WHITE PAPER

Fast-tracking Safe Autonomous Vehicles

A COMPREHENSIVE SOLUTION FOR SIMULATING AUTONOMOUS VEHICLE MILES DRIVEN

Autonomous vehicles are threatening to disrupt the automotive, aerospace and industrial equipment industries with the emergence of self-driving cars, drones and mobile autonomous robots. They promise to drastically reduce accidents, minimize congestion, bring mobility to the immobile and perform mundane or hazardous tasks in a fraction of the time required by human-controlled vehicles. This opportunity is open to traditional industry players as well as new entrants, particularly from the high-tech sector. The race to market is on.

The critical path engineering challenge to be overcome is demonstrating compliance with safety requirements. Research has shown that for a self-driving car, this could take between 8 billion and 11 billion miles of road testing. Because physical testing is clearly not a practical solution, autonomous vehicle makers are turning to “simulated miles driven, flown or maneuvered” as an alternative means of performing the required testing in a reasonable timeframe. This white paper discusses how Ansys is building the industry’s only comprehensive, open and configurable solution to validate vehicle performance against safety requirements. This includes leveraging best-in-class high-fidelity sensor models and open- and closed-loop simulations to validate the embedded software responsible for perception, localization, motion planning and motion execution.

Flown or Maneuvered — from Components to Systems

/ The Promise of Autonomous Vehicles

Autonomous vehicles are disrupting industries with the promise of significant benefits in terms of safety, society and quality of life. Experts believe that self-driving cars alone can drastically reduce the number of accidents and the costs associated with injury and loss of life. The quality of life for the visually impaired or those unable to drive for other reasons will be significantly improved. Traffic congestion will be eased for the broader driving population. Similar benefits are expected for autonomous drones with parcel delivery, asset inspection and farming applications, and advanced robots taking on mundane or hazardous human activity.

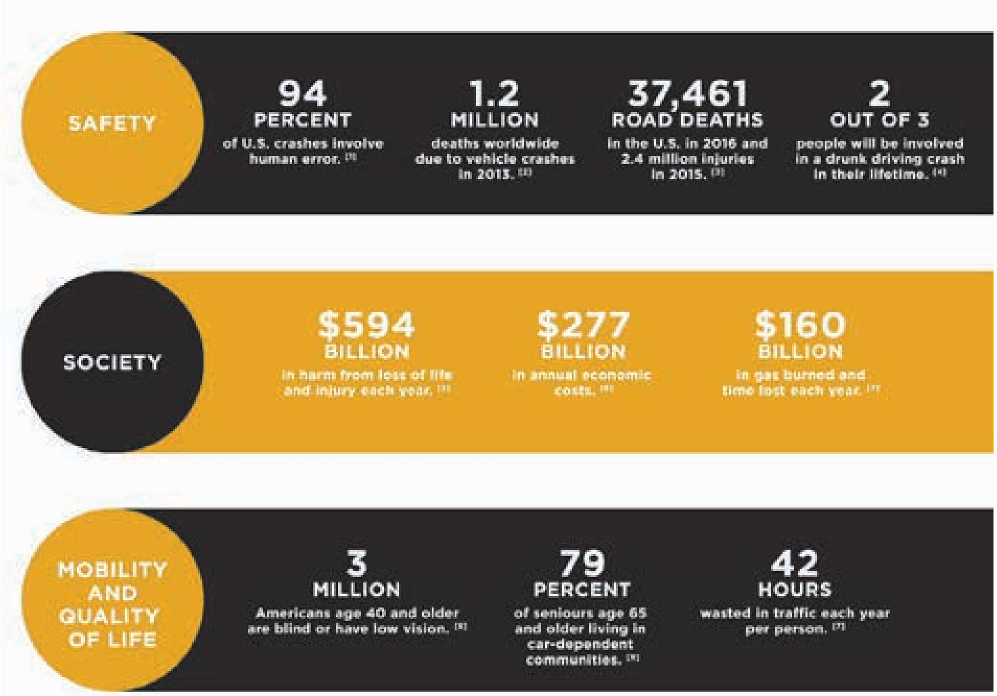


Figure 1. The promise of self-Driving cars [1]

