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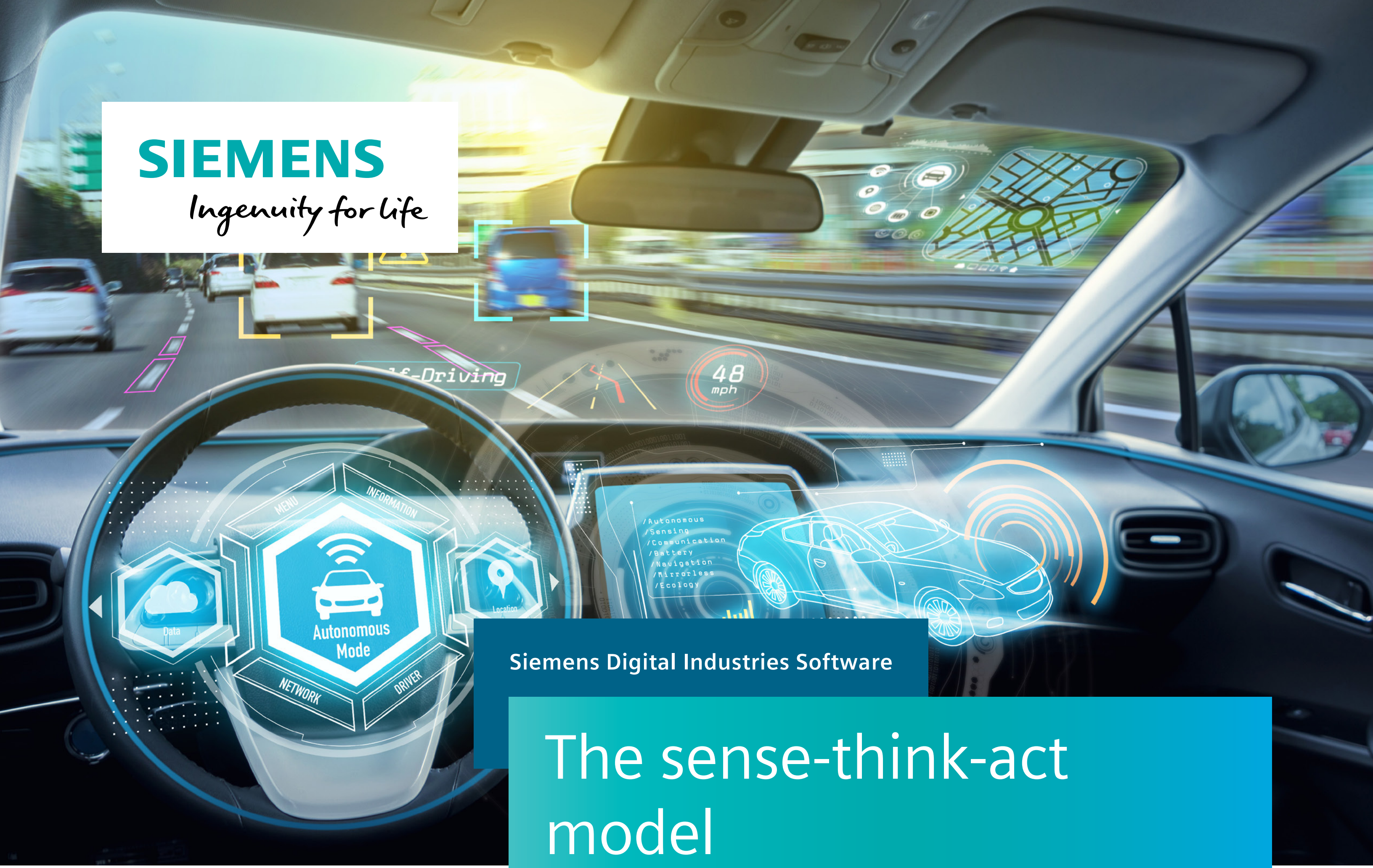

Siemens Digital Industries Software

The sense-think-act model

Accelerating design and validation of autonomous vehicles

Executive summary

Autonomous vehicles will play an essential role in future mobility. Yet even though certain autonomous functions, specifically driver assist and active safety features, have started to show up in some of the latest cars, taking the next step to fully self-driving cars will be a challenge. We have now arrived at the critical point where the vehicle takes over control from the driver and the software tends to become more important than the mechanics. This has serious implications, not the least of which are the way vehicles are designed. Guaranteeing safety-critical, sense-think-act functions requires new development paradigms and engineering methodologies.

