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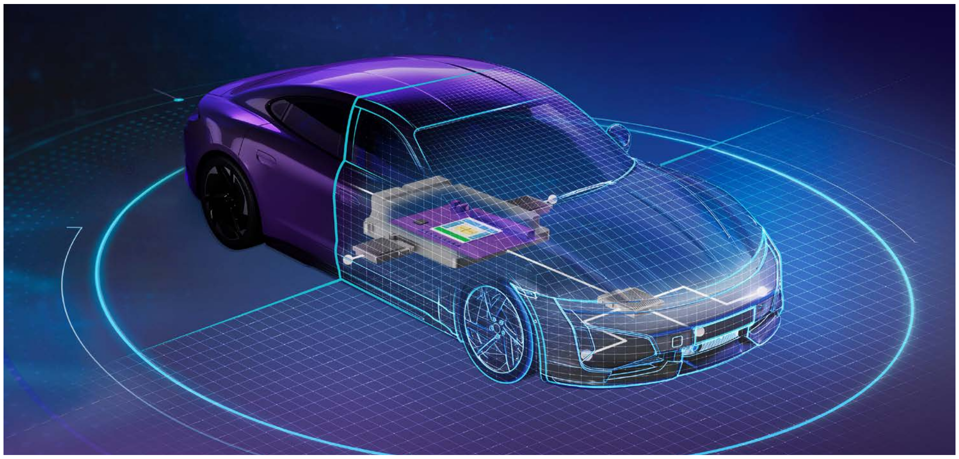
Rethinking Automotive Development: Virtualization for the Software-Defined Era

EXECUTIVE GUIDE

The High-Stakes Shift from Mechatronics to Software-Defined Vehicles — and Why Virtualization Is the Key to Staying Competitive

Content

01 | Executive Summary



The High-Stakes Shift Facing Automotive OEMs

The automotive industry is undergoing its most profound transformation in over a century.

The automotive industry is undergoing its most profound transformation in over a century. As vehicles become increasingly software-defined, the traditional business models, development processes, and organizational methodology that long sustained OEMs is now under pressure.

The rise of connected, autonomous, shared, and electric (CASE) vehicles has introduced new technical and economic pressures, while new entrants — particularly Chinese OEMs (C-OEMs) and software-native companies — are proving that speed, agility, and modular development deliver a critical edge.

In this new paradigm, **R&D efficiency — not cost at SOP — defines profitability.** The old logic of design-to-cost or measuring hours per vehicle (HPV) has become insufficient. Similarly, the maxim "better late but perfect" no longer holds up; delaying SOP in pursuit of perfection can result in substantial, unrecoverable margin loss.

Many established OEMs are now finding themselves caught between legacy structures and the urgent demands of a new development paradigm. Teams built around mechanical-first design are being asked to lead with software. Programs optimized for sequential delivery must now pivot to parallel, virtual integration and continuous verification through automated testing as business critical enablers. Meanwhile, R&D costs are soaring — often outpacing revenue growth — while integration delays threaten billions in EBIT.

This Executive Guide provides a strategic roadmap for navigating this high-stakes shift.

It is not a technical how-to or product pitch. Instead, it offers:

» Why “cost at SOP” is no longer a sufficient success metric

» How the economics of software are redefining R&D priorities

» What’s driving the urgency behind faster, more modular development cycles

» Why legacy org structures struggle — and what leaders must do to adapt

» How early virtualization and system-level automation can unlock cost savings and reduce SOP delays

Virtualization is the key enabler of this transition, offering a concrete path forward by:

- **Reducing development costs**
- **Shortening time-to-market**
- **Improving quality across the lifecycle**

02 | Disruption of Legacy Automotive Economics

Why Cost at SOP Is No Longer Enough

In 2000, the top five automakers controlled over **50%** of global sales; the top 20 accounted for **92%**.

For decades, automotive success was defined by mastery in mechanical engineering, craftsmanship, and manufacturing efficiency. The traditional model thrived on economies of scale, global platform reuse, and meticulous optimization of production costs. The benchmark was clear: deliver the highest quality at the lowest material cost — timed precisely to start of production (SOP).

This model flourished from the 1990s through the early 2010s, thanks to predictable product cycles, stable combustion-based technologies, and market dominance by a few OEMs. Oligopolistic market structures created high barriers to entry. In 2000, the top five automakers controlled over 50% of global sales; the top 20 accounted for 92%[1].

By that time, no startup had broken into the OEM top ranks. Efficiency revolved around economies of scale, modular platforms, and low material costs — not agility or adaptability.

Vehicle programs were led by an elite class of engineers — often referred to as "Car Guys" — focused on combustion mastery, physical prototyping, and cost-optimized SOP. Development milestones were gated by hardware availability and long validation loops. Production performance was measured using metrics like hours per vehicle (HPV), while platforms were reused globally with only minor localization.

[1]SOURCE: TAGESSPIEGEL

Key success factors in this era included:

- **Cost-optimized SOP:** Material savings and HPV (hours per vehicle) defined competitiveness.
- **Mechanical-first innovation:** Core competencies revolved around combustion engines, chassis tuning, and production tooling (injection molding, die casting, etc.)
- **Stable supplier dominance:** OEMs controlled supply chains and timelines with minimal disruption
- **Global scaling:** Platforms were reused across markets, enabling margin preservation with low incremental investment

This system rewarded refinement and consistency, not speed or reinvention. Vehicles were designed over 4–7 year cycles, with minimal updates post-SOP. Older models were pushed into third markets to maximize returns — the Golf 1, for instance, was produced in South Africa until 2009, more than 25 years after its German retirement in 1983[2].

But the foundation of this model is now eroding.

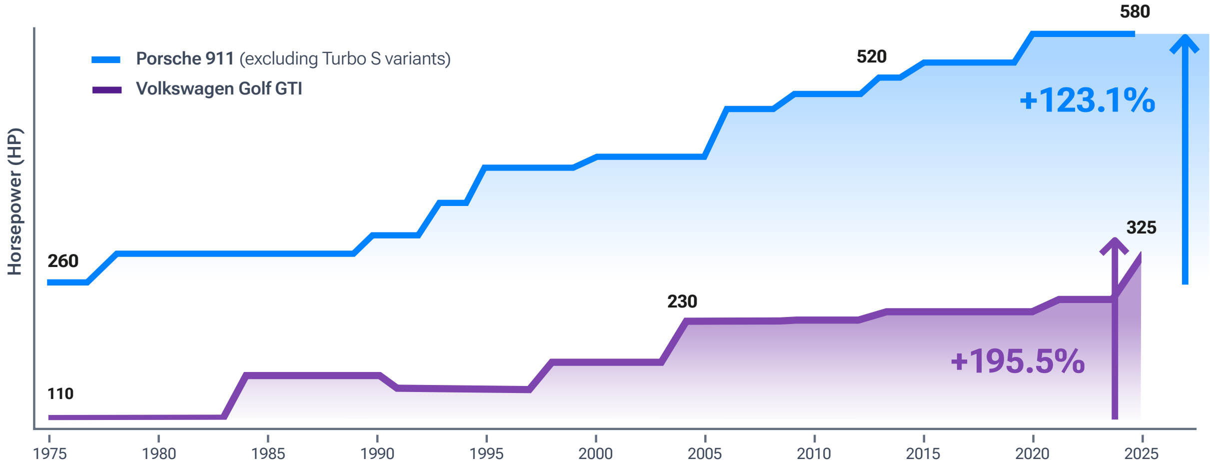
The core assumption behind traditional vehicle economics — that most value is created at SOP and captured through efficient manufacturing — no longer holds. New battery electric propulsion systems, semiconductor-driven feature sets, and software-defined vehicle (SDV) functionality have displaced material costs as the dominant source of product value. Today, innovation no longer stems solely from mechanical excellence or internal OEM ecosystems.

