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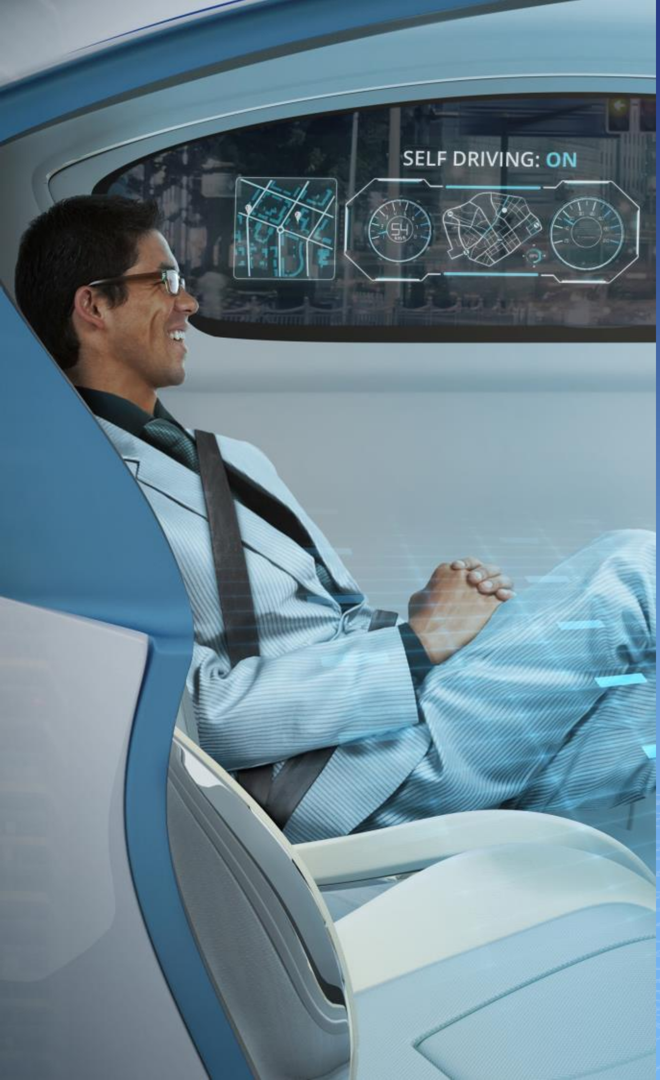

Autonomous Vehicle Development Requires Closed Loop Solutions

Autonomous Vehicles need multiple systems working together well beyond an individual vehicle

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Courtesy of Siemens

Takeaways

An enterprise-wide, even city-wide, integrated Model Based Systems Engineering approach is required for Autonomous Vehicle Development & Operations.

Takeaway #1
New sensors, embedded software, and computing advances are the building blocks that are enabling advanced driver assisted system (ADAS) features and eventually driverless autonomy vehicles. The exponential growth of vehicle-related electronics and software is changing vehicle differentiation, development, verification and validation, and lifecycle support.

Takeaway #2
To bridge the gap between today's advanced driver assisted systems and tomorrow's fully autonomous vehicles (AV), transportation management systems, from fleet coordination to traffic management, need to become connected with today's vehicles. Even sensing from other vehicles in the near vicinity will enhance autonomous vehicle capabilities.

Takeaway #3
Delivering reliable, safe autonomous and ADAS vehicles requires a data-driven, closed-loop development process and massive, continuous verification and validation processes for autonomous vehicle systems on multiple levels from the chip, to electronics, to the vehicle, and ultimately a city's infrastructure (from chip to city).

Takeaway #4
Only a fully integrated, complete lifecycle solution can move and sustain an automaker into a transportation leadership position for tomorrow. One that must be able to learn, adapt, and continually be enhanced to stay ahead of the competition.

Takeaway #5
Siemens' Digital Industries Software and Mobility solutions have been designed to keep teams integrated while improving and accelerating decision-making across the vehicle lifecycle. This in-turn enables an automaker to manage, define, connect, validate, enhance, re-validate, and ensure compliance across all the critical business domains, on premise or on the cloud.