Puneet Sinha, Mentor, A Siemens business

Abstract

Car manufacturers need to revolutionize their processes to avoid losing business to new market players who are eager to take their place. In this white paper, we discuss the challenges of developing functionality for critical hardware and software for autonomous vehicles and describe the technology components that are required to accomplish that. For each development step, we propose appropriate approaches, tools and methodologies that can support the sense-think-act paradigm for automotive original equipment manufacturers (OEMS) and suppliers with dedicated simulation software and testing solutions, as well as specialized services.

The rapidly changing automotive industry

During the past two decades, digitization has taken off and brought applications to our daily lives that we never thought possible. Perhaps the first ones to catch the eye are the functions and services we enjoy with our smartphones. You can hardly buy a device these days that doesn't have a small computer in it, which makes it self-regulating or smart and lets you communicate with it. We have seen this rapid evolution in the automotive industry as well. Around the turn of the century, features such as a telephone in the car, a Global Positioning System (GPS) and all kinds of electronic systems for comfort, safety and drivability were often considered exotic applications or expensive options. These are now almost standard equipment, even in midrange and entry-level cars.

This has more consequences than we sometimes realize. About 20 years ago, mechanical parts in cars were still dominant. Yet that is slowly but certainly changing. Today's vehicles include more than 150 electronic control units (ECUs) with accompanying software, good for one-third or more of their total cost.[1] The automotive industry is well on course to having about 50 percent of its cost driven by electronics content by 2030.[2] Software content in cars is expected to triple by 2030.[3] This dramatically increases the number of requirements to be validated. As a result, digital solutions that were formerly applied to save costs by front-loading design decisions have now become indispensable for coping with growing development complexity.

As such, we've arrived on the eve of a revolution in the automotive sector, catalyzed by electrification, vehicle autonomy and connectivity. In recent years, a largely staid automotive industry and its supply chain has exploded with new startups, collaborations and disruptions in a supply chain driven by these megatrends. Currently, there are more than 400 companies, including established automotive OEMs and startups, developing electric cars and light-duty trucks and more than 200 companies with announced autonomous driving programs (figure 1).

Paving the pathway to autonomous vehicles
Although advanced driver-assistance systems (ADAS) such as pedestrian detection, adaptive cruise control, collision avoidance, lane correction, automated parking and more are gradually becoming commonplace, fully autonomous cars (level 4/5, see figure 2) are already being tested on roads. Once the right conditions are in place, the revolution can start.

The biggest impediments at this point are governments, which must work on legislation and infrastructure, and with consumers, who must overcome their fear of relinquishing control. Putting your safety in the hands of a machine while driving 120 kilometers per hour (km/h) on the highway requires safety guarantees that will give consumers peace of mind. Researchers are still somewhat careful about making precise predictions, exactly because of the previously mentioned uncertainties, but there is a consensus that autonomous vehicles will represent a significant proportion of the market by 2030 (up to 15 percent according to McKinsey),[4] even in the most prudent scenarios.

Later in this white paper, we will look in a more systematic way at the definition of autonomous vehicles, and the tools that exist to support their development. It summarizes the technology focus areas to pave the pathway for mass introduction by 2030.

