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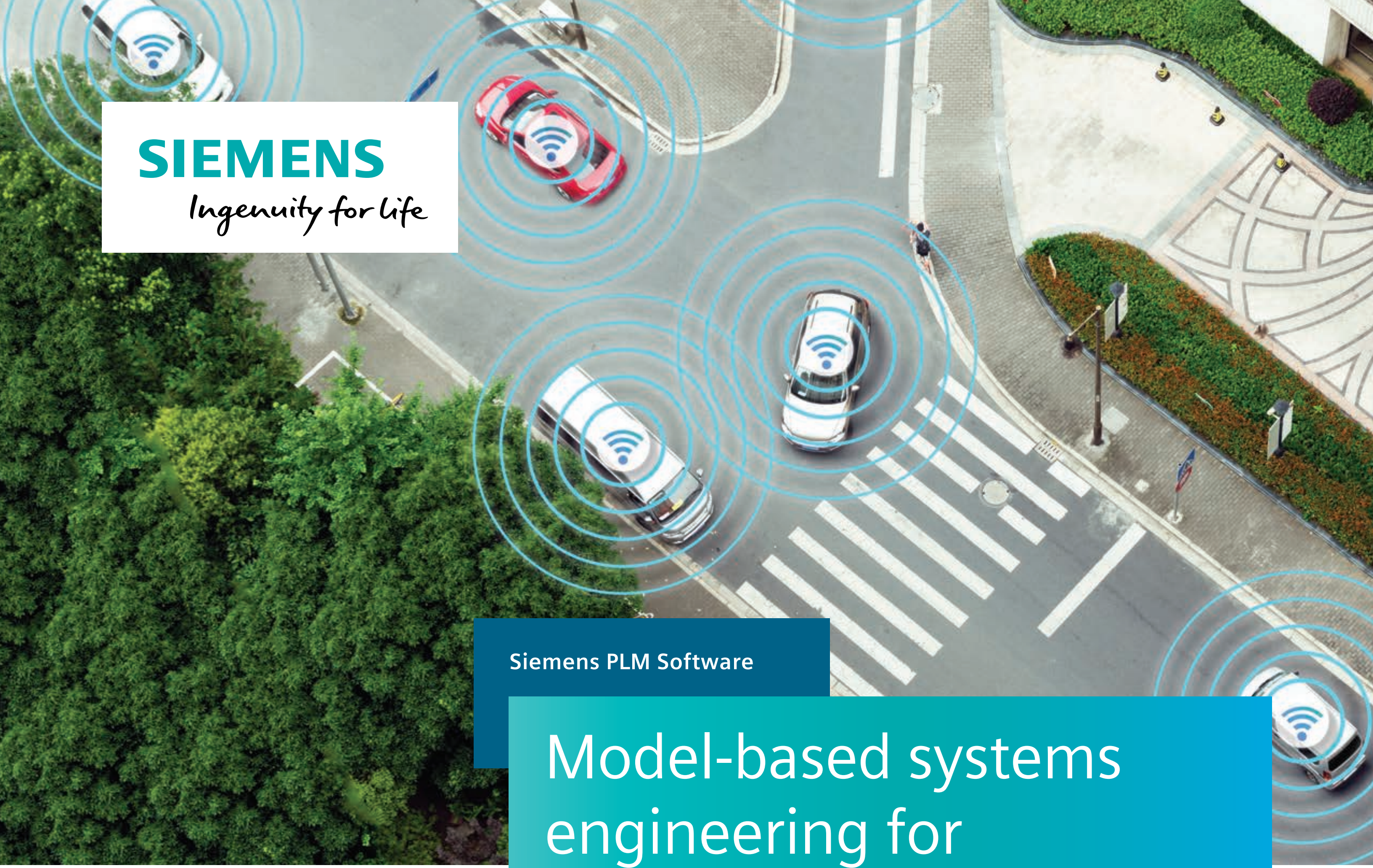

Siemens PLM Software

Model-based systems engineering for autonomous vehicle development

Executive summary

This paper examines disruptive innovations in the digitalization of the automotive industry, with a focus on the significant challenges posed by autonomous vehicles (AVs). Autonomous vehicles will require a radical transformation of the tools and processes for overall vehicle development. The industry can address the challenges with an integrated vehicle architecture complemented by a model-based systems engineering approach.