Challenges: AVs Need Pervasive Sensing

Robust perception and planning capabilities lead to error free vehicle controls—supported by new solutions

Today's automotive industry is experiencing unprecedented changes with the emergence of rideshare services and partially autonomous vehicle (AV) capabilities. New, and often more agile disrupters are entering the automotive market from all sides, as they look to topple the status-quo. Its passengers are using transportation services rather than owning a vehicle. Safe AV operation with those passengers (with no human driver) needs broader real-time sensing and judgement capabilities. This forces automotive original equipment manufacturers (OEMs) and supply chain participants to reimagine and rethink how they design, manufacture, deliver, and operate their products. The automakers must keep an eye on potential disrupters who might enable pieces of the ultimate AV solution.

Vehicles have far more systems of systems as engineers implement IoT-enablement and connected vehicle communication systems. Vehicles must be aware of their surroundings to make safe, quick, and robust driving decisions. Replacing the driver's actions such as lane following, parking, steering, braking, and accelerating, with electro-mechanical subsystems has already been delivered to consumers. These technologies have been developed with the emergence of controlling electronics and on-board software. Most of these technologies are quite mature and, in many cases, less expensive and more reliable than the mechanical systems they replaced.

Automotive software, both on-vehicle and off-vehicle, is where significant innovation is happening. Furthermore, vehicle services and software upgrades are occurring after the vehicle is manufactured. Offering additional features and services that are introduced and improved during the lifetime of the vehicle will generate new revenue streams.

In a recent eBook, CIMdata presented the need automakers and their supplier network have for a modern systems engineering approach and show how Siemens Digital Industries Software (Siemens), a proven software and service provider for the automotive industry, is enabling a highly integrated MBSE approach, Software & Systems Engineering (SSE).* This approach has been designed to address evolving challenges in new and innovative ways. According to Siemens, "…complexity in the automotive industry demands continuous engineering across domains, and to be successful, a company must start integrated and stay integrated." Only a more end-to-end and integrated approach is going to get the job done.

Sensors to see and feel are also prevalent in today's vehicles. As sensing expands, assisted driving (i.e., the combination of sensing and actuation) begins to assist the driver. This is summarized in the SAE Advanced Driver Assistance Systems definition, as illustrated in Figure 1.

Level 3 products are coming to market in the next few years, and we appear to be approaching a ***tipping point*** where we start to replace the human driver. Sensing will continue to expand within the vehicles. But this might well be extended with sensing from the operational environment (i.e., from street level, other vehicles, city-wide, and regionwide traffic management systems).

Figure 1—SAE ADAS Levels: Tipping Point to AVs

Courtesy of SAE

* See: https://www.cimdata.com/en/news/item/14646-driving-the-change-for-the-future-of-automotive-development-ebook

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Autonomous Vehicle Operation Transcends Individual Products

Systems of Systems is broader than one vehicle

With Autonomous Vehicle development, integrating the sensing, communications network, and traffic management beyond the individual vehicle will further improve operational safety. With no driver, operations must be as safe as with a driver and probably safer if all crashes are to be avoided.

Apart from self-driving technology in the vehicle, it is likely that infrastructure-based systems will contribute to the safety and traffic performance of the future mobility environment. Vehicles become nodes in networks, just as there will be infrastructure-based nodes. All nodes share information with each other. This is already happening in commercial fleets as varied as agriculture and package delivery. A systems engineering view of these different systems' boundary diagrams shows that the vehicle is now a sub-system of a connected transportation service. The services provided are changing as quickly as the pace of software and computing technology advances rather than capital-intensive mass production.

Tackling this requires Systems Design Thinking, making sure the AVs are robust in all their operational scenarios. This includes those not yet foreseen and requiring increased vigilance of the competition. Leading and managing this complexity requires integrated MBSE processes and tools, combining product development, operations, learning, and adaptation into a continuous process.