The Race Is On

The global market for autonomous vehicles is projected to grow significantly. Take self-driving cars as an example. The market is expected to reach $127 billion by 2027 with a 40 percent CAGR over the next 10 years [2]. To grasp this global opportunity, governments, through national policy and regulation, and companies, from traditional automotive and non-traditional automotive backgrounds, are racing to establish themselves as leaders in this space. Similar trends are observed in the drone and robotics areas. These trends are disrupting traditional supply chains and ecosystems.

Continuing the self-driving car example, the long-standing and highly optimized linear automotive supply chain is now a highly dynamic ecosystem in significant flux with an ever-changing landscape of acquisition, partnership and new entrants almost on a daily basis.

> ***"We need to get commercial deployment of autonomous vehicles at scale as soon as possible."*** [3]
>
> Dan Ammann
> President, General Motors

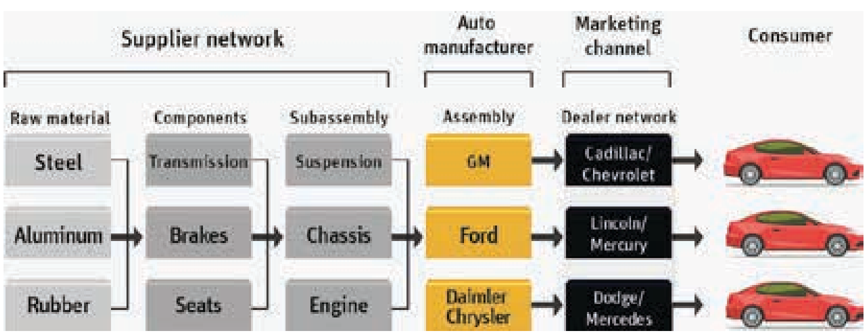
Tier 1 suppliers have an opportunity for significant growth by becoming the leading providers and knowledge holders of the core technology that enables autonomy. High-tech and semiconductor companies are maneuvering through development, acquisition and partnerships to develop the IT hardware and software platform of choice for autonomous vehicles. OEMs are fighting on two fronts: (1) They must combat new competitive threats such as Waymo, and (2) they must avoid becoming hardware suppliers to the high-tech companies' "vehicles as an app" vision with an inverted supply chain.

Without doubt, the race to market is on.

Demonstrating Safety Is the Critical Path Challenge

For self-driving cars, drones or advanced robots, the time-critical path challenge is to demonstrate that vehicles can operate safely. This means that they are safe for the occupants or goods they are transporting and for those people and objects they interact with. This is a complex problem. Recent incidents that fortunately did not result in serious damage, injury or loss of life highlight the criticality of the safety challenge. The brain of an autonomous vehicle comprises the algorithms and software it uses to perceive the environment and make decisions about its behavior. This brain needs to make the correct decisions when presented with hundreds of millions of potential situations. For example, for a self-driving car to make a right turn at an intersection, tens of thousands of parametric scenario combinations need to be examined and learned from. Ultimately, for an autonomous vehicle to be accepted and certified for widespread use, its software must be verified and validated as being as safe or safer than a human equivalent. This requirement can be quantified statistically. A study by RAND [4] revealed that in typical cases it would take between 8 billion and 11 billion miles of road testing over a period of 400 to 500 years to demonstrate the safety of autonomous cars to appropriate levels of statistical confidence. Clearly this is not a practical answer.

Figure 3. Recent autonomous vehicle safety in the news: Las Vegas self-driving bus crashes on its first day; Washington D.C., security robot Steve goes for a swim: drone strikes a Canadian passenger plane in first reported incident of its kind.