Instead, value is now created much earlier in the development cycle. In an era of connected, autonomous, shared, and electric mobility the majority of value is delivered through software that must be continuously developed, validated, and updated long after SOP.

> Mechanical gains have been substantial but are tapering off, while semiconductor progress has compounded exponentially — putting software at the center of future vehicle value.

[2]SOURCE: Porsche Newsroom, The 911 Turbo generations

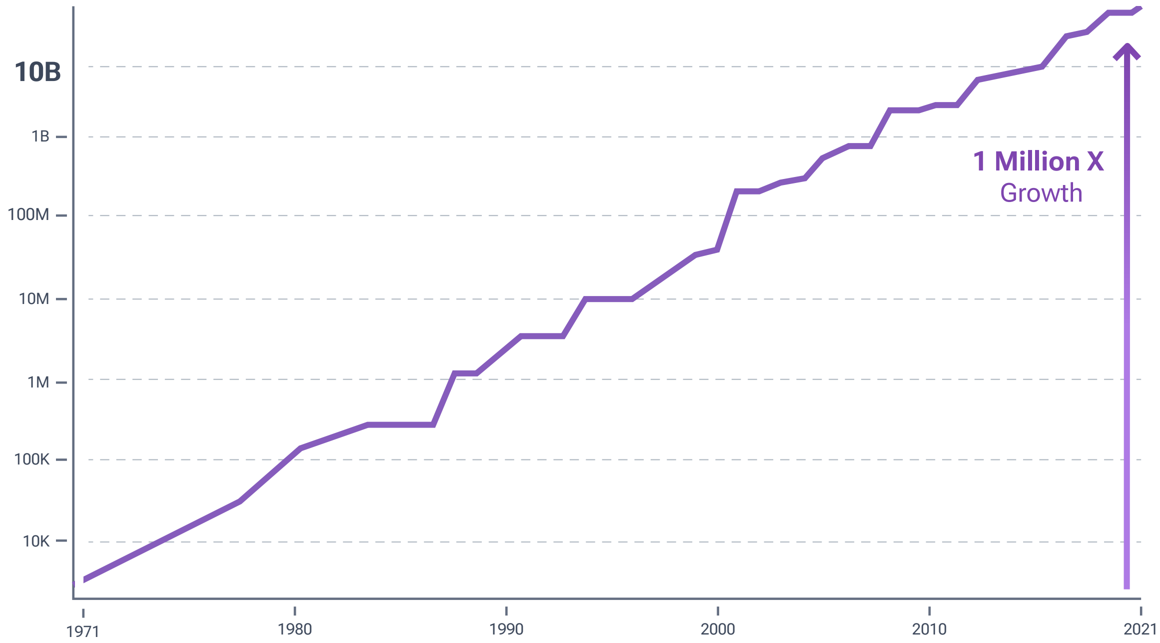
Mechanical Progress Over Time: Steady but Limited



SOURCE: Porsche Newsroom

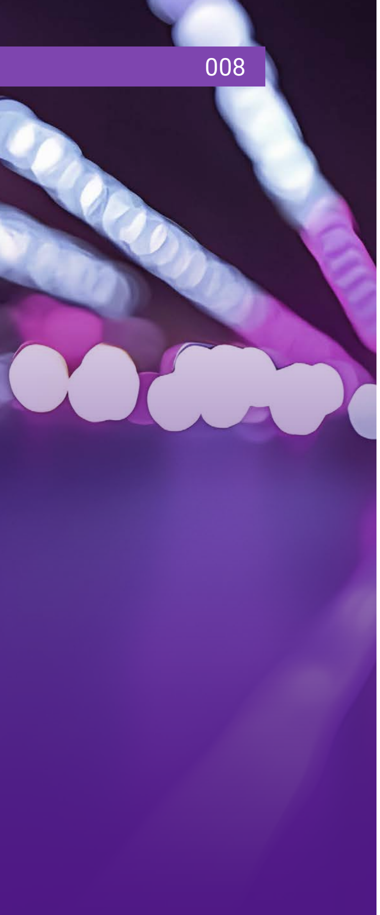
Over the past 50 years, automotive performance gains — such as horsepower increases in the VW Golf GTI and Porsche 911 — have followed a relatively linear trajectory. While these improvements are tangible, they underscore the limits of mechatronic innovation compared to the exponential complexity and performance demands now driven by software.

Moore's Law: The Number of Transistors per Microprocessor



SOURCE: Karl Rupp Microprocessor Trend Data (2022)

In contrast to mechatronic innovation, semiconductor progress has followed an exponential curve for more than five decades. This compounding growth underscores why vehicle value is increasingly shaped by software and electronics rather than mechanical performance alone.



What's Driving the Disruption?
Four Irreversible Forces

The automotive industry isn't just evolving — it's undergoing a complete restructuring driven by four global, irreversible forces. These aren't passing trends; they are structural shifts reshaping how vehicles are developed, delivered, and monetized.

1. CASE: Connected, Autonomous, Shared, and Electric

- **Connected** systems are enabling real-time data flows, infotainment platforms, real-time traffic information, vehicle-to-vehicle communication, and enhanced safety features.
- **Autonomous** vehicles promise greater efficiency, safety and comfort, but demand software-defined architecture and high-performance computing to deliver.
- **Shared mobility** is disrupting traditional ownership models with ride-hailing and carsharing services, decreasing vehicle-per-capita ratios in urban centers.
- **Electric** powertrains are essential for reducing CO_2 emissions and meeting climate goals, but introduce a whole new set of design, cost, and regulatory challenges.

Together, these shifts force automakers to build modular software architectures that can support continuous innovation — especially through over-the-air (OTA) updates. The industry's traditional seven-year product cycle no longer applies: vehicles must now evolve continuously or risk rapid obsolescence.C-OEMs are not just competing, they're leapfrogging traditional models.

> **Bottom line:** CASE is dismantling the traditional business model built on long product lifecycles and predictable upgrades. Maintaining technological relevance across these four vectors requires ongoing investment, real-time adaptability, and new organizational competencies.

2. MIC 2025 & The Rise of C-OEMs

Launched in 2015, China's Made in China 2025 (MIC2025) initiative marked a bold shift: transforming the country from the "factory of the world" into a global technology powerhouse. While China overtook the U.S. in manufacturing output in 2010, it long operated at the lower end of the global value chain — valued for cost competitiveness, not technological sophistication.

MIC 2025 aimed to change that. Through coordinated state investment and industrial policy, the initiative targets high-tech sectors including electric vehicles, autonomous driving, AI, robotics, and smart manufacturing, with the explicit goal of moving Chinese automakers up the value chain and into global leadership.