Automakers are quickly adopting new propulsion technologies, assisted driving, and in a few cases pivoting their whole focus. General Motors has identified its vision as **Zero Congestion, Zero Crashes, and Zero Emissions**.

Think of the features required to deliver **Zero Congestion**—not just autonomous vehicles but also traffic management services moving you along the safest path, maybe even one with the preferred scenic views. These kinds of features will likely enter the marketplace in fragmented ways—different times and different locales since the capabilities required will be impossible to deliver everywhere at one time. Considerations for validating a SAE ADAS Level 4 or Level 5 vehicle requires new ways of developing flexible and robust systems while taking advantage of expanded sensing to improve overall situational awareness, as shown in Figure 2. PLM solutions must support the complete lifecycle bringing operational and manufacturing considerations together with product development and field enhancements.

In this eBook, CIMdata explains how Siemens supports Autonomous Vehicle Development and Operations by focusing on performance engineering, connectedness beyond a single vehicle, and systems of systems development.

Figure 2—AVs Become Aware of Pedestrians While Operating in Connected Transportation Systems *Courtesy of Siemens*

PLM Managed Models and Usage Data Provides Closed-Loop Views

Systems of systems learning & adapting continuously

Automotive software will expand even faster as connectivity becomes ubiquitous. The design, manufacture, delivery, and support of competitive vehicles has required modern PLM solutions to enable cost effective mass production. Adoption of ADAS equipped products are at a critical inflection point leading to automatic vehicle operation allowing passengers to ride in comfort with no responsibility for driving.

SAE ADAS Level 2 and 3 equipped vehicles' complexity pale in comparison to that of level 4 or 5 AVs. Automotive software is enabling broader connectivity (both inside and outside the vehicle), improved sensing on and around vehicles, and increased "thinking." This "thinking" will expand as computing horsepower for input processing and control actuation becomes less expensive. Figure 3 depicts the connected AV.

Note the features enabled, some with the advent of onboard computers, but others with fast connections to other vehicles and transportation management systems and their computers.

AV features will be implemented by algorithms spanning these domains. Figure 4 shows the benefit of cloud architectures connecting sensors, products, experiences and beyond.

Now imagine the expanding value of IoT when the insights are measurements from other vehicles and city traffic management systems. Then there will be active management and maintenance features where Artificial Intelligence (AI) and Machine Learning (ML) occurs in the cloud and may be shared by all participants in the cityscape. To properly address the growing systems of systems complexity, PLM solutions will need to comprehend AV and city networking, interfaces, and cloud architectures. A development and operational process revolution focused on all these elements and the organizations operating AVs will be required. Integrated MBSE can help by improving the context of experiences from many vehicles in simultaneous use.

Product software is used today to control the vehicle, connect the vehicle to the owner and service organizations, as well as sense what is happening around the vehicle. All AV functional driving features (formerly relying on human seeing, listening, decision making, and hand/foot controls) will be automated by more electronic components and software. Software across the AV domains (vehicle, traffic systems, and improving sensors) will become the significant differentiator. Ultimately, PLM solutions must enable and enhance the development and adaptability of the AV systems of systems by creating a closed loop development process that seamlessly integrates recorded data and simulation results with models to improve systems' understanding.

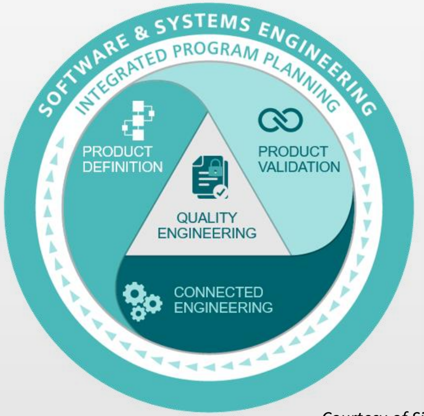
Figure 3—AVs Need Connectivity

Courtesy of GM Shanghai

Figure 4— Products, Smartly Connected via Clouds

PLM solution support continuous learning

Siemens Software & Systems Engineering (SSE) solutions directly support product development and validation of vehicles that have more and more embedded software and electronics. The explanation of these solutions was summarized in a previous eBook published last November.* Figure 5 summarizes that integrated capability.



