Technology advancements are leading to complex mechatronic systems capable of interacting with the physical world through advanced sensor technology and artificial intelligence (AI). These systems are capable of functions ranging from basic tasks up to complete autonomous operation, and they can perform these tasks as well or better than humans. However, designing, training, verifying, and validating these complex systems requires extensive simulation platforms and processing solutions that are pushing the limits of existing platforms. As a result, there is a need for closed-loop simulation platforms that not only provide the virtual environment required to develop the next generation of mechatronic systems, but also to develop the processing solutions to control them.

The Challenge of Automated Driving

The dream of automated vehicles emerged in the 1950s and some of the first self-driving vehicles were developed in the 1980s, but it has only been within the past few years that a mass production vision for automated vehicles has taken shape. Advancements in Artificial Intelligence (AI), sensors, interconnects, and semiconductor technology combined with the electrification of vehicles have created the perfect formula for vehicle automation at all levels.

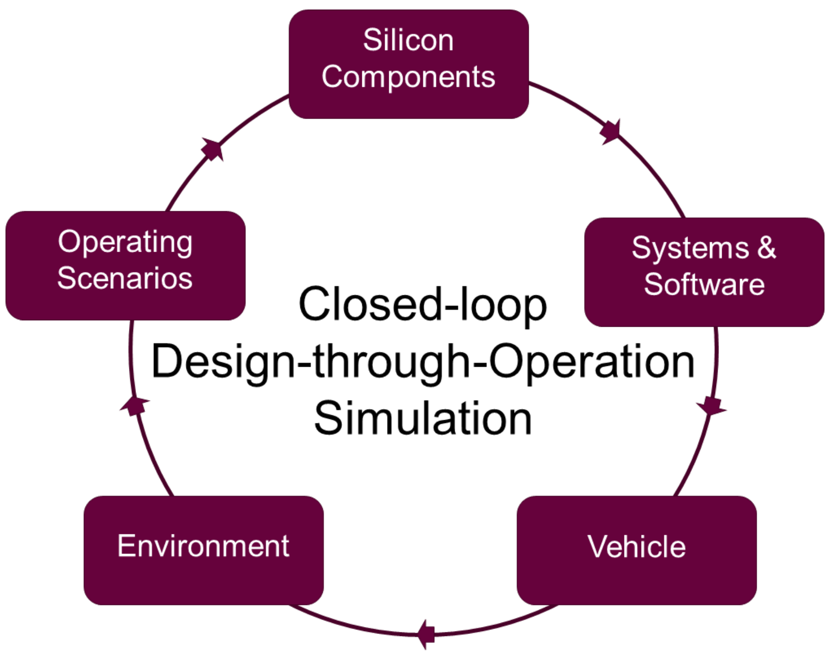
Even with these advancements, creating an automated vehicle is no small challenge. Estimates for training the AI neural network models for automated driving range from 10 billion to 20 billion hours of driving; this alone would require hundreds of years to accomplish in the real world. Even after the AI models are trained, the operation of the vehicle must be validated in a repeatable manner for all possible vehicle configurations, operating variables, and driving scenarios. Among these considerations are different road and weather conditions, different loads or the shifting of loads within the vehicle, tire and brake conditions due to temperature and wear, and faulty sensors, actuators, and electronics control units (ECUs), to name just a few. Accounting for all possible factors to ensure the safe operation of vehicle automation at any level seems an overwhelming task. However, it must be achieved to ensure the safety of the occupants, pedestrians, and others that may come within the vicinity of the vehicle.

The Age of Simulation

Just as simulators are used to train pilots and automated flight systems for a wide variety of possible flying conditions, the automotive industry is relying on simulation to overcome the challenges associated with the training, testing, and validation of automated vehicles. Through the simulation of environments, vehicles, and driving scenarios, neural network models can be trained and tested without the risk and time involved of using the actual vehicles and obstacles. Many companies are working to develop and combine vast and diverse databases of information to provide realistic driving simulations. These include roadway maps, road conditions based on weather models, friction coefficients based on tires and roadway construction information, image databases, driving scenarios, and countless other sources of information. However, this information is only useful once the vehicle design has been completed.