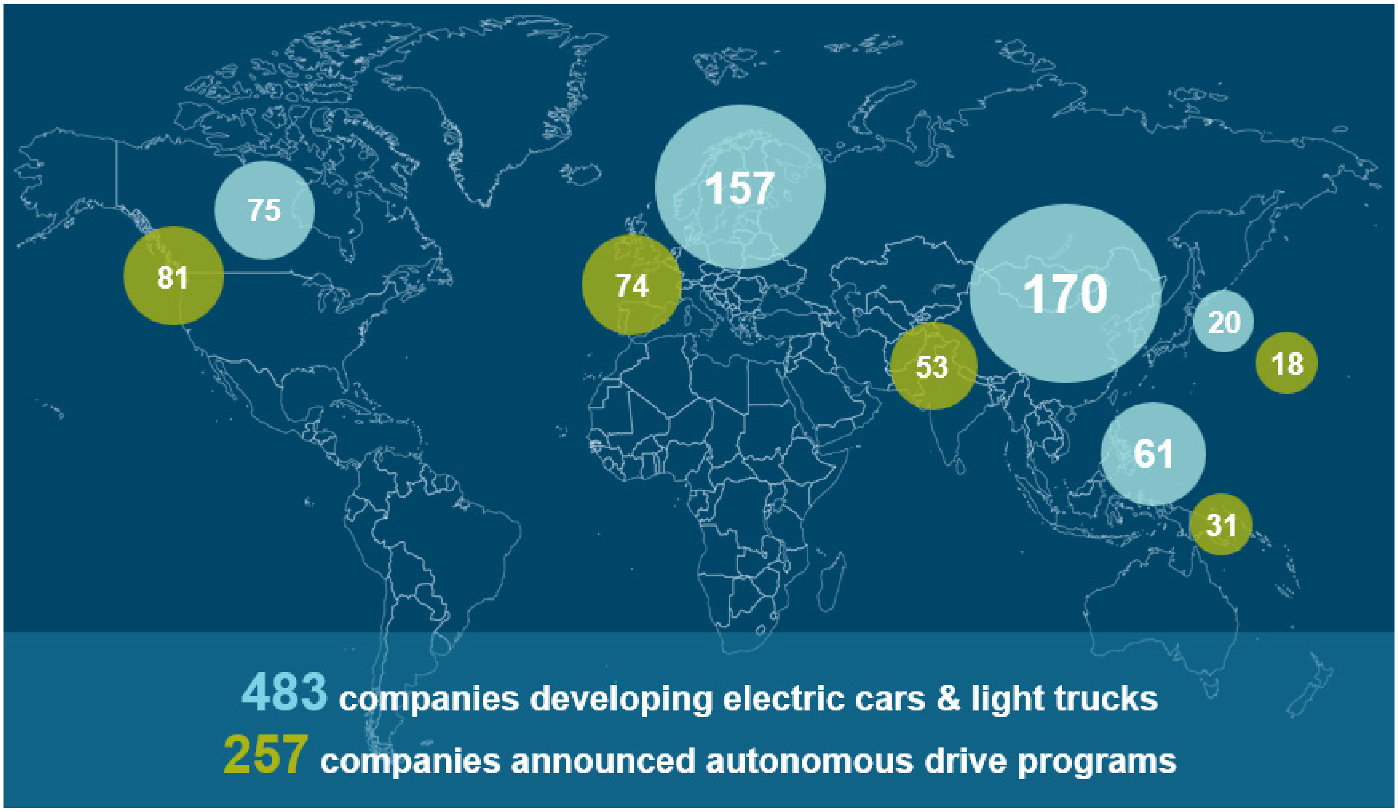

Figure 1. The changing automotive landscape with vehicle electrification and autonomy with 483 OEMs developing electric cars and light-duty trucks and 257 OEMs developing autonomous driving technology (per Siemens internal analysis).

The challenges inherent to autonomy levels

Of course, the transition to autonomous vehicles is not a binary process. Therefore, it's important to keep consistent, standardized definitions whenever discussing the subject. Autonomous driving levels as defined by SAE International standard J30165 are summarized in figure 2.

Looking at this classification and where vehicles on the market are today, it's fair to say that level 2 autonomy is already quite common. Currently, level 3 exists to some extent but will still have to become mainstream in the coming years. Levels 4 and 5 are still largely in the testing phase.

However, moving to levels 4 and 5 will be quite a step. In that case, the role of the car will become, at least in certain circumstances/scenarios, more important than the role of the driver. That means the vehicle must be fully capable of observing the environment, interpreting it, making decisions quickly and acting accordingly. However, being able to do all this as well as the best possible driver won't even be enough. The self-driving car will have to do much better, because every wrong decision, incident and accident will be closely monitored and can be extremely harmful for the manufacturer or even for the entire industry. Negative publicity because of technology miscues can cause serious delays for the entire market introduction process of autonomous vehicles.

But that's not the only difficulty. After all, the transfer of control also shifts responsibility from the driver to the vehicle OEM, or to other stakeholders in the vehicle lifecycle management process. Imagine the complexity when something happens, for example, in terms of insurance. Therefore, OEMs must be able to prove the performance of the vehicles has been tested in all possible scenarios and circumstances, such as inclement weather and poor road conditions. Theoretically, this means billions of testing miles. So autonomous cars will be tested more virtually than physically, and this will probably be the largest cost item during the entire engineering process.