Courtesy of Siemens

Figure 5—Key Pillars of Software & Systems Engineering

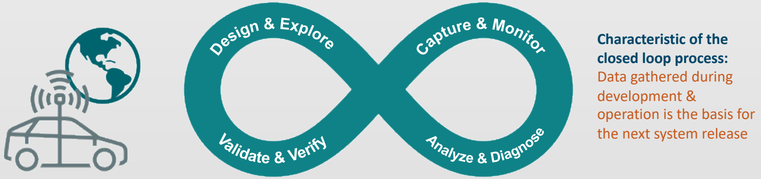
How then do AV development, validation, and upgrades benefit from SSE? Siemens has identified a DevOps-based vision where there are continuous learning and adjustment to products. See the infinity loop and the four phases connected as a closed loop in Figure 6. Data gathered during development and operation is the basis for the next release. Learning and adaptation are as important as development and manufacturing. This is the basis for Siemens Autonomous Vehicle Development (AVD) platform built upon their Xcelerator family of solutions.

The automotive industry has done this for decades over product lifecycles covering a few years—learnings from the field applied well to new product features and appearing in the next model is the automakers' best practice. This was constrained by the time and capital investment in mechanical and electronics manufacturing. With AVs, when a new feature is enabled with just software or an after-mass-production sensor kit, the constraint becomes the ability to validate the new configuration of features spanning the domains from chips to controllers to vehicles to cities.

Let's consider three topics:

- Systems of systems
- Connectedness
- Performance engineering

AV development and operations need the capabilities Siemens' AVD provides—a PLM ecosystem that connects people, product data, and processes across disciplines and around the globe. It fosters continuous learning and producing greater products and their adaptations faster.



Courtesy of Siemens

Figure 6—Siemens AVD—Infinity Learning Cycles

* SSE eBook: https://www.cimdata.com/en/news/item/14646-driving-the-change-for-the-future-of-automotive-development-ebook

Engineering Beyond Individual Vehicles

AV systems of systems development Is broad

There remains a gap in the journey from today's Level 1, 2, and 3 ADAS capabilities to capabilities needed for a fully AV, see Figure 7. With AV development, integrating the sensing, communications network, and traffic management beyond the vehicle will be required to bridge this gap. Complexity grows as connecting vehicles to different infrastructures expands.

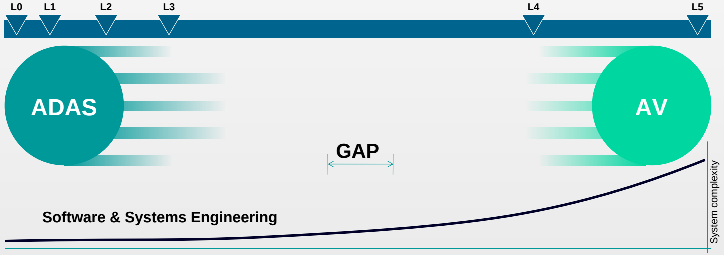


Figure 7—ADAS to AV is Not an incremental Progression

Courtesy of Siemens

Connected transportation systems with AVs go beyond the boundary of an individual vehicle. Complexity is caused when connecting vehicles to different infrastructures—starting with service and moving quickly toward travel efficiency. A systems engineering view of these different systems' boundary diagrams shows that the vehicle is now a sub-system of a connected transportation service.

The embedded computers are located onboard and in the cloud. Yes, IT departments managing cloud installations, both at OEMs and cities, will need to be part of the future transportation services leveraging integrated MBSE. They need a framework that allows dynamic configurations of services using proven and new components. The framework helps organize the development, testing, and packaging of future transportation services.

