HIL
  - Prove the simulations can be trusted
  - Run a set of the **same scenarios** in each of the workflow stages for correlation



Accelerating SDV Dev. with Virtual ECUs

- **Enable Shift-left**
  - Test early and test often
  - Rapidly identify issues while they are still fresh in the developers' minds
  - Leverage SIL and Rapid Software Validation workflows

- **Virtual ECU**
  - Shift from HIL to SIL
  - Run with AUTOSAR Classic software
  - Rapid software updates as part of CI / CD workflows

vECU on SIL | Rapid HIL | VIL V&V

Summary

Main lesson from Silicon Valley re: Software Quality

- **Validation results - Generated in hours**
- **Accessibility - ALL developers**

Workflow - Three Stages in one CI/CD process

1. Shift left with vECUs
2. Rapid HIL farm
3. VIL for software validation

The CarMaker virtual vehicle prototype

1. All dependent ECUs integrated and connected together via the Virtual Vehicle Prototype
2. Correlate virtual test results with physical test results
3. Part of a larger eco-system with Partners

Achievable today

- Biggest challenge: Organizational change