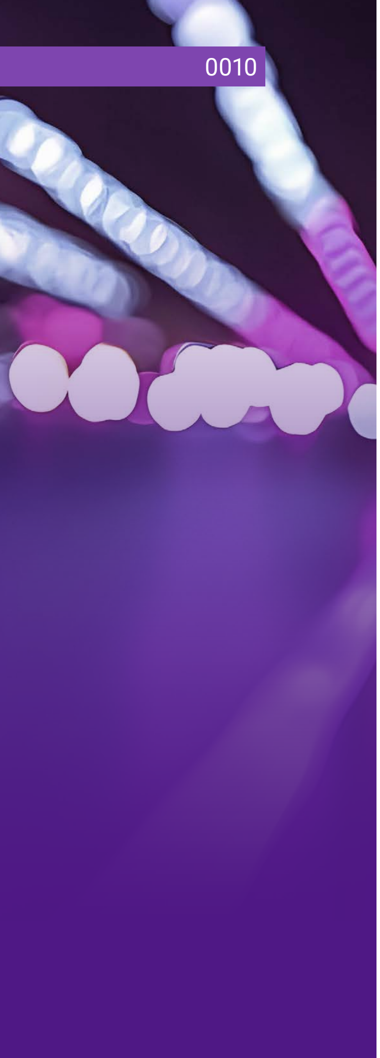
The results have been dramatic. Chinese OEMs (C-OEMs) are now delivering vertically integrated, full-stack solutions that rival and often outpace legacy incumbents. This includes AI-powered software, innovative powertrain tech, and agile development cycles. With government-backed investment, domestic scale, and growing global exports, Other nations have taken notice. MIC 2025 triggered a global trade and tech war, as the U.S. and its allies scrambled to protect their own high-value manufacturing sectors. A decade later, tensions have only escalated. In 2025, the U.S. imposed new tariffs and export controls — further entrenching the divide between Chinese and Western automotive ecosystems.

The results have been dramatic.

Chinese OEMs (C-OEMs) are now delivering vertically integrated, full-stack solutions that rival and often outpace legacy incumbents.

This deepening technological decoupling has strategic consequences for global OEMs. Many now maintain separate vehicle architectures for the Chinese and international markets — driving up development costs and fragmenting their software stacks. Meanwhile, C-OEMs continue to scale at speed, driven by national alignment, software-native talent, and full-stack control.

MIC2025 is a national industrial strategy to move Chinese manufacturing up the global value chain — with the automotive sector at its core.



3. Tougher Regulations

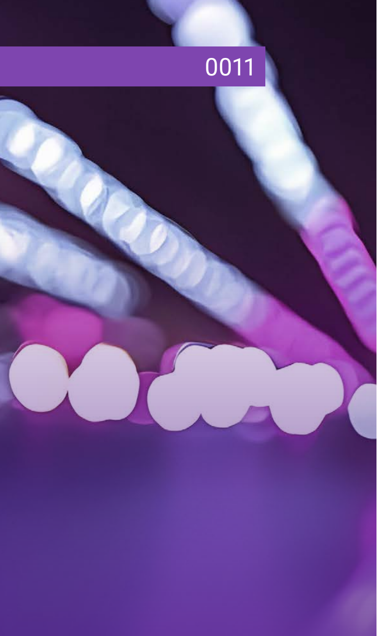
Sparked in part by the Dieselgate scandal, which revealed deep flaws in OEM testing practices and compliance transparency, a wave of global reforms has dramatically raised the bar for emissions, safety, and traceability. Key regulations such as **ZEV3 in the U.S. and EU7 standards in Europe**, alongside widespread adoption of UNECE and other cross-border frameworks, have set new global baselines for compliance. Over the past decade, mounting regulatory pressures have become one of the most transformative — and costly — forces reshaping automotive development:

- **Tighter Emissions Standards:** More stringent limits on NOx, particulate matter, and carbon emissions.
- **Real-World Testing:** Mandatory on-road testing alongside traditional lab assessments.
- **Onboard Monitoring**: Mandatory data transmission (e.g., China’s RTM) even for EVs.
- **Battery Electric Vehicle (BEV) Safety:** New regulations require thermal propagation protections in all electric vehicles, addressing the risk of battery fires and ensuring containment.

The costs of compliance are immense — not only in fines, but in forced retrofits, delayed production, and eroded brand trust. Legacy OEMs have poured unplanned millions into re-engineering vehicles already on the road, with some models needing full redesigns to meet emerging standards.

> **In Short:** Regulations have become an invisible tax on legacy architectures. Fragmented systems, outdated tooling, and slow update cycles make it harder and costlier for traditional OEMs to respond than for modular, software-native entrants.

[3]SOURCE: McKinsey, Tech at the edge: Trends reshaping the future of IT and business
[4]SOURCE: Bain & Company, Engineering and R&D Report 2023



Legacy OEMs are now investing 20–30% of their R&D budgets in software development.

This pivot has created a profound skill gap across all levels of legacy organizations.

4. The Collapse of Legacy Economics

Innovation in the mechatronics field has decelerated significantly. By contrast, software complexity has exploded. In 2020, McKinsey projected that software complexity would grow five to six times faster than productivity increases[3]. The result: legacy OEMs are now investing 20–30% of their R&D budgets in software development[4] — a dramatic shift for companies historically focused on combustion and hardware refinement.

This pivot has created a profound skill gap across all levels of legacy organizations. At the operational level, gaps in developer expertise are often addressed through acquisitions and hiring. But the bigger challenge lies at the top: most board-level and C-suite leaders at traditional OEMs still come from mechanical engineering or business backgrounds. They often lack the IT and systems knowledge required to navigate the complexity of modern vehicle development — and it shows in the boardroom.

This lack of digital fluency is exacerbated by rising geopolitical and economic tensions. Many foreign OEMs have responded to the rapid rise of Chinese OEMs (C-OEMs) with a strategy of technological decoupling — maintaining separate tech stacks for Chinese and global markets. While this may ease regulatory and security concerns, it drastically increases development and maintenance costs. Teams are forced to work in silos, global platforms fragment, and timelines slip.

The industry's core economic assumptions are unraveling. Where OEMs once relied on stable, oligopolistic market conditions and global scale, they now face a fractured, fast-moving competitive landscape. The race to deliver on CASE (Connected, Autonomous, Shared, and Electric) has led to massive capital expenditures — and disappointing returns.

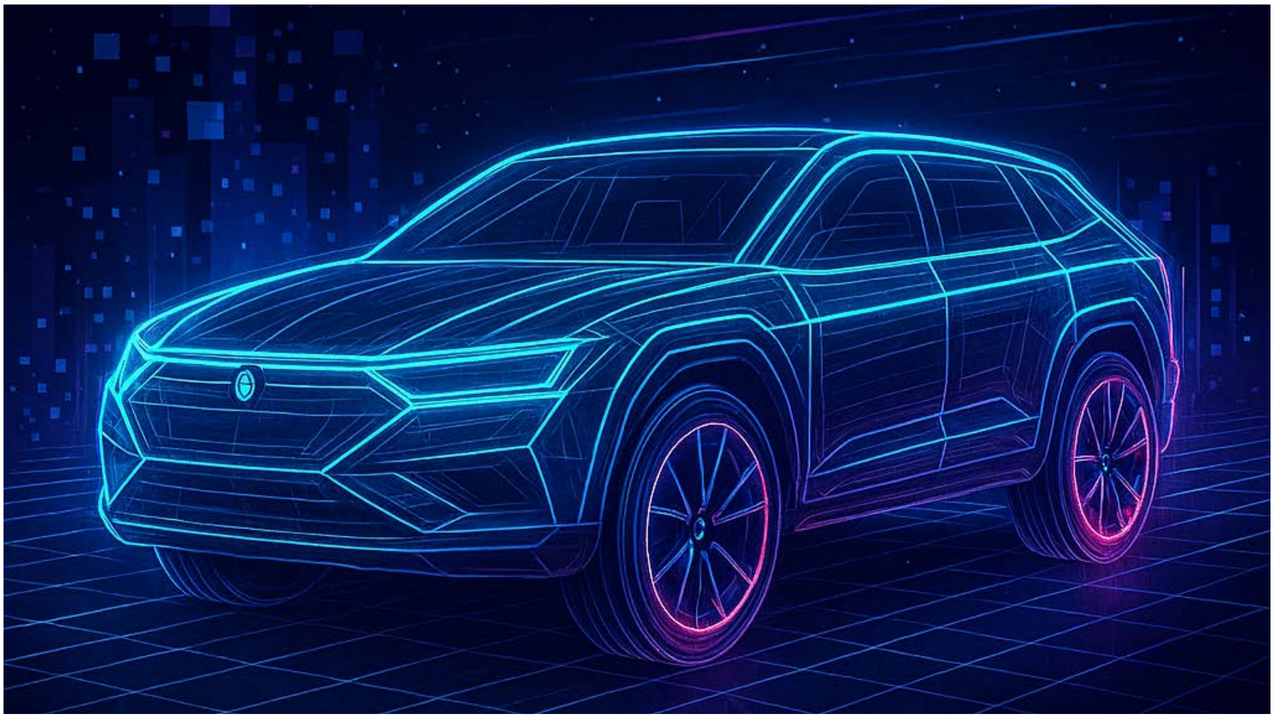
Profitability has plummeted:

- In 2024, the average EBIT of the world's leading automakers is projected to fall to 6.3%, down from 8.0% in 2023 — a 20.5% decline[3].
- External shocks, such as tariffs imposed by the U.S. administration, are making things worse. GM has already lowered its forecast by $4–5 billion, and Mercedes-Benz has withdrawn its annual outlook entirely[4].

[3]SOURCE: McKinsey, Tech at the edge: Trends reshaping the future of IT and business
[4]SOURCE: Bain & Company, Engineering and R&D Report 2023

Challenge: Surviving Transformation

Legacy OEMs are now facing an existential crossroads. According to BCG, adapting to the new landscape requires a complete operational and strategic reset. Many of the weaknesses that had accumulated over the past decade — particularly those obscured by COVID-era demand spikes and government EV subsidies — have now been laid bare.



> Legacy OEMs are now facing an existential crossroads.

The sunsetting of subsidies in key markets like China and Europe, combined with intensifying competition from C-OEMs and software-native entrants, has left legacy players exposed. Without significant and sustainable transformation, these companies risk entering a downward spiral of cost-cutting, SOP delays, and lost competitiveness.

As McKinsey bluntly put it in a 2023 report, "the automotive industry is in the greatest transformation of its history."

This transformation is not just about building EVs or modernizing R&D. It demands a rethinking of leadership, development models, and revenue strategies while navigating massive capital demands, high-speed innovation cycles, and growing geopolitical decoupling between Western and Chinese supply chains.

Consequence:
Billions in Losses for Legacy OEMs

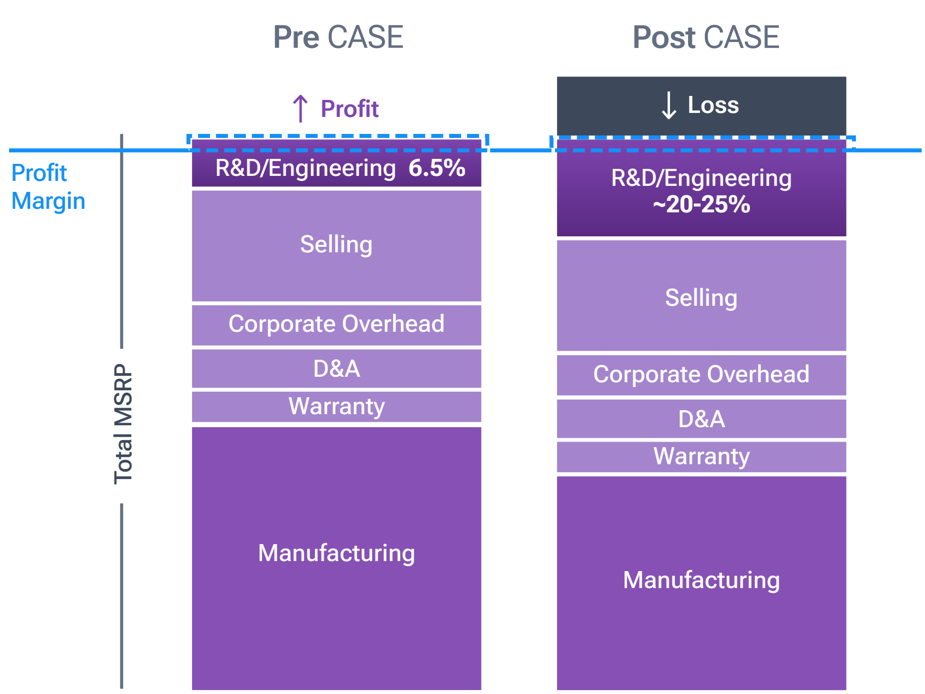
The financial implications of this transformation are severe — and in many cases, already materializing as:

Exploding CAPEX Demands

The shift from a per-unit cost optimization model (traditional automotive economics) to a software-driven, R&D-centric model is driving massive, one-time CAPEX investments. These are necessary to build modern development platforms, testing infrastructure, and internal software capabilities but they are not easily recouped through the old volume-based strategies.

The consulting firm Berylls estimates the additional costs compared to the planned costs at up to 1600%. Recent examples show that budget overruns of several hundred percent are not uncommon, and they endanger not only the profitability of a project but also the entire company.

Shifting R&D Impact on Vehicle Pricing in the CASE Era

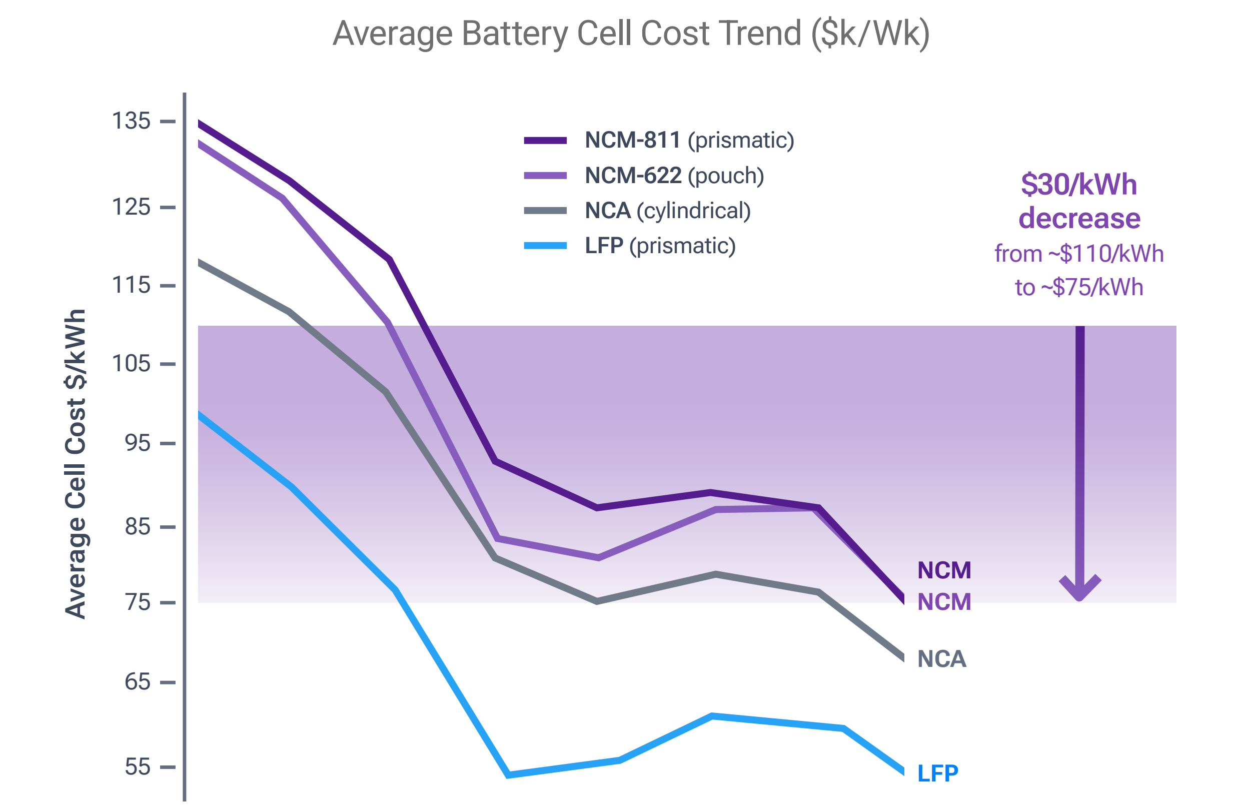


SOURCE: Center for Transportation Research Energy Systems Division; Synopsys Inc.