Siemens has capabilities that enable co-development using the Arcadia method, shown in Figure 8. An individual AV will be a subsystem at the physical layer with features enabled across all layers. The operational analysis will vary depending on the locale. Automakers will need these techniques that originated in defense industries. Siemens combines integrated MBSE and the Arcadia methods providing the framework for AV development and operations.

Tackling this requires Systems Design Thinking, making sure the AVs are robust in all their operational scenarios. This includes those not yet foreseen and requires increased vigilance of the competition. Leading and managing this complexity requires integrated MBSE processes and tools, combining product development, operations, learning, and adaptation into a continuous process. An architectural framework allows different disciplines to develop their systems in parallel, even asynchronously.

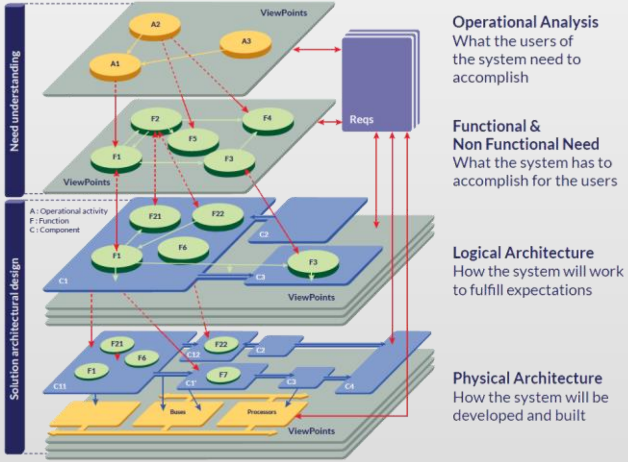


Figure 8 — AVs Need Architectural Frameworks

Courtesy of eclipse.org

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Connectedness Enables Learning & Adaptation

Electronics & high-speed networks make connectedness continuous

Siemens' Xcelerator platform provides tools that ease the engineering and production of vehicles with more electronics, whether for more and new types of sensors or new types of off-board communications. As stated earlier, AVs will use AI/ML with powerful computing platforms both within the vehicle and provided as a service from the city. How are these AV subsystems engineered to work within the larger city level systems? How will the AV adapt as new operational ecosystems are encountered? Connections are required during development and operations. Not just communications networks, but design traceability as well.

In previous commentaries and interviews CIMdata explained the importance of the synergies between engineering and manufacturing disciplines. How Siemens delivers integrated E/E Development capabilities, using a common Product Configurator with the mechanical engineering development tools, was covered in 2020. The summary from that commentary stated—"Capital is the comprehensive Electrical/Electronic Systems development solution within Xcelerator. This solution portfolio includes direct support of systems, electrical, networks, and software development—all technologies core to today's complex vehicles. Transparency across discipline silos improves product decisions during development, manufacturing, and operations. Expansion of Siemens' Capital solution brings new levels of integration for holistic engineering. Systems engineers are more empowered to help the software, mechanical, and electrical disciplines understand their operating context, which in turn improves the speed and accuracy of decisions. With this solution customers will see improved time to market as all engineers together make better decisions faster."

Siemens Xcelerator elements—Capital and Polarion, ease the work to translate a functional architecture of a mobility network into vehicles with E/E, network, and software architectures. Maintaining traceability between all architectural elements becomes increasingly critical to guarantee complex wire harness design, optimized network design, and efficient embedded software implementations. Think of this as connected architectural contexts maintained across the product lifecycle. It is a framework to explore learnings, advances, and adaptations.

Making AV connectedness continuous requires an understanding of systems and subsystems development and integration from electronics containing chips to on-board computers to cities and beyond. Siemens' vision of how their AVD addresses this is shown in Figure 9.