Automotive supply chain ten years ago.
Data courtesy: McGraw Hill/Irwin, McGraw Hills Companies

Benchmark Failure Rate				
	How many miles (years[a]) would autonomous vehicles have to be driven...	(A) 1.09 fatalities per 100 million miles?	(B) 77 reported injuries per 100 million miles?	(C) 190 reported crashes per 100 million miles
Statistical Question	[1] without failure to demonstrate with 95% confidence that their failure rate is at most...	275 million miles (12.5 years)	3.9 million miles (2 months)	1.6 million miles (1 month)
	(2) To demonstrate with 95% confidence their failure rate to within 20% of the true rate of...	8.8 billion miles (400 years)	125 million miles (5.7 years)	51 million miles (2.3 years)
	(3) To demonstrate with 95% confidence and 80% power that their failure rate is 20% better than the human driver failure rate of...	11 billion miles (500 years)	161 million miles (7.3 years)	65 million miles (3 years)

[a] We assess the time it would take to complete the requisite miles with a fleet of 100 autonomous vehicles (larger than any known existing fleet) driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour.

Figure 4. RAND [4] findings on the number of miles needed to demonstrate the safety of an autonomous vehicle with appropriate levels of statistical confidence.

/ Simulating Miles Driven Is the Only Practical Answer

To overcome this limitation, companies have turned to simulation. Waymo, a division of Alphabet Inc. and one of the front-runners in the race, reported the impact that simulation is making in their development efforts [1]. This is summarized in Figure 5. Physical road testing and scenarios where the original situation has been replayed with a perturbation have an important role to play in the overall safety demonstration process. However, simulations that provide an accurate interpretation of the physical reality of the autonomous vehicle and its environment to validate performance against safety requirements are the only practical way to market.

Figure 5. The unrivalled power of simulating miles driven: the only way to market for an autonomous vehicle. [1]

/ Successfully Simulating Miles Driven

Open and Closed Loop Simulation

In addition to the already complex systems on board today's vehicles, components that make a vehicle autonomous are sensors (radar, lidar, cameras, etc.), electronics and semiconductors, and software and actuators. Designing and developing these components requires high-fidelity physics-based simulations conducted in an open loop environment. Such simulations ensure that the performance of the sensor and its interaction with the environment is captured in the most accurate way possible. They also ensure that in the real world, these sensors perform as expected and are able to survive the harsh operational environment they will be exposed to. Likewise, the embedded software associated with these devices can be developed with model-based methods and verified via simulation to speed up compliance with standards such as ISO 26262 in automotive and DO-178C in aerospace applications. These component applications and Ansys solutions for them are discussed in more detail later in this white paper. In a closed loop simulation, a virtual representation of the autonomous vehicle, complete with high-fidelity virtual sensors and actuators, is placed in a virtual environment and driven by the same software as the real-world autonomous vehicle. As the vehicle drives in this environment, accurate sensor models replicate what the vehicle will "see" in the real world; the perception, localization, planning and execution software drives the car as it would in the real world. Multiple virtual autonomous vehicles can be driven for millions of miles in this virtual environment in a much faster, safer and more economical way when compared with road tests.

Developing Autonomous Vehicle Software

The embedded software responsible for perception, localization, motion planning and motion execution is the brain of the autonomous vehicle. Artificial intelligence (AI), machine learning (ML) and deep learning (DL) are key techniques being used to create the brain of the vehicle. However, being non-deterministic, these techniques face significant challenges: (1) a lack of clear traceability between the outputs of the algorithms and the functional safety requirements of the system; and (2) compliance with accepted best practices for high-integrity, safety-critical software such as model based systems engineering (MBSE), safety analyses and certified code generation. A solution to these challenges is the Command-Monitor (or COM-MON) architecture. A simple analogy can be made to the left and right sides of the brain. The command side, equivalent to the creative left side of the brain, contains the AI/ML/DL algorithms and is in normal control of the vehicle, responding creatively to the demands placed upon it. However, should the command side fail by instructing a dangerous operation, the monitor side takes over and produces a short duration mission that ends in a safe state. This is the equivalent of the logical right side of the human brain taking over. The monitor side is developed using best practices for safety-critical software engineering and functional safety analysis.