SOP Delays

Start of Production (SOP) delays are now more than just operational headaches — they are existential threats. Missing SOP deadlines delays cost-down ramps and increases exposure to falling battery prices and faster innovation cycles.

For battery electric vehicles (BEVs), the cost disadvantage of a six-month delay can exceed $5,500 per vehicle, with a total program loss exceeding $1 billion annually for high-volume models.[5] Cost disadvantages of $30–40 per kWh are common in late-stage models that miss key battery transitions. These price gaps cannot be bridged through legacy compensation tactics like keeping the previous model in market longer — especially as older BEVs become uncompetitive in range, charging time, and cost structure.



SOURCE: Fastmarkets. *Excluding profit margins and assuming 10 GWh/yr production rate with 5% cell scrap rate.

Battery Cost Sensitivity (per 80 kWh BEV)

- Cell cost reduction (delta): **$30 / kWh**
- Average BEV pack size: **80 kWh / vehicle**
- Battery cost savings: **$2,400 / vehicle**
- Potential MSRP impact: **$5,000 – $8,000 / vehicle**

[5]SOURCE: Fastmarkets, Electric vehicle economics: How lithium-ion cell costs impact EV prices

Increased Recalls and Quality Risk

Legacy OEMs have also seen a rise in software-related recalls and OTA patch cycles that erode EBIT margins and damage brand trust. These issues stem not just from technical debt but from a systemic skills gap at the leadership level. Most legacy boardrooms still skew heavily toward mechanical or business management backgrounds, with insufficient representation from software and IT disciplines — a critical liability in a software-first landscape.

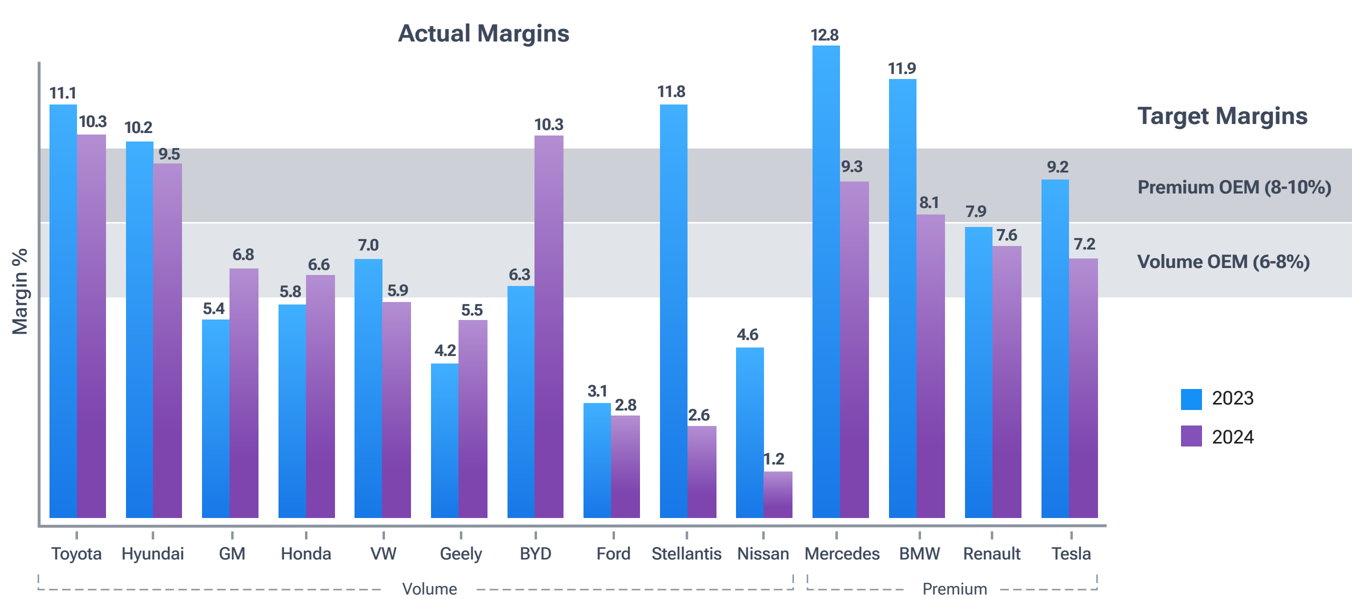
Margin Compression Across the Board

Premium OEMs like BMW and Mercedes are targeting EBITs of 8–10%. But volume players like Ford, Stellantis, Nissan, and VW — many of which require 6–8% just to cover development costs — are in critical territory.

> Industrywide, the average EBIT margin is falling. OEM EBIT margins fell to 5.4% in Q1 2025 — more than **40% below their 2021 peak.**[6]

These margin pressures are compounded by unpredictable macro events. Recent U.S. tariff announcements have prompted Mercedes-Benz to withdraw its annual forecast and caused General Motors to lower its business outlook by $4–5 billion USD.[8]

OEM Margins Under Pressure



SOURCE: Center of Automotive Management

[6]SOURCE: Bain & Company, Automotive Profitability: How OEM and Supplier Margins Are Faring
[7]SOURCE: Fastmarkets, Electric vehicle economics: How lithium-ion cell costs impact EV prices
[8]SOURCE: Reuters, Mercedes pulls earnings guidance amid Trump tariff uncertainty

03 | Resolution: A Software First Approach

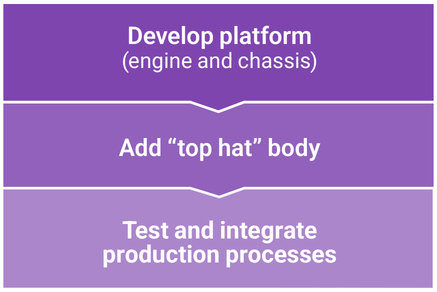
Continuous Development, Integration & Validation: Overcoming Big Bang Integration

> In today's automotive landscape, software and electronics are no longer secondary features

In today's automotive landscape, software and electronics are no longer secondary features — they are the foundation of vehicle functionality. This shift has transformed how systems are integrated and validated, creating new challenges for OEMs and suppliers.

Big Bang Integration: Why It's a Problem

Historically, automotive hardware integration followed a staged process:



This stepwise approach allowed engineers to isolate and resolve major mechatronic issues , during assembly — before fine-tuning, automation, and software.

Now, in the era of SDVs, all ECUs (electronic control units) and software must be fully integrated and operational from the start. The result is the "Big Bang" integration model — where the complete software and electronics stack must function together at the initial build stage.