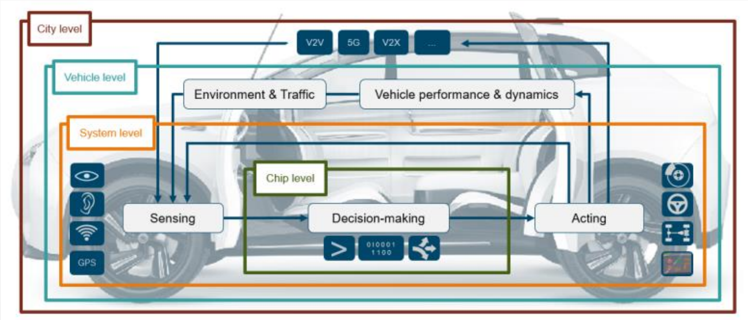

Figure 9—Systems of Systems AV Product Development

Courtesy of Siemens

Enabling AV adaptation via in-field upgrades using Over-The-Air re-programming capabilities to refresh vehicle software requires coordinating a release with back-office computer services (e.g., traffic management, route planning, and tele-communications connections). This will make **connectedness continuous**—always there, learning, and then deciding if adaptation is needed.

Vehicle to vehicle communications of position, direction, and immediate congestion will enable groups of AVs to maneuver more effectively. Effective transportation is measured by performance measures. Architectural frameworks, a chip-to-city mindset, and constant learning will redefine what vehicle performance engineering means in the future.

* See: https://www.cimdata.com/en/resources/complimentary-reports-research/commentaries/item/14411-capital-expansion-addresses-e-e-systems-complexity-commentary

Performance Engineering Solves AV Challenges

Affordable validation requires focused test scenarios

Some automaker executives have claimed AVs require billions of miles of testing to achieve a salable, certified product. On the other hand, software systems with millions of lines of code rely on automated, daily test suites where anomalies are detected automatically. Quality teams then assess and often adjust the next release, which is provided in a few days, not years. Performance engineering goes beyond verification test suites and includes an assessment of varying conditions like weather, velocities, road condition, friction, and many more.

Siemens understands the challenge of thorough, useful testing and has assembled their verification and validation solutions to cover the complete AV domain, see Figure 10. Automating the creation of scenario variations, simulation run orchestration, execution, assessment and post-processing into digestible reports is required to accomplish affordable validation.

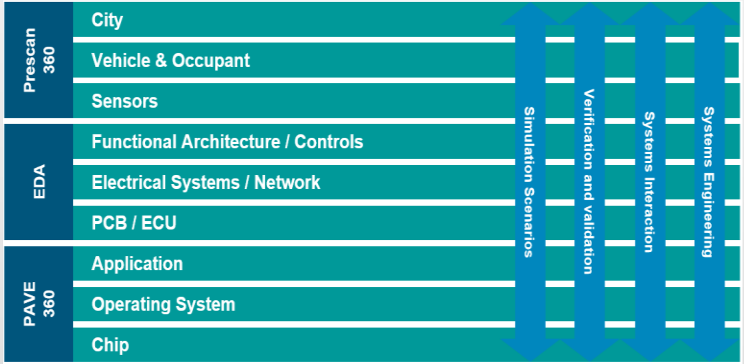

Figure 10 — PAVE360/EDA/PRESCAN360 Provides Verification and Validation from Chip to City

Courtesy of Siemens

Furthermore, Siemens AVD encompasses solutions to add a functional performance testing capability within the embedded software environment, being able to run repeatable functional performance tests with varying boundary conditions. Accurate models of the vehicle, the sensors and the environment are captured in simulation, enabling faster than real time evaluation in a cluster or cloud. Thousands of miles of testing can be done in a fraction of the time driving would entail.

As automated transportation becomes a service, instead of vehicle ownership, the operational data collected gets used increasingly to improve overall travel efficiency. Furthermore, learning through identification, creation, and management of new scenarios based on current field measurements will be essential to provide product and service validation affordably. As new features are developed across the AV framework, they are validated using the latest experiences.

