SELF-DRIVING SAFETY REPORT
OUR MISSION

We believe that the next generation of transportation is autonomous. From shared and personal vehicles, to long- and short-distance travel, to delivery and logistics, autonomy will fundamentally improve the way the world moves. At NVIDIA, our automotive team’s mission is to develop self-driving technology that enables safer, less congested roads and mobility for all.

“Safety is the most important aspect of a self-driving vehicle. NVIDIA’s creation of a safe self-driving platform is one of our greatest endeavors, and provides a critical ingredient for automakers to bring autonomous vehicles to market.”

Jensen Huang
NVIDIA founder and CEO
INTRODUCTION

Two decades ago, NVIDIA invented the GPU, sparking a revolution in computing. This core technology was born in the gaming and professional visualization industries, and has now translated to revolutionary leaps in high-performance and accelerated computing, as well as artificial intelligence (AI). As we’ve scaled our business and taken on new challenges, our systems and products have pushed boundaries in robotics, healthcare, medicine, space exploration, and entertainment. NVIDIA is also applying our technology-driven vision, computational performance, and energy efficiency to the transportation industry—helping vehicle makers around the world realize the dream of safe, reliable autonomous vehicles.

Autonomous vehicles are transforming the transportation industry. They have the potential to save lives by drastically reducing vehicle-related accidents, reduce traffic congestion and energy consumption, increase productivity, and provide mobility to those who are unable to drive.

Breakthroughs in AI and computing are also opening future fleets to dramatic new functionality, fundamentally transforming the vehicle architecture for the first time in decades into a truly software-defined architecture. Like all modern computing devices, these intelligent vehicles are supported by a large team of AI experts and software engineers, dedicated to improving the performance and capability of the car as technology advances. Capabilities and services can be added using over-the-air updates to every customer throughout the entire life of the car.

NVIDIA partners with vehicle makers, suppliers, sensor manufacturers, mapping companies, and startups around the world to develop the best solutions for the new world of mobility. We provide the systems architecture, AI supercomputing hardware, and full software stack required to build all types of vehicles—from AI-assisted cars and trucks to fully autonomous shuttles and robotaxis.

It all starts with NVIDIA DRIVE™, our highly scalable platform that can enable all levels of autonomous driving as defined by the Society of Automotive Engineers (SAE). These range from the most advanced driver-assistance system features (SAE Level 2: driver-assisted) through robotaxis (SAE Level 5: full autonomous).

The computational requirements of fully autonomous driving are enormous—easily up to 100 times higher than advanced vehicles in production today. With NVIDIA DRIVE, our partners achieve an increase in safety, running sophisticated hardware and software with many levels of diverse and redundant algorithms in real-time.

To streamline development, we’ve created a single software-defined scalable architecture that advances each level of autonomy with additional hardware and software while preserving the core architecture. The same strategy holds for safety. Our architecture enriches the overall system with elements that consistently improve safety.

NVIDIA has created essential technologies for building robust, end-to-end systems for the research, development, and deployment of self-driving vehicles, spanning from the data center to the edge. We offer a range of hardware and software solutions, from powerful GPUs and servers to a complete AI training infrastructure and in-vehicle autonomous driving supercomputers. We also support academic research and early-stage developers, partnering with dozens of universities worldwide and teaching courses on AI development at our Deep Learning Institute. As we identify challenges, we turn them into opportunities and build solutions.

This report provides an overview of NVIDIA’s autonomous vehicle technologies and how our unique contributions in safety architecture, co-designed hardware and software, design tools, methodologies, and best practices enable the highest possible levels of reliability and safety.

The underlying principle for safety is to introduce redundancy and diversity into the system. NVIDIA applies this principle when architecting processors and computing platforms, designing algorithms for driving and mapping, and integrating sensors into the vehicle.

As an example, a car equipped with 10 high-resolution cameras generates 2 gigapixels per second of data. Processing that data through multiple deep neural networks converts it into a rich, highly detailed understanding of the world around the vehicle, including other cars, pedestrians, and obstacles. This allows the vehicle to make decisions that are safe and reliable, ensuring a smooth and enjoyable driving experience.