Finally, moving to levels 4 and 5, the role of software will become dominant over mechanics. That means functionality will be heavily driven by intelligence rather than vehicle hardware components. Consequently, OEMs will need to move to an engineering process in which their vehicles can get upgrades; for example, to improve their performance or adapt to a changing environment. In practice, that means they need tools that allow product design to continue after delivery. They will need a managed approach supported by powerful product and application lifecycle management (ALM) solutions, in which they can keep track of all individual products and study the impact of upgrades on the vehicle's performance and certification.

The next sections discuss how currently OEMs and their suppliers are working on functions that take over tasks from the driver, the challenges they face, and which technologies exist to support them.

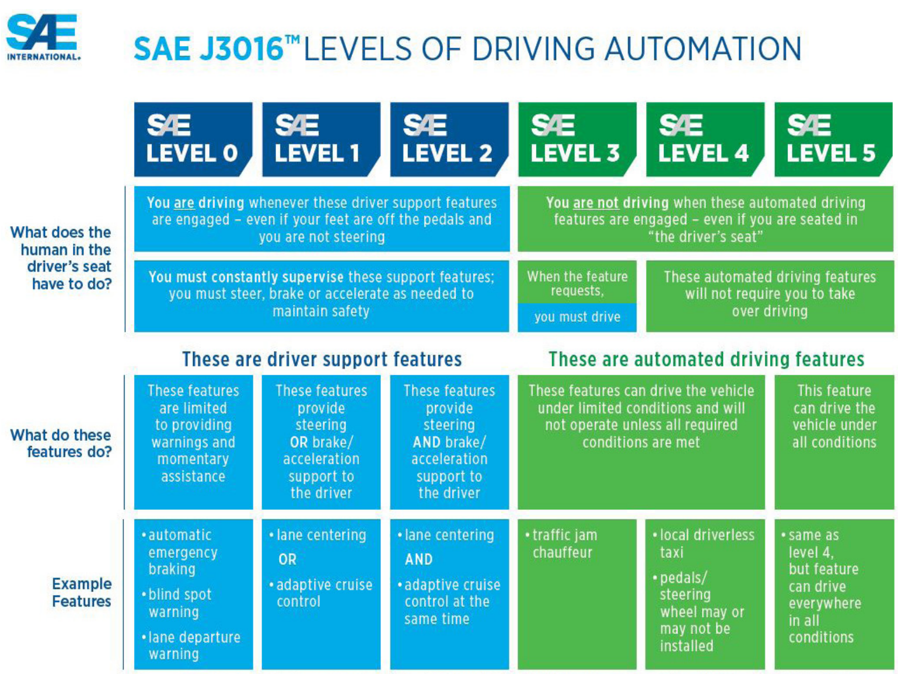

Figure 2. SAE levels of autonomous driving.

The sense-think-act model

Self-driving functionalities always combine capabilities that fit into one of the three segments of the sense-think-act model, which for decades has been the leading paradigm for robotics, research and development (R&D) and engineering. The difficulty is the three elements in this model are diverse and far-reaching expertise is necessary in each of them. Success can only be achieved by combining specialization in different disciplines in a systematic manner. There will need to be more intense collaboration than ever between different departments in OEMs, but also between OEMs and all types of suppliers. Developing autonomous vehicles is an enormous challenge and requires the help of partners who have overarching knowledge they can apply on an ad hoc basis.

Siemens Digital Industries Software wants to be that partner. Many years ago, we started with a clear vision of future mobility, looking for specialists in the industry and uniting them (among other ways) by acquiring technology companies. Today, with our extensive portfolio, we are offering solutions to design and develop critical systems that will disrupt everything from chips to city and make the deployment of autonomous vehicles and the future of mobility possible. For autonomous driving, we are helping customers globally with specialized engineering software for systems and vehicle development, verification and validation in various disciplines, advanced test solutions and design exploration tools, as well as platforms for product lifecycle and data management, and domain experts who provide customized engineering services.

Sense

Before it can make proper decisions, the autonomous vehicle needs a robust 360-degree view in all weather and traffic conditions. To this end, both the sensors as well as their integration into the vehicle are important. All sensor types have their strengths and weaknesses. Therefore, within the industry, there is a consensus that no single kind of sensor can handle the job on its own. A complementary combination of lidars, radars, cameras and ultrasonic sensors will always be required.