Managing Data

According to Intel, "a flood of data is coming" [5] as a result of the shift to autonomous vehicles. A single autonomous car will generate 4,000 GB of data per day. This figure grows significantly higher when the physical world data from the car are combined with the virtual world and virtual sensor data generated through the simulated experience. Managing and mining these data to derive actionable insight and connecting to the open loop and closed loop vehicle simulations are fundamental capabilities for the successful simulation of miles driven.

/ A Comprehensive Solution for Simulating

Autonomous Vehicles Miles Driven

Delivering the promise of autonomous vehicles requires validating performance against safety through simulation. This means connecting the software brain of the vehicle to open loop and closed loop vehicle and environment simulations, and managing vast quantities of physical and virtual data. It also requires bringing hardware components into the simulation loop and adapting to specific development environments, vehicle architectures and network connections.

In short, it means a solution that is open and that can be configured to the end user's requirements.

Ansys is building the industry's only comprehensive solution for simulating autonomous vehicle miles driven. This solution is open and configurable to validate vehicle performance against safety requirements through simulated miles driven. Its open nature integrates an ecosystem that includes, but is not limited to, high-fidelity physics, sensor models, vehicle dynamics, world scenarios, embedded software, connectivity, data analytics and functional safety analysis. It can be configured to a given development environment, hardware-in-the-loop requirements and vehicle architecture.

The solution is shown schematically in Figure 6.

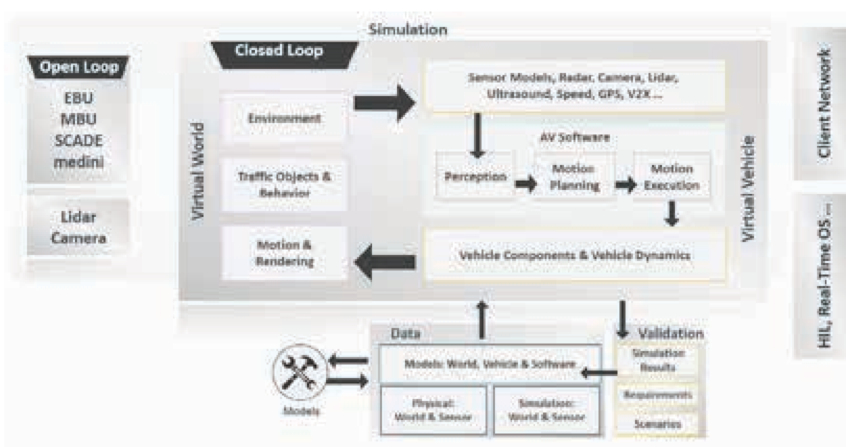
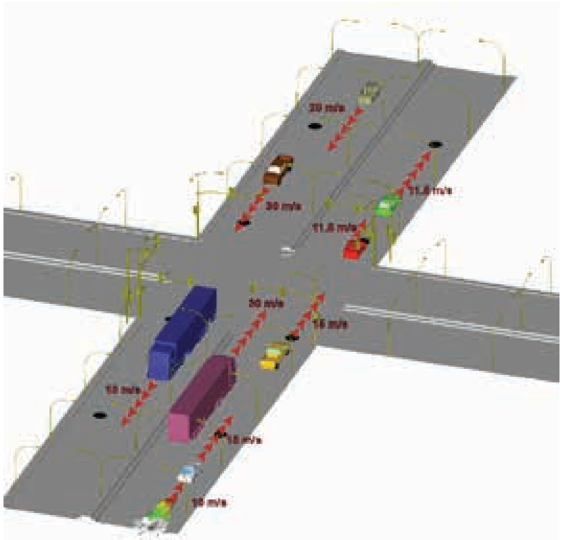


Figure 6. Illustration of the Ansys comprehensive solution for simulating autonomous vehicles miles driven.