THE BENEFITS OF SELF-DRIVING VEHICLES

Data collected by the U.S. Department of Transportation in 2019 highlights the urgent need for autonomous driving solutions. The traffic crash fatality rate was 1.1 per 100 million miles traveled, and in the previous year, the rate of pedestrian fatalities rose to its highest level since 1990. The National Highway Traffic Safety Administration estimates that 94 percent of traffic crashes are caused by human error, including distracted driving, drowsiness, speeding, and alcohol impairment.

Fortunately, technology that augments or replaces the driver can mitigate the vast majority of those incidents. It can also significantly reduce the number of hours commuters waste in traffic each year (currently averaging 42 hours) and the $160 billion lost to traffic congestion. Additionally, automated driving leads to more efficient traffic patterns, so it can reduce the amount of air pollution the transportation industry contributes, estimated in 2018 to be 28 percent of all U.S. greenhouse gas emissions.

COMPUTE ENABLES GREATER SAFETY

NVIDIA provides the high-performance computing necessary to enable redundant sensors, diverse algorithms, and additional diagnostics to support safer operation. We equip cars with many types of redundant sensors for sensor fusion. Then, multiple diverse AI deep neural networks and algorithms for perception, mapping, localization, and path planning are run on a combination of integrated GPUs, CPUs, deep learning accelerators (DLAs), and programmable vision accelerators (PVAs) for the safest possible driving.
THE FOUR PILLARS OF SAFE AUTONOMOUS DRIVING

NVIDIA offers a unified hardware and software architecture throughout its autonomous vehicle research, design, and deployment infrastructure. We deliver the technology to address the four major pillars essential to making safe self-driving vehicles a reality.

PILLAR 1
ARTIFICIAL INTELLIGENCE DESIGN AND IMPLEMENTATION PLATFORM

PILLAR 2
DEVELOPMENT INFRASTRUCTURE THAT SUPPORTS DEEP LEARNING

PILLAR 3
DATA CENTER SOLUTION FOR ROBUST SIMULATION AND TESTING

PILLAR 4
BEST-IN-CLASS PERVERSIVE SAFETY PROGRAM

This report details each of these pillars and how our autonomous vehicle safety program addresses industry guidelines and standards.

HOW DOES AN AUTONOMOUS VEHICLE WORK?

A fully autonomous vehicle can drive on its own through a combination of functionalities: perception, sensor fusion, localization to a high-definition map, path planning, and actuation. Cameras, radar, and lidar sensors enable the vehicle to see the 360-degree world around it, detecting traffic signals, pedestrians, vehicles, infrastructure, and other vital information. An on-board AI supercomputer interprets that data in real-time and combines it with cloud-based, high-definition mapping systems to safely navigate an optimal route. This self-driving system allows the vehicle to detect and anticipate how objects and people along its path are moving, and then automatically control the vehicle's steering, acceleration, and braking systems. The AI systems are capable of superhuman levels of perception and performance. They track all activity around the vehicle and never get tired, distracted, or impaired. The result is increased safety on our roads.
SAFETY REQUIRES HIGH-PERFORMANCE COMPUTING

The NVIDIA DRIVE architecture enables vehicle manufacturers to build and deploy self-driving cars and trucks that are functionally safe and can be demonstrated compliant to international safety standards such as ISO 26262 and ISO/DIS 21448, NHTSA recommendations, and global NCAP requirements.

For self-driving cars, processing performance translates to safety. The greater the compute, the more sophisticated the algorithms, DNNs and number of networks that can be run. NVIDIA offers an unprecedented 2,000 trillion operations per second of deep learning compute on the next-generation DRIVE AGX Pegasus robotaxi platform.

PILLAR 1
ARTIFICIAL INTELLIGENCE DESIGN AND IMPLEMENTATION PLATFORM

NVIDIA DRIVE is the world’s first scalable AI platform that spans the entire range of autonomous driving, from AI-assisted driving to robotaxis. It consists of hardware and software that work together to enable the production of automated and self-driving vehicles. Our platform combines deep learning, sensor fusion, and surround vision to enable a safe driving experience. With high-performance computing, the vehicle can understand in real-time what’s happening around it, precisely localize itself on a high-definition map, and plan a safe path forward.