To ensure the validation of automated vehicles while reducing the development cost and time, the industry needs a simulation platform that can test and retest the operation of the vehicle during the design of the vehicle's systems. This would allow the test results to be fed back into the design, creating a closed-loop system that would improve the design, operation, and physical characteristics of the system in near real-time, as well as train and test the vehicle. Vehicle and systems designers would be able to experiment with different sensors, actuators, ECUs, and even processing solutions to test for optimal configurations and performance. For example, the simulations could be used to determine the placement of sensors, the best actuators and ECUs for response and power consumption, the selection of tires based on the vehicle weight and dimensions, or the battery displacement for the desired range of an electric vehicle (EV).

Figure 2. Revised circulation simulation diagram



Source: TIRIAS Research

This simulation environment could also be used in the development of the system, from the individual components to the entire vehicle design. While models of many components, such as sensors, actuators, and ECUs, are available today, one model is often missing – the processing solution or System and a Chip (SoC). These SoCs are often designed for a broad range of applications and system requirements but there is a limit to the scaling of SoCs. As a result, there is a need for custom SoCs and the ability to design, verify, and validate them in the same simulation environment as the rest of the vehicle components and systems.

The Need for Custom SoCs

There are many off-the-shelf (OTS) SoCs that can be used for automated vehicle sensor fusion, AI processing, control, and infotainment. Trends in the semiconductor industry combined with the performance and design requirements for automotive systems indicate there is a need for specialized (custom) SoCs. The key economic principle of the semiconductor industry is making things smaller at the same cost and power, but this is becoming increasingly difficult. Moore's Law (the doubling of the number of transistors per given area every few years) is slowing as a result of limitations of physics as we get to extremely small semiconductor structures. This trend, combined with the increasing cost of manufacturing these small structures using advanced lithography techniques like multi-patterning, immersion, and Extreme Ultraviolet (EUV), is increasing the cost per transistor, while the performance efficiency benefits are decreasing with each process generation. The industry is now using packaging technology innovations, such as multichip modules (often referred to as chiplets) and die stacking, to improve cost, performance, and density. However, scaling in this manner will not keep pace with the exponential increase in electronic systems and data processing requirements driven by the electrification and automation of vehicles.

Automated vehicles require extensive processing of sensor data, AI processing, and vehicle control. The average automated vehicle is likely to produce between 2TB to 4TB of data an hour through an array of external sensors, including cameras, RADAR, LiDAR, and ultrasonic, plus data from internal sensors and ECUs. All this data must be processed and then acted upon using neural networks in real time. A data center, in comparison, would require a minimum of a dual-socket x86 server with multiple GPU or FPGA accelerators to process this much data in real time.

Vehicles have limited amounts of power, space, and heat dissipation capability. Additional power consumption and dissipation by the electronic systems reduce the gas/charge rating of the vehicle, especially on hybrid and electric vehicles. Additional electronic systems also add to the weight of the vehicle, further reducing gas/charge mileage. That data center server required for real-time data processing would be large, heavy, and require several hundred watts of power and extensive air or liquid cooling.

As a result, it is not feasible to design a data center solution into a vehicle and likewise it will become increasingly difficult to rely on general-purpose SoCs to handle the massive amounts of data and real-time processing requirements of automated vehicles. Just as the battery and electro-mechanical drives will have to optimized for each vehicle, so too will SoCs have to be customized for specific vehicles to produce the optimal system solution.

The Decision to Use Custom SoCs

The decision to use off-the-shelf (OTS) or custom SoCs is often related to the rate of change in standards, the market, and technology. As an example, the handset/smartphone market was founded around OTS SoCs, but as the market and technology matured, the industry leaders (Apple, Huawei, and Samsung) began to develop their own custom SoCs to differentiate from other vendors. In a similar manner, many cloud data center companies are now developing custom SoCs and accelerators, like Amazon's Graviton server processor and Google's Tensor Processing Unit (TPU), to accelerate certain types of workloads. This transition toward the use of custom SoCs and accelerators is likely to continue across most compute intensive applications.