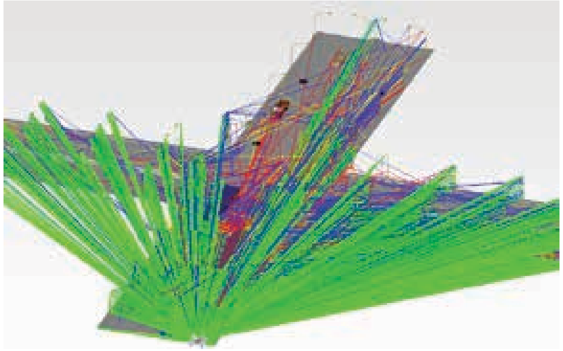
Simulating the Components

Assessing the overall system is required to demonstrate safety through simulated miles driven. However, simulation also plays a key role in the design and development of the discrete components of the vehicles that enable autonomy. A self-driving car, a drone or a robot all contain a number of these common components that benefit from simulation. Ansys provides the most accurate capabilities on the market today — with component accuracy being the foundation for the demonstration of safety in the overall system representation.



Simulation plays a fundamental role in the development of radar, lidar, camera and ultrasonic sensors as well as GPS and V2X systems. This extends from sensor module design, to studying the module's installed performance on the vehicle, to understanding what the sensor reports for moving and stationary targets on a full, dynamic scene. In the above left image, we see the relative motion of vehicles at an intersection. The above right image shows how simulation can be used to assess the complexity and effectiveness of a radar on one of the vehicles.

Semiconductors



Semiconductors are evolving rapidly to support the specific needs of autonomous vehicles, pushing the limits of system reliability. Increased functionality and power density in next-generation FinFET designs are leading to self-heating of the devices and Joule heating of the wires, causing wide variations in on-chip temperatures. Higher temperature, higher current and higher resistances are pushing the limit for electromigration (EM) and electrostatic discharge (ESD) failures on-chip. In addition, advanced 2.5/3D and wafer-level packaging technologies are bringing the die and wafer together while creating more thermal hot spots that will impact both the chip and system level EM and ESD. Ansys offers a comprehensive, thermal-aware EM solution that models self-heat effects and overall junction temperature variation of the die for accurate signoff. ESD integrity analysis from the device level, all the way to IO, IP and SoC is also provided, along with modeling capabilities for IO and IP for SoC level analysis and full-chip modeling capability for system-level ESD verification and signoff.