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Automotive technology trends

According to McKinsey, the last five years have seen a tenfold increase in vehicle software to control many aspects of vehicle behavior. This increase only partially covers advanced driver-assistance systems (ADASs) for a Level 2 vehicle. For example, the 2017 Ford F150 has exceeded 150 millions lines of software, a staggering number and one that will continue to grow as new features and services are added on the journey to autonomous driving.

In terms of market scale, an IHS study has projected an autonomous market of 21 million units by 2035. Other studies have suggested that within 10 years of regulatory approval, 95 percent of all passenger miles will be served by on-demand autonomous vehicles. And in terms of forecasting transportation-as-a-service, not only will most of the passenger miles be served by autonomous vehicles, they will be delivered at one-third of the cost of today's on-demand services.

The role of cars will dramatically change in the next 10 years from one of active travel to more of an entertainment or productivity service. Where currently the driver is still in charge and control, by 2025 the vehicle will take over most of the control. Vehicle interiors will become a design focus and the automobile will transform into a living room on wheels. Uber will move towards fully autonomous ride sharing so drivers will no longer be needed, and the company will expand into package delivery, hauling and transportation. In a fully autonomous world, everyone in New York City could be delivered to work in a two-hour period with less than five percent of today's vehicles. Consider the impact on productivity, the environment and the economy.

Self-driving cars will upend automobile ownership models, and force traditional manufacturers to think more like transport service providers, engineering vehicles for commercial fleets. Fleet maintenance and repairs will evolve to models more like the airline industry.

Vehicle-to-everything (V2X) connectivity will become essential to safe, reliable and efficient transportation services and enable automated driving. Vehicles will communicate with other vehicles (V2V), with roadway infrastructure (V2I) and with pedestrians (V2P) using real-time, reliable information flows. Vehicle-to-network (V2N) communications will enable open cloud computing to provide the connective tissue for smart transportation services. As the amount of data from vehicles grows exponentially, industry players must determine how to monetize that data into valuable products and services.

Challenges in autonomous vehicle development

The rapid development and convergence of technologies that enable self-driving automobiles present many new challenges for industry players. Chief among these are:

Trust and confidence

Overcoming the anxiety of giving total control to the vehicle is the key business problem of the automotive industry. The industry must convince consumers of their safety and reliability, because the stakes are so high for relinquishing

control. While the enabling technologies rush ahead, much work remains to be done to understand how people learn to trust AVs. The implementations of ADAS and AV features – how people interact with and understand them – are potential sources of distrust and uncertainty.

AVs must behave, communicate and react in a manner that makes it easier for people to trust them with their lives, not only as passengers, but also as pedestrians and drivers on the roads with them. The industry must go far beyond preaching the societal benefits and emerging business models to tackle the hard work of making people feel safe, confident, and comfortable when using driverless cars. The trust and confidence must be won at the component, systems, vehicle, and V2X communication levels, and by OEMs, suppliers, and third parties.

Vehicle certification

Achieving fully autonomous, Level 5 vehicle certification will not be feasible with physical testing. Toyota president and CEO Akio Toyoda has estimated that 8.8 billion miles of testing will be needed before its autonomous vehicles reach customers. With that volume, much of the testing will have to be virtualized and digitalized.

Before road testing of AVs begins, big data representing the ground truths of road, environment and traffic, along with regulatory databases, will help build virtual simulations and synthetic scenarios. Companies developing AVs will use a mixture of three environments for validation and verification (V&V):

- Purely virtual, with model-in-the loop (MiL) and software-in-the-loop (SiL) V&V for millions of scenarios
- Physical-virtual, with hardware-in-the-loop (HiL), driver-in-the-loop (DiL) and vehicle-in-the-loop (ViL)
- Physical, proving-ground field testing

The Roland Berger consultancy predicts that design validation will be a major – if not the largest – cost component in the overall development of automated systems.