While this may seem efficient, this model has increased the complexity of detecting and resolving system errors, often leading to new bugs when previous fixes are implemented. A phenomenon known as regression cycles. It also carries a **significant number of hidden costs.**

Bugs often surface only during final testing or validation, when fixes are at their most expensive, leading to costly late error detection. Even when failures are identified, pinpointing their origins can be difficult; problems may stem from any module or interface, complicating root cause analysis. Centralized systems further intensify the challenge, as they involve thousands of signals and parameters that must be managed within complex test environments. In such conditions, certain defects remain hidden, a phenomenon of integration blindness that makes assembling effective and manageable test scenarios increasingly difficult — both technically and organizationally.

Slow feedback loops compound the issue, as delayed insights hinder timely fixes and escalate costs. These are not merely practical hurdles but the inevitable mathematical consequences of scaling system size: with every skipped integration layer, the validation effort grows exponentially — or worse.

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Virtualization: Breaking the Hardware Bottleneck

To overcome Big Bang integration, testing must happen early and often — in full system context, without waiting for hardware.

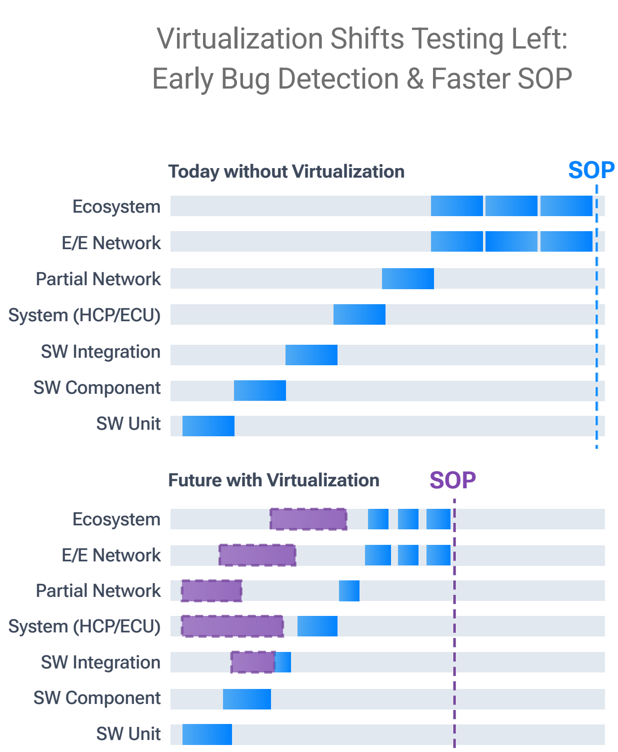
Virtualization, widely adopted in other industries, addresses this by replicating the vehicle's systems and operating environment. This enables teams to test ECU interactions across the full system before physical prototypes exist and to simulate environmental scenarios and conditions to trigger real-world ECU responses.

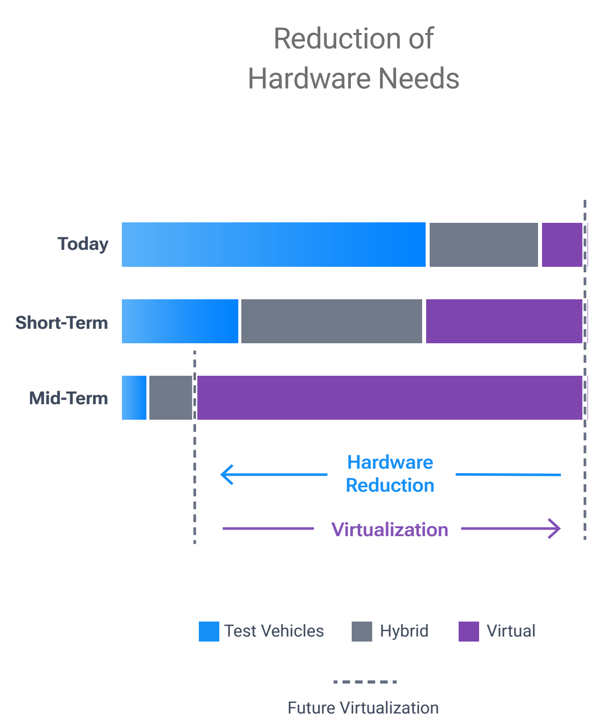
While traditional **hardware-in-the-loop (HIL) testing** remains valuable, it is inherently limited: it requires the actual hardware and supports only its specific configuration. As long as testing, integration, and development depend heavily on hardware-oriented processes and stages, Big Bang integration is likely to occur.

Virtualization removes these constraints, making it possible to:

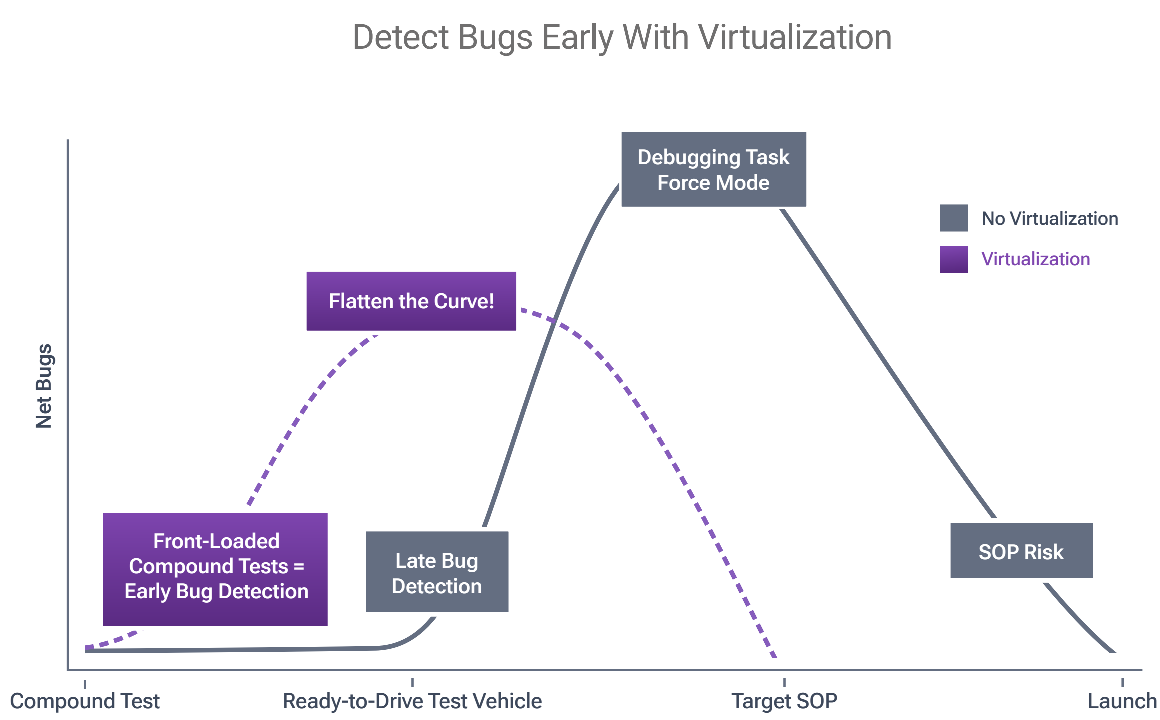
- Perform **continuous integration** from the earliest development stages.
- Execute **scalable, reproducible test setups** that expand coverage without expanding physical resources
- Deliver **faster feedback loops** that reduce escalation events and dependency on firefighting task forces.