Today, many SoCs combine multiple CPU cores with a host of different accelerators, including Graphics Processing Units (GPUs), Digital Signal Processors (DSPs), Field Programmable Gate Array (FPGAs), Video Processing Units (VPUs), Image Processing Units (ISPs), Neural Processing Units (NPUs), and other licensed or specialized accelerators. Developing a custom SoC allows a company to optimize the chip for the intended workloads and system design constraints.

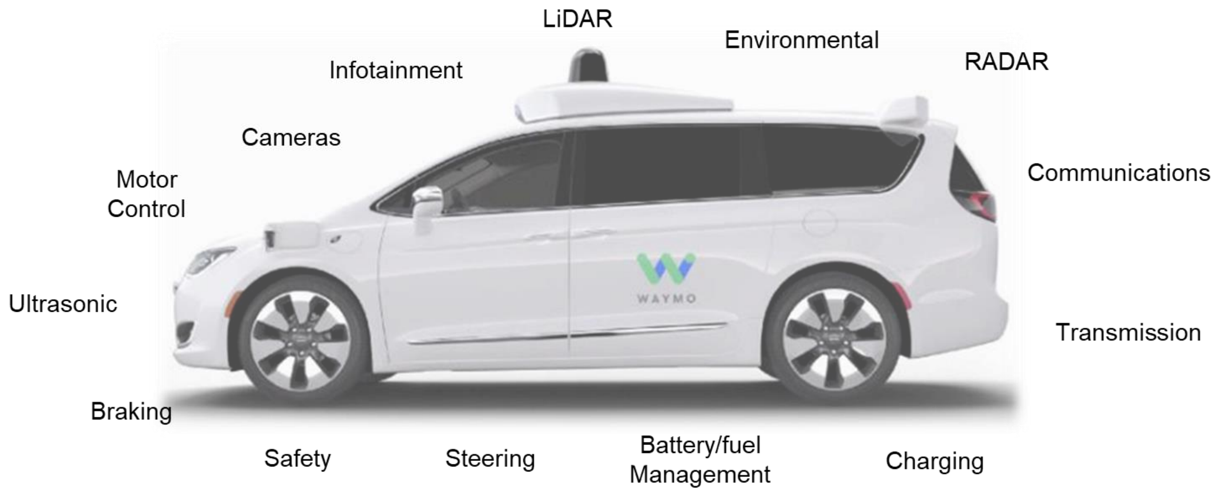
Many automotive equipment and vehicle manufacturers are now developing, or considering, custom SoCs for several reasons, including to build an optimized solution for their platform, to differentiate from other vendors, and to reduce their dependence on traditional computing semiconductor vendors. The first highly visible case is Tesla, which announced that it is now in production of its own neural processing chipset performing 36.8 Tera Operations per Second (TOPS) at 72W. Tesla began its assisted/self-driving efforts with a Mobileye chipset and then moved to an Nvidia platform before developing its own AI chipset. While the overall performance of the Tesla custom chipset is far shy of the 320 TOPS performance capability of the Nvidia Drive AGX Pegasus platform, the custom silicon is optimized for Tesla's vehicle configurations and software, and the new computing platform is saving the company 20% over the cost of the Nvidia platform. Many other automotive equipment and vehicle manufacturers are now following suit through in-house design efforts or through semiconductor partners.

The cost and complexity of semiconductor design and manufacturing is often a deterrent to developing chipsets, but with the increased availability of semiconductor intellectual property (IP), advanced Electronic Design Automation (EDA) tools, third-party design resources, and foundry services from companies like Globalfoundries, Samsung, and TSMC, more companies can develop their own custom SoCs. TIRIAS Research estimates that there are over 300 government labs, universities, semiconductor start-ups, veteran semiconductor companies, system OEMs, data center vendors, and end application OEMs (like automotive OEMs) developing AI chipsets for various markets and applications. In the case of Tesla, the company hired veteran chipset designers from AMD, Apple, and other companies to develop the computing platform.