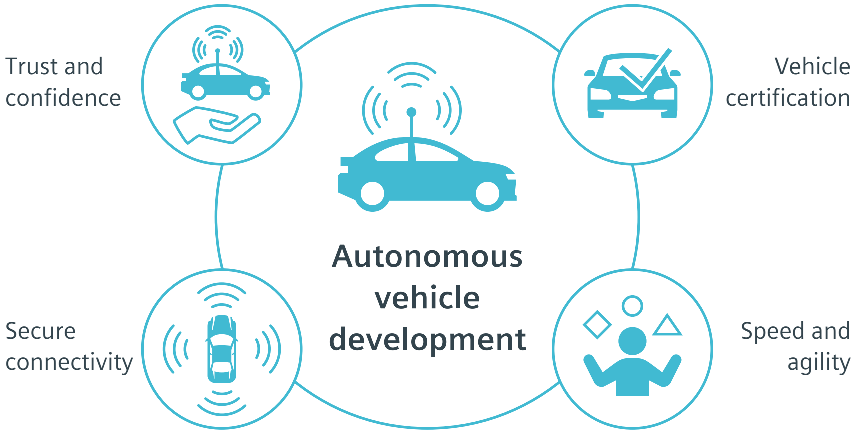
Secure connectivity

Autonomous vehicles will require inviolable defenses, performance and robustness. One of the key problems lies in safeguarding AV systems that depend on external connectivity platforms. On the road, autonomous vehicles will require connectivity to other vehicles and to infrastructure, and the safety and security of that connectivity is crucial. The industry must have tools to simulate and validate V2X communications and faults from hacking, cellular communication issues, infrastructure and system or software defects.

Speed and agility

There is formidable competition in the market for autonomous vehicles, not only among traditional automotive OEMs and their supply chains, but also from large technology companies, ride-sharing services and startups. Legacy practices that were used to develop traditional automobiles are a barrier for developing next-generation automotive solutions.

AV development will require a total systems engineering approach, with multi-domain systems modeling and comprehensive information continuity ("digital thread") tying all processes together. Although the potential benefits of successfully developing AVs are enormous, they can be realized only by companies who demonstrate unprecedented speed in development, and extreme agility in responding to rapid technological and market developments.



Critical challenges in autonomous vehicle development

The autonomous driving process

At a fundamental level, three capabilities are required for typical advanced driver-assistance system (ADAS) and autonomous vehicle (AV) features:

Sensing

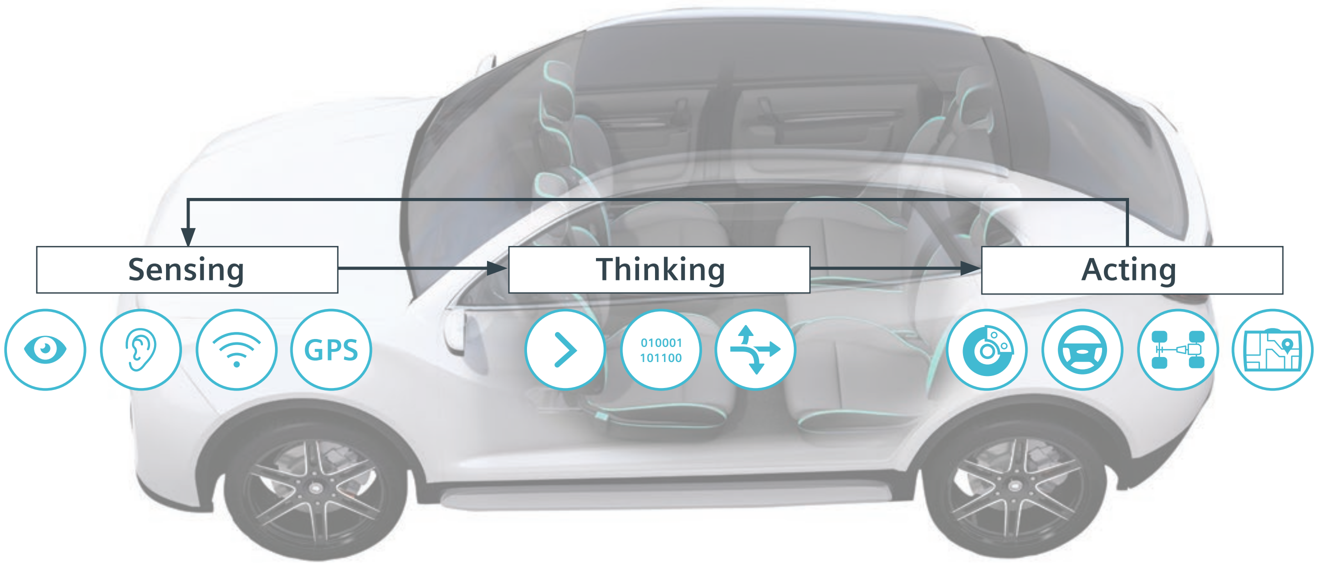
Autonomous vehicles must understand their environments, and this capability will require the integration of complex sensors. The leading 2016 vehicles with ADASs had, on average, 11 on-board image sensors (cameras, radar and LIDAR). A fully autonomous vehicle is expected to incorporate more than 25 image sensors, and the market for image sensors in the next ten years is expected to grow by 800 percent, from 65 million to over 500 million.