In the virtual-first paradigm, the first hardware built is already a minimum viable product, used to verify — not discover — integration results. Physical prototypes become scarce by design, reserved for late-stage verification rather than ongoing development cycles. This shift demands commitment at all organizational levels; if hardware remains readily accessible, teams risk reverting to legacy hardware-driven practices, undermining the transformation. Sustaining change requires aligning tools, processes, and culture so that virtual validation becomes the default and physical verification the exception.





SOURCE: Synopsys, Inc.

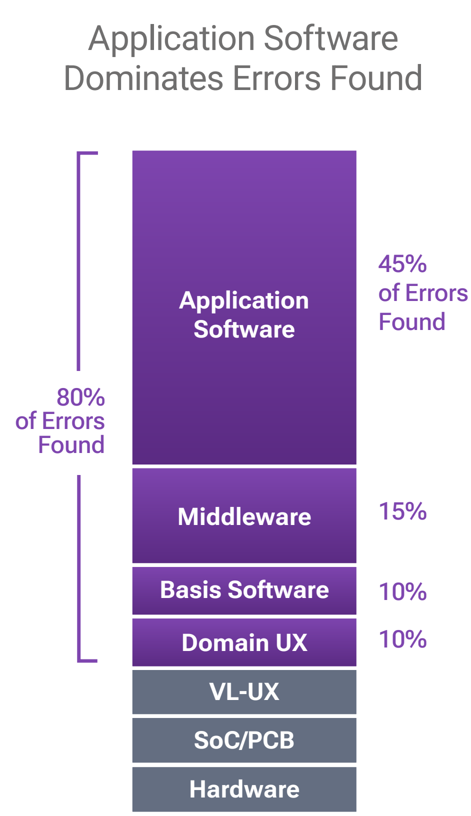


SOURCE: Synopsys, Inc.

Automated Testing: Enabling Sustainable Continuous Development

By removing hardware bottlenecks, virtualization creates the foundation for automated testing — the engine that powers true continuous development, integration, and validation. With automated testing, integration can occur as soon as code is ready, not just at predetermined milestones.

Automated testing transforms automotive software development from milestone-driven verification to continuous quality assurance. In this model, every code change is submitted to an automated framework for validation and merged into the main software stack only when tests pass. This ensures software remains executable and reliable at each step, eliminating the risks of "Big Bang" integrations.



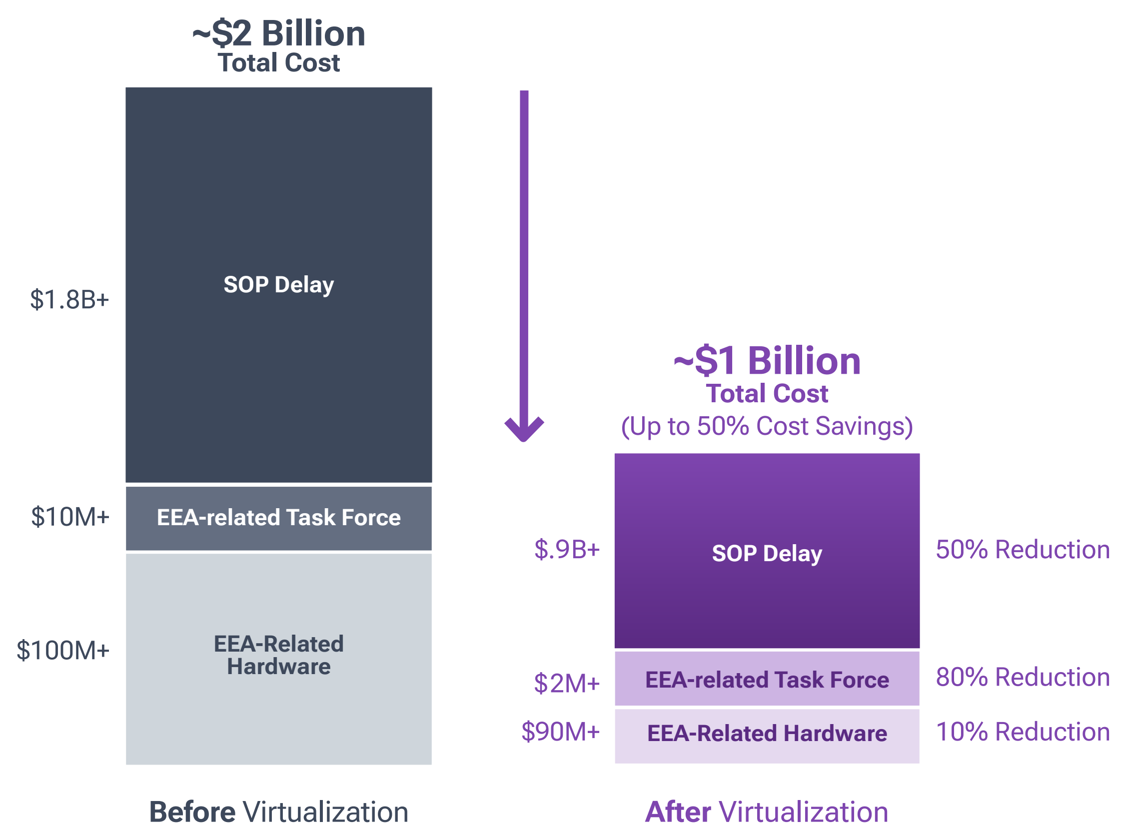
SOURCE: Synopsys, Inc.

Traditional testing often comes too late — triggered by release schedules or resource availability — producing feedback that is inconsistent and costly to act on. Automation solves this by making testing infrastructure, not just activity: every change is gated by a permanent, executable quality check.

Effective systems combine three essentials: machine-executable test cases embedded into CI/CD pipelines, reproducible environments built on virtualized ECUs and scalable simulations, and coverage aligned to the development stage so errors trace directly to their source.

To remain effective under constant change, tests must also follow modern software design principles like modularity, abstraction, and reuse.

Virtualization Cuts SOP Delay Costs in Half



SOURCE: Synopsys Inc.

Implementing Virtualization and Automatization

Virtualization as a Mainstream Development Path — Not an Expert Tool

In many automotive programs, virtualization remains trapped in the role of an "expert tool" — used selectively rather than embraced across the development lifecycle. This is often due to two factors: omnipresent resource and time constraints and a reluctance to commit substantial upfront investment in virtual methods with benefits — including faster fault localization and higher test throughput — realized later in the process.

The default instinct is clear: if a vehicle function is ultimately experienced in the vehicle, then the vehicle must be the best place to test it. For certain domains, like crash testing, decades of proven results have overturned that assumption. Virtual methods are now fully accepted there. Yet for EE (electrical/electronic) functions and systems, that same level of acceptance has not been achieved.

Closing the Acceptance Gap

The real challenge is cultural as much as technical:

- **Developers and testers** — particularly those working on hardware-intensive functions or integration — must trust that virtual environments can evaluate these functions as effectively as a physical vehicle.
- **Virtual systems** must be easy to use, deliver reliable results, and scale across global teams without specialized expertise.
- **Leadership commitment is essential:** executives and senior managers must actively champion and model the use of virtualization to drive adoption across organizations.

Only when those conditions are met, will the benefits compound: virtual development becomes faster, more consistent, and more collaborative. The transition from physical to virtual testing — from vehicle to model — is not just about capability; it is about behavior. For virtualization to become the preferred tool for developers, testers, and integration experts, it must be embedded into the organization's default way of working.

Design Principles for Virtualization Platforms

Simplicity as a Design Imperative
A virtualization platform should integrate seamlessly into existing workflows, supporting core tasks without disrupting familiar processes. Reducing onboarding time and minimizing friction is essential. When simplicity is built in from the start, adoption happens naturally — users feel comfortable, confident, and able to focus on their work rather than the tool.