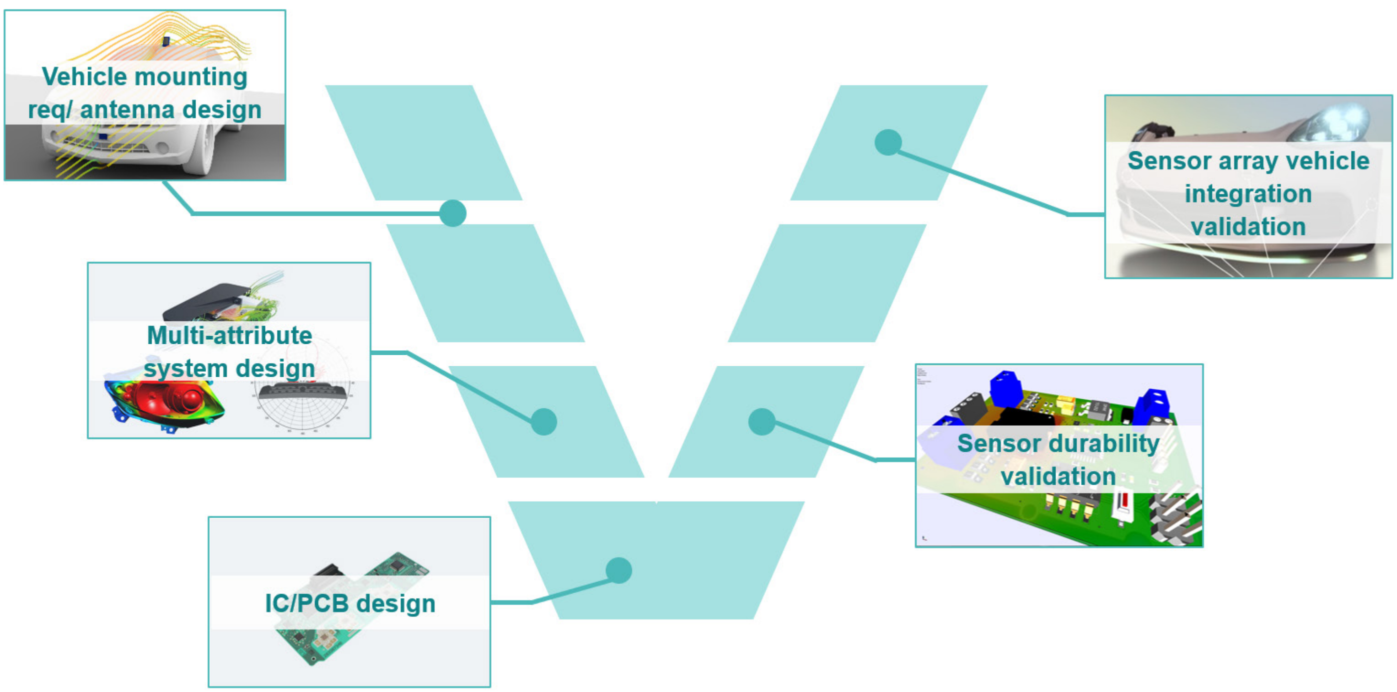

Figure 3. Pictured is Siemens' sensor hardware development and vehicle integration portfolio for vision and non-vision sensors, which are critical for autonomous driving.

Sensor hardware design and vehicle integration
The Simcenter™ software, hardware and engineering services portfolio facilitates collaboration in electronics and mechanical verticals that enable companies to easily account for multidisciplinary design considerations from early prototyping stages. With seamless connectivity with electronic design automation (EDA) tools and computer-aided design (CAD), Simcenter Flotherm™ software and Simcenter FLOEFD™ software enable sensor vendors and OEMs alike to ensure robust thermal design from chip to sensor (system) and vehicle integration. Improper thermal design is one of the main reasons for sensors and electronics failure. Problems can manifest themselves at various stages, from chip, structure and attachment points to integration with the vehicle, where there can be active cooling present, or moisture, fog or other issues. Having a digital thread that connects all these levels presents enormous efficiency advantages as small changes of any kind can immediately be propagated to all possible levels. Using Simcenter 3D accelerates ultrasonic sensors, radar and antenna design and bumper integration in addition to optimizing the number of these sensors and ensuring the implications of bumper material, paint and weather elements on performance. Additionally, integrated workflow from sensors electronics circuit simulation to CAD to thermal and structural simulation allows Tier 1 suppliers and OEMs to ensure sensors design and integration is robust enough for desired in-field lifetime.