Performance Engineering has always focused on what customers value—safety, fun, luxury, lifestyles. Performance engineering for AVs needs to:

- Look into a much bigger safety case since there is no driver as fallback in an unexpected emergency situation.
- Realize passenger comfort criteria will change. People will look differently at a Mobility as a Service vehicle. How important will leather and wood interiors be when you ask for a ride?
- The accelerating pace of changing consumer tastes, thus the need to adjust performance measures will change at a faster and faster pace.

AV performance engineering will be more sensitive to consumer values as they will move from car performance and status symbol to human safety, responsibility, and convenience (e.g., Zero Crashes, Zero Congestion, Zero Emissions).

Siemens AVD solutions provide test creation and management capabilities for execution and correlation studies at all levels of AV design and operations, utilizing a unique combination of local and cloud-based technologies.

Siemens AVD Brings Digitalization to AVs Development

Siemens AVD is the enterprise-wide digitalization solution enabling development processes from Chip to City

Today's leading automotive companies' challenges can no longer be solved with yesterday's solutions, nor by throwing more miles of testing at the problem. Tomorrow's automakers designing, producing, and operating AVs must manage the increased complexity of integrating their products within an overall transportation ecosystem. AVs are realistically possible when sensing becomes shared, and the guidance and insights of traffic flow help avoid congestion. To strive and thrive, a fully integrated enterprise PLM approach must be taken to move and sustain an automaker into a leadership position for tomorrow—one that starts integrated and stays integrated across the enterprise and supply-chains as well as from individual vehicles and their Chips to Cities where they operate. The AV automaker must learn, adapt, and adjust continually to stay ahead of its competition.

Solutions must provide closed-loop development processes which encourage learning across the complete lifecycle. The interaction of all the systems of systems throughout today's rapidly evolving transportation networks must be addressed. Comprehensive configuration management is a keystone to effective and integrated MBSE within PLM solutions. Siemens' AVD[1] is a PLM platform with an integrated MBSE-enabling solution, designed to keep teams integrated from start to finish, leveraging cloud-based collaboration technology, allowing you to improve decision-making across an extended enterprise if the AV is in operation.

Leading automotive companies have used Siemens' solutions for more than 30 years, starting with drawings, moving to geometric models for both products and their factories, then managing simulations to replace physical prototype evaluations. It comes as no surprise that Siemens has now assembled what the automakers need for the next innovative wave of Autonomous Vehicles.

[1] See:<https://www.plm.automation.siemens.com/global/en/industries/automotive-transportation/autonomous-vehicles.html>

CIMdata has previously summarized specific SSE capabilities.[2,3,4,5] In this eBook, AV challenges and how Siemens is addressing them have been introduced. A broad ***systems of systems*** architectural framework, enterprise and interactive ***connectedness***, and refined ***performance engineering*** are needed for successful autonomous vehicle development. Commentaries covering each of these topics will be available soon.

AV development requires all the Siemens capabilities and the coordination with architecture methods like Arcadia to propel automakers into the future. Siemens' mobility solutions help companies operate fleets and city traffic systems. Ultimately, Siemens enables a holistic Digital Thread for the complete AV life that allows an automaker's transportation products and services to be future-proof, despite the complexities inherent with autonomous vehicle development and operations.

[2] SSE eBook: https://www.cimdata.com/en/news/item/14646-driving-the-change-for-the-future-of-automotive-development-ebook
[3] Product Validation Commentary: https://www.cimdata.com/en/resources/complimentary-reports-research/commentaries/item/15189-mbse-product-validation-as-part-of-a-closed-loop-vehicle-lifecycle-commentary
[4] Product Definition: https://www.cimdata.com/en/resources/complimentary-reports-research/commentaries/item/14794-product-definition-drives-integrated-mbse-commentary
[5] E/E Connected Engineering: https://www.cimdata.com/en/resources/complimentary-reports-research/commentaries/item/14887-connected-engineering-accelerates-innovation-commentary

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