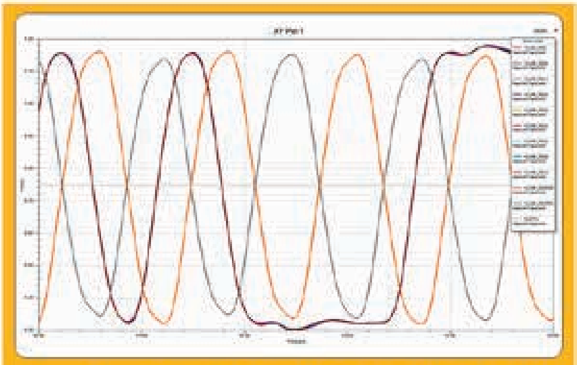
Electronics Reliability

The requirements for robust performance of electronic systems on the vehicle, from the chip all the way to the installed sensor, places new demands on the reliability of the electronics system. Ansys offers a simulation-driven chip–package–system (CPS) development methodology that is multiscale, multiphysics and multi-user. The methodology is multiscale in that it provides simulation technologies that range from the nanometer scale, used in IC and other chip designs, to the meter scale of autonomous vehicles. Multiphysics solutions can simulate various physical phenomena across chips, packages and systems, including power optimization, signal power and thermal integrity, electrostatic discharge (ESD), electromagnetic interference/electromagnetic compatibility (EMI/ EMC), heat transfer, fluid dynamics and structural mechanics. The multi-user aspect enables chip, package and system designers to use the simulation platform to simulate and collaborate on various physical phenomenon to create increasingly complex products. As an example of using Ansys solutions to increase electronics reliability, Interconnect Engineering, Inc. used the full functionality of the Ansys Electronics Desktop to analyze, diagnose and implement a solution for a customer's crosstalk issue, which would have resulted in at least one costly re-spin to solve the problem. Without Ansys solutions, they may have never found the true culprit causing the crosstalk.

Embedded Software, Functional Safety and a Model-based Approach

With more electronics comes more software. Ensuring the reliability of the embedded software code within systems becomes critical to the safety of passengers and pedestrians. The development of an ISO 26262 qualified code generator helps automotive OEMs and suppliers drastically reduce development costs while ensuring that their embedded software applications will meet stringent safety standards. The same is true for DO-178C in aerospace. Ansys SCADE tools provide a code generator that is part of a model-based design solution in which modeling and simulation are used throughout the product development lifecycle as the authoritative definition and verification of the product design. Ansys provides production-proven, model-based development solutions for critical systems and software engineers that reduce cost, risk and time-to-certification. Further, Ansys automates the analysis and verification of functional safety for electronic control systems. This helps to implement step-by-step modeling, analysis and verification processes that conform to applicable safety standards. The result is a system architecture that accounts for the safe, reliable interactions of dozens of components. Ansys medini analyze also automates the analysis of failure modes and ensures that safety mechanisms are in place to protect against them over a wide range of operating scenarios.

Engineers at Piaggio Aerospace, a multinational aerospace manufacturing company headquartered in Villanova d'Albenga (Liguria), Italy, were tasked with developing a new P.1HH HammerHead unmanned aerial vehicle (UAV). This required developing approximately 300,000 lines of code for the vehicle control and management system (VCMS) — the digital infrastructure performing aircraft command and control — which had to meet DO-178B standards. Piaggio Aerospace selected Ansys SCADE as the development environment for the VCMS, since SCADE automatically generates source code from the model and minimizes the effort required to verify that the source code corresponds to the system model. The Ansys SCADE KCG code generator is qualified as a DO-178B development tool, so conformance of the code to the input model is trusted, eliminating the need for verification activities related to the coding phase. The project was completed in only 18 months. The VCMS was developed and verified in an estimated one-third the time that would have been required had the code been handwritten.


Reduced crosstalk resulting from using layers closer to the primary side

In conclusion, whether you are designing and developing a component, a subsystem or an entire autonomous vehicle, simulation is the key to winning the race to market. Ansys is at the forefront of this race, leveraging a history of high-fidelity simulations for component, subsystem and system design to build the industry's only comprehensive solution for simulating autonomous vehicle miles driven, flown or maneuvered.

Learn More

Learn more about Ansys and Autonomous Vehicles at http://www.ansys.com/autonomous

[1]On the Road to Fully Self-Driving, WAYMO Safety Report, 2017: http://www.ansys.com/autonomous
[2]http://www.businesswire.com/news/home/20170711005684/en/126.8-Billion-Autonomous-Vehicle-Market-2017-2023--
[3]https://blog.caranddriver.com/gm-and-cruise-finally-give-a-peek- behind-the-curtain-of-their-automated-driving-program/
[5]RAND Corporation, Driving to Safety: How Many Miles of Driving Would it Take to Demonstrate Autonomous Vehicle Reliability?, Kalra and Paddock, 2016
[4]https://www.networkworld.com/article/3147892/internet/one- autonomous-car-will-use-4000-gb-of-dataday.html

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