There are additional challenges for sensors vendors and OEMs: For instance, how do you make sure that once integrated, sensors will continue operating reliably for the lifespan of the vehicle? This becomes even more challenging as many of the new sensor technologies and startups are becoming a major part of the sensors supply chain. It's difficult for sensor manufacturers to answer this question on their own. As they do not always work directly with the OEMs during development, they cannot just mount the sensors in the vehicles and test them. So it is mandatory to create an integrated workflow, including electronics, thermal and dynamic structural simulation. This can allow both OEMs and sensor manufacturers to frontload lifetime predictions. A digital thread with seamlessly integrated workflow could start, for example, from the printed circuit board (PCB) level (Xpedition) and move to CAD, where thermal and flow analyses can be performed (Simcenter FLOEFD). Thermal and flow simulation analysis within the native CAD environment can be then used for thermal stress and dynamic vibration analysis (Simcenter 3D), which serves as the basis for fatigue analysis. This integrated workflow that leverages the Siemens software portfolio has been demonstrated to reduce sensor development and vehicle integration time by five to 20 times and foster close collaboration among vendors and auto OEMs.

Sensor performance with digital twin of the world
Additionally, we must consider the overall performance after integration. That's because optimal results can only be achieved if the entire set of sensors – not just individual sensors – perform as required. Further, one could think of including all of them in a vehicle and test. But relying on only a testing-based approach is not practical or even feasible, as by many estimates more than 8 billion miles of testing will be needed, including safety-critical edge cases. Simcenter Prescan™ software – with its physics-based sensor performance simulation capabilities for all vision and non-vision sensors along with unique abilities to include realistic surrounding environment (we call it digital twin of the world) – offers a robust solution to this problem. These sensor models are scalable, from simple, fast calculations that allow you to see which objects fall within sensor range, to complex realistic calculations that describe the physics behind the sensor and the interaction with the environment, and can evaluate what happens when circumstances change, for example, when entering a tunnel at night time, in fog and more. It offers the possibility to include the environment in simulations, which is a unique but critical feature.

In addition, the Siemens integrated portfolio of simulation and testing solutions and associated engineering services help companies take the journey from virtual to physical world. We support the integration of sensors in test vehicles, perform tests on public roads and can actively support testing on proving grounds.

Think
The data from the different vision and non-vision sensors must be combined in a comprehensive environmental model, which should be used for calculations to make decisions and trigger actuators. This process is obviously critical and must meet the highest safety and security standards. Further, it needs to happen in real time. The latter is only possible if it is supported by built-in intelligence, enabling the vehicle to quickly recognize all possible scenarios. Machine training and learning are essential here. Both these aspects are huge challenges and are crucial to the success of the autonomous vehicle business.

Data fusion

Scaling up the data fusion architecture of today's (or near future) ADAS vehicles to achieve level 4/5 vehicle autonomy is not prudent. To date, ADAS systems generally use a distributed computation architecture that pushes data processing to each node or sensor type, which are then sent to different applications or fusion modules. Building on such distributed computation architecture for autonomous vehicles has important disadvantages, such as unacceptable system latency in the transfer of safety critical information, the loss of potentially useful data at the edge nodes, and rapid increases in cost and power consumption as systems become more complex.

By contrast, Siemens Digital Industries Software offers a centralized raw data fusion platform, the DRS360™ Autonomous Driving Platform, which eliminates the inherent limitations of these distributed architectures. With DRS360 technology and the associated engineering services, it is possible to empower companies to connect raw sensor data of any kind to a centralized automated driving compute module over high-speed communication lines, and then fuse this data in real time. The high-speed, low-latency communication framework makes all sensor data, raw and processed, always available across the entire system. This data is then processed when required only in the region of interest. In this way, Siemens can dramatically reduce the central processing unit (CPU) load and fully support autonomous driving functionalities using less than 100 watts of power.

Machine learning training and validation

Scarcity of training data and validation of machine learning algorithms are key challenges for every auto OEM and technology supplier in the AV space. Training and validation of machine learning, not just for usual driving scenarios but also for covering safety-critical corner cases, is a daunting task. Relying heavily on real-world testing is not feasible as it is estimated that billions of training[6] miles will be necessary to fully allow safe autonomous driving. To date, machine learning is mainly applied with cameras. Training and validation of machine learning algorithms for autonomous vehicles with both vision and non-vision sensors is a new challenge. Additionally, the current manual process for object classification is inefficient and not scalable.