Thinking

Autonomous vehicles will need to be capable of fusing data from sensors and thinking intelligently through the scenarios within their environments. To realize this capability, companies must create highly sophisticated integrated circuits and software that will eventually replace the human/environment interface with on-board decision support, through which the machine understands its full 360-degree presence.

Acting

Vehicles must act in a safe, repeatable and reliable manner, with complex algorithms controlling steering, acceleration and braking. Custom silicon is essential to efficiently performing the complex algorithms for ADAS and autonomous driving. This silicon must be silicon-true, efficiently modeled and incorporated into the virtual test environment to definitively demonstrate compliance. Certifying this behavior will require exhaustive testing that includes coverage of staggering numbers of use cases. Because this level of testing is clearly not feasible, these complex problems will require a new approach for product development.



Rethinking the traditional development process

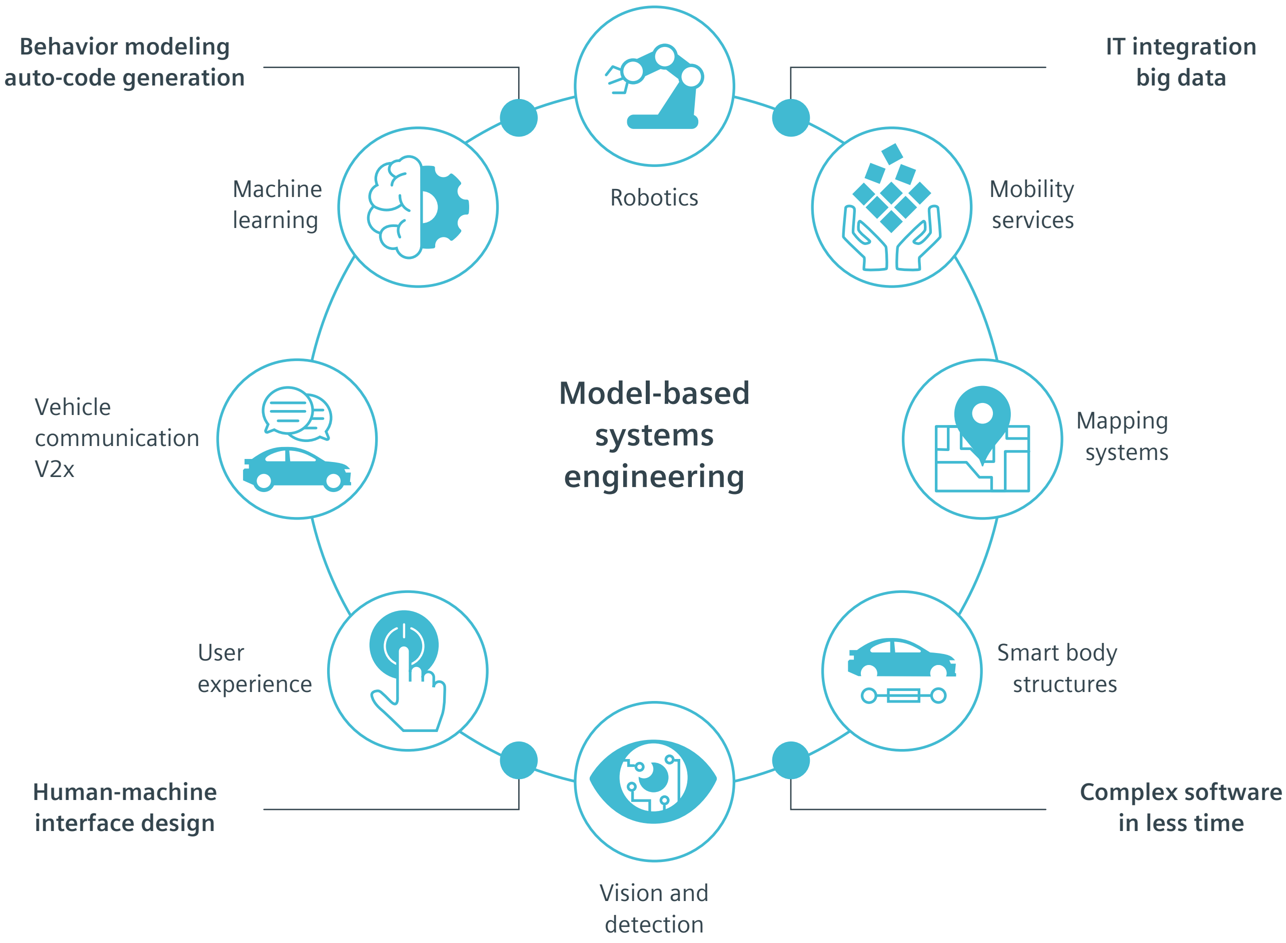
To address the challenges of autonomous vehicle development, automotive companies must rethink the traditional product development process, from their IT systems to the underlying methodologies. It is of limited use to formulate new vehicle solutions on traditional product lifycle management systems. Many companies recognize that traditional engineering and manufacturing approaches cannot provide the rapid time-to-value or accelerated development cycles that the market expects, and are formulating separate entities to move faster.