It's Takes More to Design an SoC for Automotive

Unfortunately, developing a custom SoC for an electro-mechanical system like a vehicle is much more challenging than developing an SoC for a smartphone, server, or other computing platform. In the latter, the SoC is designed around a software workload and possibly some limited sensor data. For a vehicle, the SoC must be designed around a complex sensor array, a variety of mechanical and semiconductor components, and the functional operation and safety requirements of a vehicle. This requires a very complex simulation model commonly referred to as a "digital twin," a complete digital simulation of an electro-mechanical platform, or in this case, a vehicle.

Figure 3. Potential System Components in Automated Vehicles



Source: TIRIAS Research

Full Simulation from Silicon to Vehicle

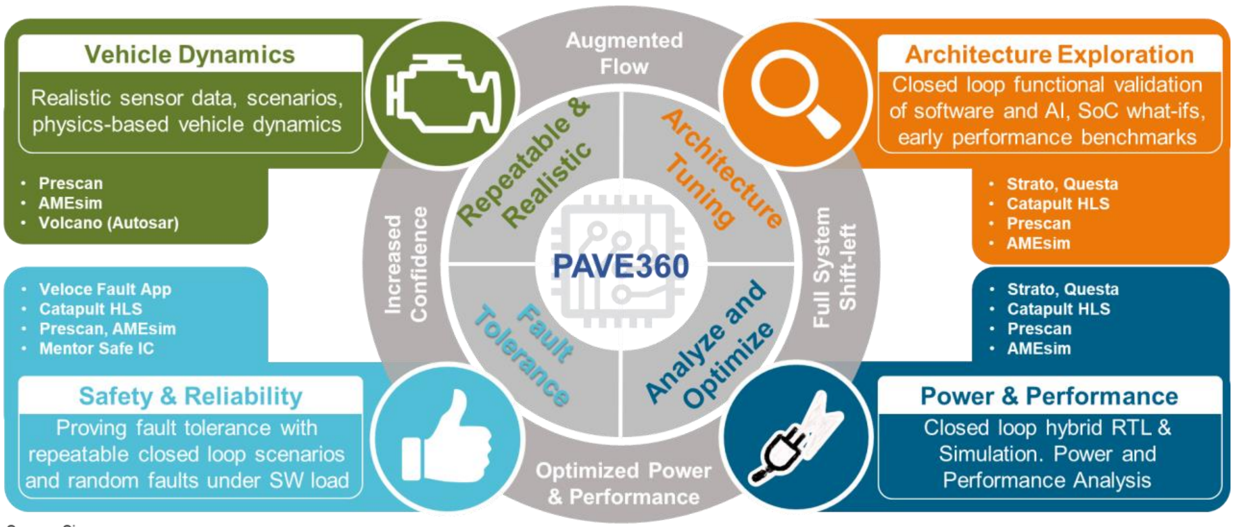
To overcome the challenges of designing automated vehicles, Siemens has developed a wide range of simulation solutions. These design, verification, and validation solutions work together to allow designers to simulate complete systems, including sensors, SoCs, vehicle networks, actuators, ECUs, and even complete vehicles. The solutions also simulate operating conditions, including other vehicles, infrastructure systems, environmental conditions, and driving scenarios.