Siemens Digital Industries Software can help companies accelerate machine learning by allowing them to combine real-life data with synthetic data to address these challenges. Leveraging Simcenter Prescan for simulating sensor performance as well as the surrounding environment to capture and tweak the generation of any weather and lighting conditions, users can generate synthetic training data from cameras, radars and lidars. In addition, data captured during real world testing can be seamlessly converted to Simcenter Prescan scenarios, and object classification is automated. Importantly, rare safety-critical corner cases can be included with Simcenter Prescan plugins with accident databases from various countries.

Our approach focuses on virtual validation of machine learning algorithms leveraging Simcenter Prescan integration with DRS360 and NVIDIA processing units. With this closed loop real time hardware-in-the-loop (HiL) approach, all functionalities in the entire autonomous driving process can be tested virtually, but with realistic boundary conditions. For example, you can validate the algorithms for environmental perception, or the control logics. Significantly, our platform enables users to connect our software and solutions to a third party and proposes interfaces in such a way that components from other vendors can also be included in these simulations and validations in a user-friendly manner.

Act

Ultimately, the autonomous vehicle must act upon the decisions that have been taken. This involves technologies in three key areas: the electrical and electronics (E/E) architecture, the ECUs with embedded software and innovative control algorithms. Complexity of vehicle EE architecture is exploding with vehicle autonomy. Even in today's (level 1/2) luxury cars, one can already find six to eight sensors, over 150 ECUs and more than 5,000 meters of electrical cable. When aiming for autonomy level 4 or 5, these numbers will multiply many times, so the development complexity will increase exponentially, and new challenges will arise.

Increasing complexities with E/E systems means one can no longer define the E/E architecture in a manual process that considers all autonomous functions individually. Instead, they will need to take a comprehensive model-based approach that deliver deterministic outcomes from the start. With Siemens' Capital™ software, companies can start from a deterministic, overarching multi-domain base model, which will be refined step-by-step, and take into consideration all components from the beginning, including electrical wiring, software, hardware and networks. See figure 4. In this way, engineering departments can choose between design options in an effective manner and immediately virtually evaluate their implications for all domains. By doing performance balancing, tradeoff analysis and verification and validation during early development stages, they can deliver the right architecture faster and with more confidence. Our model-based systems engineering approach is underpinned by application and product lifecycle management (PLM) platforms for bi-directional traceability of requirements throughout the engineering process, until certification and beyond.

Figure 4. This figure is a screenshot of Simcenter Prescan simulation results showing how it helps sensors perform simulation accounting for the surrounding environment (sun light, shades etc.) and traffic.

The criticality of ECU embedded software design and validation for autonomous driving poses new challenges. By combining the Volcano platform with Simcenter Amesim™ software and Simcenter Embedded Software Designer, software can automatically translate system definitions into ECU software via a generative flow according to AUTomotive Open System ARchitecture (AUTOSAR) industry standard methodologies. This greatly accelerates the code generation and protects from safety issues such as hacking. In addition, our standard execution platforms for AUTOSAR, Linux and real-time operation systems have a proven track record, so OEMs can be sure that they will behave correctly in terms of safety and security. And finally, we enable verification and validation of ECU software. These include all possible simulation tools for model-in-the-loop (MiL), architecture-in-the-loop (AiL), software-in-the-loop (SiL) and HiL test platforms, so the embedded software can be virtually tested during its entire design cycle for accuracy, reliability and operational aspects.

And finally, we have the control algorithms, which are obviously not a new discipline in the automotive industry. However, new challenges arise for autonomous vehicles. Reactive controllers will no longer be sufficient. Control algorithms for autonomous vehicles need to increase anticipation as it will need to account for not just vehicle dynamics variables, but also for ensuring appropriate trajectory planning and account for the environment and traffic around the vehicle. For example, algorithm development for automated valet parking needs to include sensor inputs, trajectory planning and tire dynamics, which is critical for low-speed maneuvers. Siemens Digital Industries Software has the tools and engineering expertise that can actively support OEMs with the development of model predictive control (MPC) algorithms. Our engineering services propose the right level of support to guide users in setting up and conducting co-simulations for virtual validation and has dedicated simulation tools in-house for specials such as tire dynamics. In addition, we support the instrumentation of an existing vehicle and the ability to test it extensively in real life.