Reliability as the Foundation of Trust
Virtualization must produce consistent, reproducible results — free from the variability of hardware setups or prior test conditions. But reliability is more than a technical benchmark; it's about trust. Users need to believe the outputs are valid, accurate, and actionable. That trust is earned through transparent processes, rigorous validation, and a proven track record of results that match physical benchmarks.

Speed as a Competitive Advantage
The system should deliver faster-than-real-time results and drastically reduce setup times. This speed isn't just about numbers on a chart — it must translate into tangible productivity gains, enabling teams to iterate quickly, explore more alternatives, and make confident decisions earlier in the development cycle.

Scalability as a Global Enabler
A truly scalable virtualization platform supports 24/7 collaboration across distributed teams and enables rapid creation and validation of complex product variants. But scalability must also be accessible, empowering every user — regardless of location, role — to contribute effectively.

From Capability to Culture: Driving Adoption
Even when a virtualization system meets all these design principles, its success depends on people. Developers, testers, and integration experts must not only use virtualization — they must prefer it over traditional vehicle-based testing. That preference transforms virtualization from a promising tool into a lasting strategic advantage.

To foster this shift, organizations must focus on:

- **User Empowerment:** Provide hands-on training, clear documentation, and responsive support to build confidence and competence.
- **Workflow Alignment:** Ensure tools fit naturally into daily routines and existing toolchains.
- **Cultural Change:** Share success stories, encourage experimentation, and recognize teams who lead adoption.
- **Continuous Feedback:** Involve users in shaping the platform so it evolves alongside their needs.

When virtualization is not only technically superior but also trusted, preferred, and championed by its users, it stops being "just another system" — and becomes **the new standard for how modern vehicles are developed, tested, and brought to market.**

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Cloud-Native Approach: One Single Source of Truth

From centralized control to global collaboration

Traditionally, vehicle development revolved around a lead development center that created the platform or lead vehicle. This process depended on building and testing numerous prototypes, each representing only part of the final product's variance in the field. To cover as many configurations and corner cases as possible, test vehicles were shipped to suppliers, brands, and regional teams to develop or produce derivatives — but decision-making power remained concentrated at the central site.

This **centralized, sequential, and hardware-heavy model** no longer meets the demands of modern programs. Sequential development increases time to market and leads to errors discovered late, often only when testing vehicles in different markets and contexts. Fundamental software changes are required by different brands or users that have different functionalities. Resolving them can take months as teams confirm and reproduce issues across locations, then negotiate responsibilities for fixes.

To identify and resolve issues earlier — across all brands, markets, and configurations — development must be parallel and fully collaborative. A hardware-based approach would require an enormous and unsustainable increase in prototypes, while virtualization removes that bottleneck.

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With a **cloud-native virtualization platform**, geographically distributed teams can develop, test, and integrate in the same environment, on the same virtual prototypes, in real time. Error relevance and root cause can be confirmed in minutes instead of months. Global teams share a **single source of truth** where different R&D teams work together seamlessly.

Rather than physically co-locating teams in "project houses," cloud-native architectures enable virtual prototypes to be deployed instantly via global data centers or cloud infrastructure, with compute resources available on demand. This turns time zone differences into an advantage, enabling 24/7 testing and integration cycles, high-frequency collaboration, and seamless coordination across geographically distributed teams.

Faster resolution, fewer debates

In traditional distributed setups, reproducing an error found by one team can be time-consuming — even with advanced trace technology. Confirming its relevance and existence takes additional time, and resolving it requires a root cause analysis. In a cloud-native system, every team sees the same error conditions instantly and can test resolution strategies within a shared virtual environment. This eliminates months of back-and-forth over whether an issue exists, what's causing it, or which team should fix it.

Enabling automation and AI

A cloud-based virtualization framework also lays the groundwork for AI-assisted testing and integration. Many error detection, classification, and resolution steps can be automated — a leap that's nearly impossible with physical prototypes or HIL systems.

> In short, **cloud-native virtualization transforms distributed development from a logistical challenge into a competitive advantage,** enabling faster decisions, higher quality, and truly global collaboration.

Virtual Artifacts as the Key Deliverable – Software First

Deploying virtually first requires more than R&D buy-in. It demands cross-functional commitment: purchasing and legal teams must ensure that RFQs specify the delivery of virtual systems, while IT must provide globally accessible cloud infrastructure to include all relevant sites and suppliers in a holistic work environment.

In this model, virtual ECUs (vECUs) are delivered before any physical hardware. Only after the vECU has been validated in the virtual environment should a physical ECU be shipped to the prototype workshop — and then only if vehicle assembly is necessary. This shifts hardware validation from an investigative exercise into a final confirmation step, dramatically reducing costly rework.

Virtual work environments must remain agnostic to vECU modeling standards, allowing teams to choose modeling approaches that fit their needs. This freedom is essential for tailoring virtual systems to meet unique project needs and optimize performance. Testing environments should accommodate vECUs from a variety of sources to ensure integration and compatibility across platforms. OEMs can combine open-source components with ecosystem-aware commercial tools to define tailored toolchains, but must still enforce standardized interfaces and quality criteria to make virtual integration seamlesses.

Increasing the Speed of the Feedback Loop – The Right Test Strategy

Automation only delivers value if tests remain valid amid constant change. In a continuous development environment, daily modifications to features, requirements, architectures, and interfaces are inevitable. Automated testing must be resilient to these shifts, not just fast.

This necessitates a new standard in test design including separation of concerns, single source of truth and test logic abstraction. These principles, derived from modern software engineering — abstraction, encapsulation, and interface decoupling—are equally applicable to testing. Tests should go beyond binary pass/fail to provide actionable insights: which features are impacted, what dependencies are at risk, and where regressions may occur. Automated traceability is essential, enabling engineers and product owners to make informed decisions without manual investigation.

In a CI/CD framework, feedback speed depends more on test maintenance than execution. Tests must adapt quickly so that new features can be validated with minimal setup. Updates should align with ongoing implementation, and regression analysis should minimize reliance on manual deduction.

> Ultimately, this approach **ensures that testing keeps pace with development** — enabling quality assurance that is both scalable and fully integrated into the delivery pipeline.

Conclusion: Virtualization & Automation – Foundation for AI-Driven Integration

Virtualization enables a decisive shift from reactive, hardware-bound development to a proactive, software-first approach. When paired with automation, it becomes an integral part of the development lifecycle — reducing SOP delays, cutting R&D costs, and accelerating time-to-market. These are not just technical optimizations; they are strategic levers for restoring profitability and competitiveness in a CASE-driven industry.

A key advantage is parallelization: developers can verify and validate results without waiting for preliminary outputs from other departments. This concurrency shortens the product development cycle and enables faster launches.

The financial implications are significant. Large OEMs spend hundreds of millions of dollars each year on test vehicles, with at least half of that tied to software and electronics issues. Virtualization can cut these costs by at least 20%, and in some cases by 50–60%.

More critically, it reduces the risk of costly SOP delays—where a six-month delay can cost $1.5–2 billion. By cutting the likelihood of such delays in half, virtualization can deliver long-term EBIT gains of up to $1 billion. For BEVs, the combined effect on cost avoidance and material efficiency could exceed $2 billion.

In short, virtualization is both an immediate cost saver and a safeguard for launch timelines.

By embedding it — alongside automation — into the core development process, OEMs position themselves for higher profitability, faster innovation, and a stronger competitive edge.

Find out how Synopsys can help. Accelerate your automotive innovation today.

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