The embodiment of the Siemens solutions is a platform called PAVE360. The technical description of PAVE360 is a "mixed-fidelity pre-silicon verification and validation environment." In more practical terms, PAVE360 is a comprehensive simulation environment that allows semiconductor designers to develop and test high-performance virtual SoCs within a virtual car driving in a virtual world under controlled and repeatable virtual conditions. PAVE360 includes hardware and software components to model and test both virtual and physical systems using a complete digital twin of the vehicle being designed. Key Siemens components of the PAVE360 platform include:

- Simcenter Prescan for scenario and physics-based sensor modeling
- Veloce, Questa, VirtuaLab for high-fidelity modeling of computational SoCs and ISO 26262 fault campaign execution
- Simcenter Amesim for physics-based electromechanical modeling of vehicle dynamics
- X-Step for 5G vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) modeling of smart cities
- Catapult HLS for modeling and developing high-speed AI accelerators

- Volcano Vehicle System Architecture for AUTOSAR compliant hardware and software design
- Mentor Safe IC for automated ISO 26262 RTL analysis and synthesis
- TeamCenter for product lifecycle management
- Polarion for product requirements and application lifecycle management
- Virtual Auto Network to connect virtual and physical systems through CAN, LIN, Flexray and Automotive Ethernet communications protocols

Figure 5. PAVE360 Platform Components



Source: Siemens

PAVE360 enables the modeling and development of high-performance SoCs capable of high-bandwidth sensor fusion, real-time AI neural network processing, and automotive safety-certified control solutions in conjunction with the software and the rest of the vehicle platform. The result is more efficient SoCs optimized for the platform, a shorter development cycle, and lower risk in the development and manufacturing of automated vehicles and vehicle systems.

While the main function of PAVE360 is to enable the design of SoCs, its versatility is a benefit to all other automotive systems designers allowing for the simultaneous development of silicon, software, and electromechanical components using the FMI/FMU, TLM2.0 and Simulink standards. PAVE360 is a physics-based simulation platform with extensive libraries, which allows designers to develop or import models for silicon or electromechanical components ranging from sensors to ECUs. The models can be changed and tested during development of the individual components. Once the component designs are complete, high-fidelity models of each component are used for verification testing.

PAVE360 can be leveraged as a shared resource between different design groups and companies as a secure environment that protects the IP of each group. Because of the simultaneous development, the PAVE360 platform can also be used to monitor the status of the individual semiconductor, software, and electromechanical system components. The platform can also be used for testing In-vehicle Infotainment (IVI) and Vehicle-to-everything (V2X) communications systems.

More importantly, PAVE360 is designed around the functional safety standards required for automotive applications including ISO-26262, the functional safety standard for electrical and electronic systems, and ISO-21448, the safety standard for the intended functionality of the vehicle. By simulating the entire platform for the development of the SoC, electronic system, software, and vehicle design, designers can ensure that the entire platform meets the required safety standards before committing any portion of the platform to production.

A PAVE360 platform is on display at the Siemens Center for Practical Autonomy in Novi, Michigan, near Detroit. Further installations of Centers for Practical Autonomy with PAVE360 are in the planning stages for Germany, Japan, China and Korea.

Figure 6. The PAVE360 platform at the Siemens Center for Practical Autonomy in Novi, Michigan

Source: Siemens

Conclusion

Recent accidents resulting in human deaths caused by automated vehicles, ranging from an autonomous Uber taxi to Tesla's Autopilot function, demonstrated the challenges of developing automated systems that ensure the safety of life. Siemens has demonstrated its commitment to addressing the design, testing, and validation of automotive system by investing over €11 billion (US$12.4 billion) in acquisitions combined with internal R&D to bring together the components supporting PAVE360.

Figure 4. Siemens PLM Software Acquisition Contributing to PAVE360

Siemens PLM Software Acquisitions

2018	Sarokal, Austemper Design Systems, Mendix, Lightwork Design
2017	Mentor Graphics, Tass International, Infolytica & Solido Design
2016	CD-adapco & Bentley Systems
2015	Polarion Software
2014	LMS International, Tesis PLMware & Camstar Systems
2012	Perfect Costing & Kineo CAM
2011	Vistagy
2009	VRConnect
2008	IBS & Active
2007	Elan Software Systems
2001	Orsi Group

Source: Siemens

No other platform offers the ability to design and test virtual SoCs from concept through operation in a mechatronic system and for all levels of automated control like the PAVE360. In conjunction with other Siemens industrial solutions, designers now can go from concept though manufacturing, verification, and even lifecycle management in a closed-loop virtual environment.