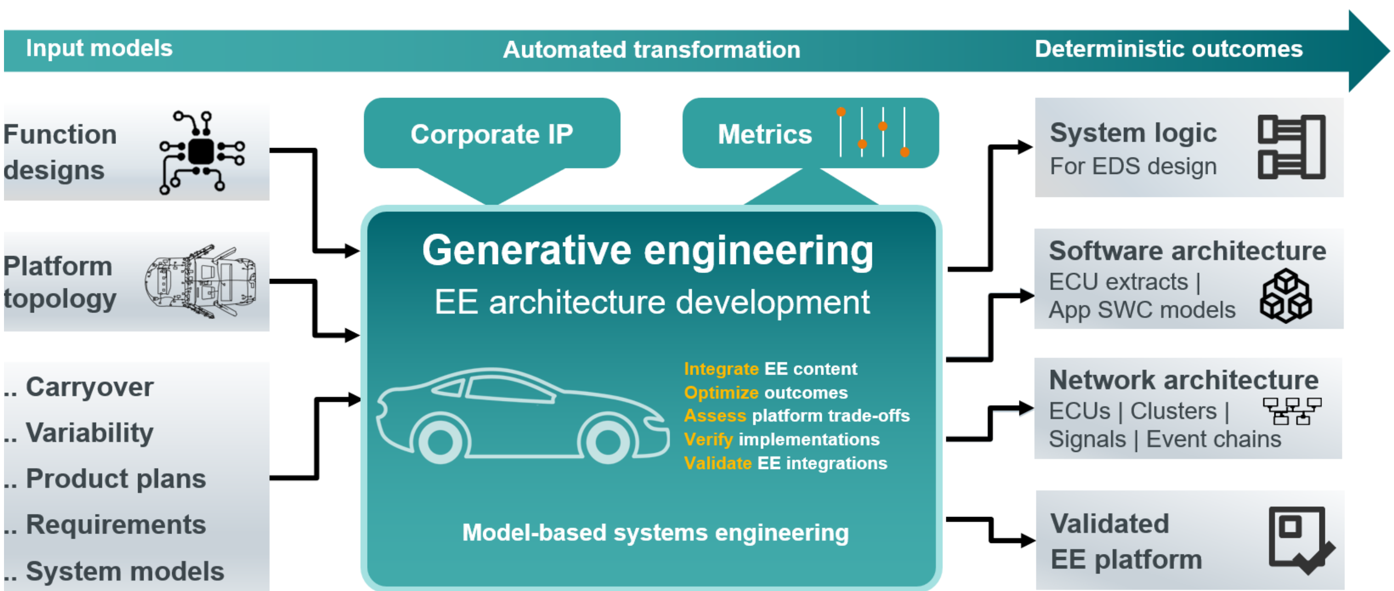

Figure 5. Generative engineering with Siemens portfolio for EE system development and validation for autonomous driving.

Conclusion

By 2030, a significant share of vehicles is expected to be fully autonomous. The transition has already started. We are now at the point where autonomy level 2 and level 3 functionalities, such as adaptive cruise control, lane centering and automated parking are already quite common. Yet taking the step to level 4 and level 5, which needs to happen in the coming years, will be challenging. The fact that software will gain importance over mechanics, and that fully self-driving cars will have to completely replace the driver, will have huge implications on many aspects of automotive development.

Automakers and their suppliers will have to revolutionize their current processes that deliver discrete product generations. Instead, they will need a new approach in which they remove the boundaries between design and product life after delivery to allow individual vehicles and components to get constant upgrades for performance improvement, safety-related updates and more. This requires thorough PLM and traceability.

Additionally, these new processes will have to manage unprecedented complexity during development. More than ever before, vehicle systems will combine functions and capabilities from different departments or even companies. For autonomous functionalities, those are the various elements from the sense-think-act model. And as the required expertise in those domains is so diverse and profound, it will be important to have partners like Siemens, which has overarching know-how and a solutions portfolio that spans the entire range of applications.

Siemens has mastered all aspects of autonomous driving functionalities, offering OEMs and their suppliers specialized engineering software for systems and vehicle development, verification and validation in various disciplines, advanced test solutions and design exploration tools. Further, we offer platforms for product lifecycle and data management and domain experts who provide customized engineering services.

Siemens can help OEMs and sensor manufacturers achieve 360-degree vision in any weather and traffic condition by offering them simulation and testing technologies that uniquely integrate the electronics part with the entire mechanical vertical. Additionally, Siemens can increase data fusion efficiency and confidence in machine learning with a centralized raw data fusion platform and advanced methodologies for registration and generation of driving scenarios for virtual validation. Finally, Siemens provides a wide range of simulation tools and virtual test platforms for the design and real-time validation of E/E architecture, embedded software and controls algorithms to ensure a safe and secure operation of autonomous vehicle functions.

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