Traditionally, OEMs have established plaftorm teams responsible for the vehicle, powertrain and major subsystems of a family of products; now companies are shifting to create new mobility platform teams to integrate software and new services with the vehicle. This integration falls outside the realm of traditional development processes, which must adapt to the future challenge.

Model-based systems engineering

To develop future autonomous vehicles, companies must adopt model-based systems engineering (MBSE) methodologies. MBSE is a formalized application of modeling to support system requirements, analysis, design and validation and verification (V&V) activities, beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.

With the MBSE approach, engineers can capture the needed complexity and behaviors of advanced real-time features for autonomous vehicles; it enables development teams to understand an area of interest or concern and provide unambiguous communication among interested parties. Now more than ever, the MBSE approach is necessary to address the complex multidisciplinary, multi-domain process of autonomous vehicle development, which must meticulously orchestrate mechanical, electrical and electronic, and software and controls engineering.



MBSE is the methodology that accommodates the seismic shift of product development to software as the primary source of automotive innovation, and integrates control systems and electrical systems with hardware development processes. The approach can be leveraged by automotive companies to design-in safety and security, which is needed to reassure skeptical customers and meet unprecedented requirements for reliability and durability in autonomous vehicles. MBSE further assists with road-worthy certification of autonomus vehicles that can be acheived with smart digitialization of virtual simulation representing millions of scenarios. All of these factors require a fundamental shift to system-level modeling and simulation across engineering domains.

Most automotive engineering organizations have not yet fully adopted MBSE; they operate with hybrid approaches in which document-based engineering and model-based engineering coexist. Defining the scope of MBSE effort is an important task and should be clearly identified early in the process. This scope should explicitly specify what lies outside the boundary of the MBSE effort, and identify:

- Which functions of the system will be captured by the MBSE model and which will not
- Which form or components will be modeled, and which will not
- Which organizations will contribute and which will not be expected to

The key is to enable a robust digital thread connecting the engineering data capturing intent, behavior and scope of systems across the engineering and organizational domains and providing traceability from product definition to design and through production to how the vehicles perform in the field.

Digital innovation platform

The Siemens digitalization approach to MBSE brings together the much needed multi-domain product development – mechanical, electrical, electronic, controls and software – along with attribute optimization considerations across cost, quality, reliability, manufacturability and more.

Siemens provides a comprehensive toolset ecosystem on an engineering platform spanning mechanical, electrical, electronics and controls domains with product lifecycle management as the backbone for MBSE, and providing a consistent process framework for systems engineering across all development domains with an integrated definition of the product. This digital innovation platform brings together all cross-domain knowledge and makes it accessible to authorized users regardless of their organizational or geographic locations. To promote innovation, the platform enables multi-domain engineering teams to start integrated and stay integrated throughout the lifecycle of autonomous vehicles.

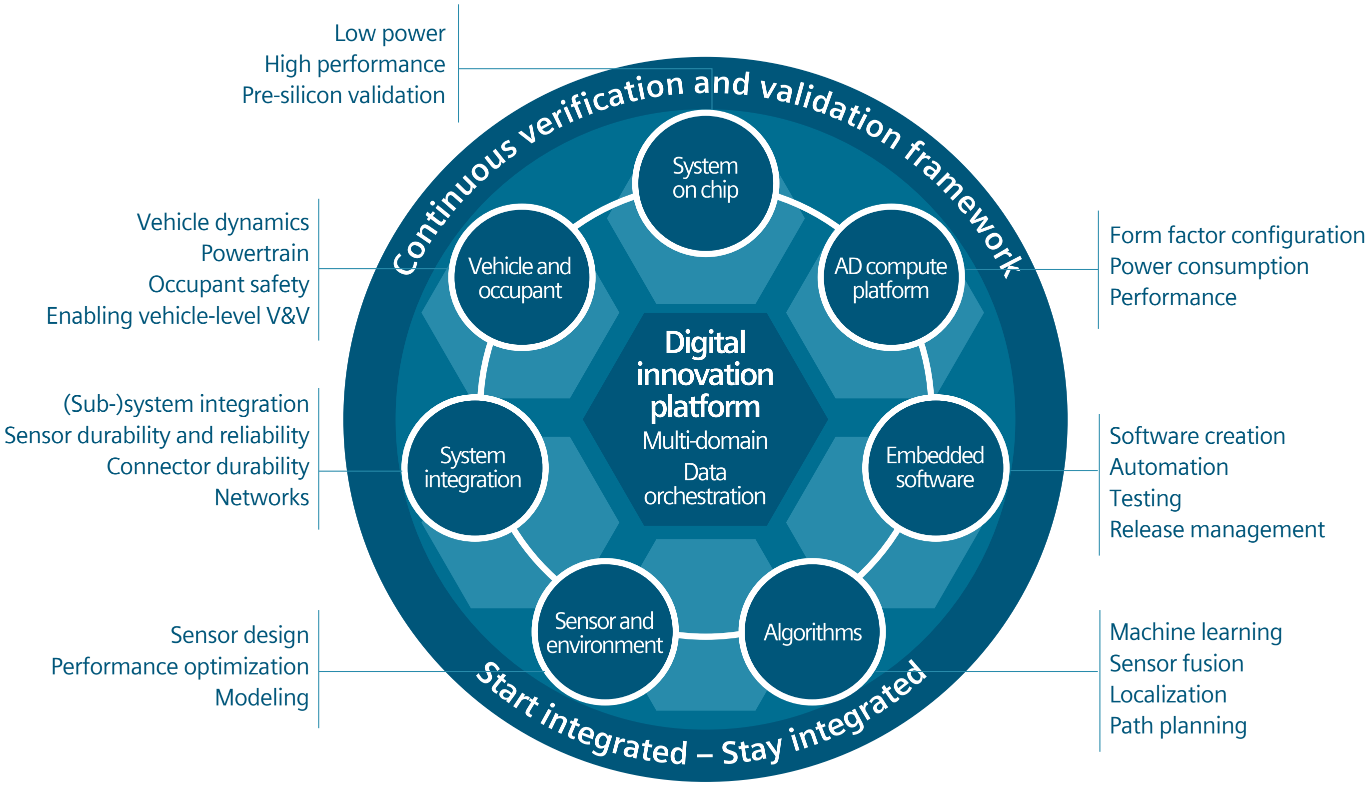
Key enablers of the digital innovation platform with MBSE approach include:

- Cross-discipline process and change orchestration to manage and coordinate all of the MBSE data and processes for advanced vehicle systems.
- Multi-domain traceability and configuration – from mechanics and physics through electronics and electrical to software and controls, the innovation platform integrates tools and processes for engineering autonomous vehicles, with full multi-domain traceability and configuration.
- Requirements management, verification and validation communicate requirements across all sources – regulations, industry standards, market needs, contractual commitments and consumer expectations – to guide teams in the development of next-generation automotive solutions. Companies can allocate requirements to domains or functions for decision-making visibility and accountability all the way down to verification and validation, with a closed loop back into design.

- Functional and systems modeling – comprehensive tools for modeling product architectures and systems. The system modeling environment captures, organizes and relates system functions and logic elements, establishing a cohesive view that communicates how everything fits together.
- Validation and verification – Given that it is impractical or impossible to physically validate AVs with billions of miles of testing scenarios, testing must be virtualized to a large extent to achieve the level of confidence needed for AV systems. Virtualization and digitalization also assists with the continuous and regressive nature of changes and improvements to complex control algorithms required in complex AV systems design. The Siemens innovation platform supports continuous validation and verification throughout the systems development lifecycle that guides planning and realization. From the decomposition of requirements and creation of system specifications to integration and decomposition of features and their validation, Siemens solutions deliver leading-edge tools for verifying development against requirements, validating that designs fulfill real-world and user needs, and managing V&V processes.
- Physics and mechanical engineering – Computer-aided design, engineering and manufacturing and a portfolio of simulation solutions offer leading technologies for designing, optimizing and engineering the mechanical and physical aspects of AV systems. These solutions seamlessly integrate across the product innovation platform, and have been proven in widespread use among automotive OEMs and suppliers.
- Electrical and electronics engineering – For engineering vehicle electronic and electrical systems and communications networks, the digital innovation platform includes solutions for printed circuit board (PCB) design, automotive system and network design, validation and testing, embedded software and electrical system and wire harness design. These solutions enable electrical architecture optimization for distributed software implementations that consider functional redundancies for safety and security, network bandwidth and overloading; signal/interface latency, CPU usage, wire content and more. The capabilities also allow for hardware consolidation and software function optimizations across multiple variants of vehicle builds for engineering and component cost and time savings. The tools are integrated with PLM and support cross-organizational and multi-domain collaboration.
- Software and controls engineering - Autonomous vehicles are software-intensive mechatronic systems integrating more than a hundred electronic control units (ECUs) connected through various types of networks. Autonomous driving will require some of the most complex software implementations that carmakers have ever faced, integrating information from sensors, traffic data from the cloud and data coming from other vehicles or infrastructure. The digital innovation platform must integrate solutions to support a virtual design, verification and validation process, including application lifecycle management for software development; embedded software design solutions for test-driven software modeling and coding, and embedded operating systems and autonomous computation development platforms.

Conclusion

The development of autonomous vehicles will require a comprehensive portfolio of integrated solutions for model-based systems engineering and a digital innovation platform supporting a comprehensive range of development tasks, from system-on-chip design, to systems integration across electrical, software and hardware, to vehicle- and occupant-level simulations.



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