To safely operate, self-driving vehicles require supercomputers powerful enough to process all the sensor data in real time. Our underlying hardware solutions include:

DRIVE AGX

This in-vehicle supercomputer is based on NVIDIA® Xavier™, the world’s first in-vehicle AI SoC designed for autonomous machines. It can simultaneously run numerous DNNs to provide safety and reliability. It’s also architecturally compatible with the upcoming NVIDIA Orin™ SoC, allowing developers to seamlessly transfer software to the latest-generation hardware.

DRIVE AGX Pegasus™

This high-performance AI supercomputer integrates multiple SoCs and GPUs, delivering the performance required for fully autonomous driving.

DRIVE Hyperion™

This complete AV data collection and perception evaluation platform includes DRIVE AGX Pegasus, along with sensors for autonomous driving, sensors for driver monitoring, sensors for localization, and other accessories.

NVIDIA DRIVE Software enables our customers to develop production-quality applications for automated and autonomous vehicles. It’s a full-stack solution that contains software modules, libraries, frameworks, and source packages that developers and researchers can use to optimize, validate, and deploy their work, including:

DRIVE OS

The foundation of the DRIVE Software stack, DRIVE OS is the underlying real-time operating system software and includes a safety application framework as well as support of Adaptive AUTOSAR. It includes NVIDIA for sensor input processing, NVIDIA CUDA® libraries for efficient parallel computing implementations, NVIDIA TensorRT™ for real-time AI inference, and other developer tools and modules to access hardware engines.

DRIVE Mapping

Our mapping solution integrates a scalable sensor suite, SDKs, and co-integrated high-definition maps available through partnerships with leading mapping companies. Our end-to-end mapping technologies also help collect environment data, create HD maps, and keep them updated.

NVIDIA DRIVE Mapping

Our intelligent experience open software platform delivers interior sensing for innovative AI cockpit solutions. It provides perception applications to access features and DNNs for advanced driver and occupant monitoring, AR/VR visualization, and natural language interactions between the vehicle and passengers.

The NVIDIA DRIVE architecture enables vehicle manufacturers to build and deploy self-driving cars and trucks that are functionally safe and can be demonstrated compliant to international safety standards such as ISO 26262 and ISO/DIS 21448, NHTSA recommendations, and global NCAP requirements.
In addition to in-vehicle supercomputing hardware, NVIDIA solutions power the data centers used to solve critical challenges faced in the development of safe AVs. A single test vehicle can generate petabytes of data each year. Capturing, managing, and processing this massive amount of data for an entire fleet of vehicles requires a fundamentally new computing architecture and infrastructure.

### PILLAR 2

**DEVELOPMENT INFRASTRUCTURE THAT SUPPORTS DEEP LEARNING**

In addition to in-vehicle supercomputing hardware, NVIDIA solutions power the data centers used to solve critical challenges faced in the development of safe AVs. A single test vehicle can generate petabytes of data each year. Capturing, managing, and processing this massive amount of data for an entire fleet of vehicles requires a fundamentally new computing architecture and infrastructure.

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**NVIDIA DRIVE Infrastructure** consists of the hardware and software needed for the massive data collection, deep learning development, and traceability to support large autonomous fleets. It runs on the NVIDIA DGX™ Saturn V—our AI supercomputer comprised of 2,140 GPUs—and is capable of 974 petaflops for AI model development and training. To ensure that Saturn V is fully utilized, there are several layers of software that orchestrate the tasks from hundreds of developers in an efficient production pipeline.

Our AI infrastructure helps developers create and quickly train DNN models to enable highly accurate perception systems for autonomous vehicles. For example, we used DRIVE Infrastructure to create dozens of neural networks that separately cover perception of lanes and road boundaries, road markings, signs, vehicles, wait conditions, free space, and more. Because of the safety-critical nature of these networks, DRIVE Infrastructure also includes purpose-built deep learning compilers and runtime engines that have been specially qualified to fulfill automotive-grade requirements.

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**PILLAR 3**

**DATA CENTER SOLUTION FOR ROBUST SIMULATION AND TESTING**

Before any autonomous vehicle can safely navigate on the road, engineers must first test and validate the AI algorithms and other software that enable the vehicle to drive itself. AI-powered autonomous vehicles must be able to respond properly to the incredibly diverse situations they could experience, such as emergency vehicles, pedestrians, animals, and a virtually infinite number of other obstacles—including scenarios that are too dangerous to test in the real world.

In addition, AVs must perform regardless of weather, road, or lighting conditions. There’s no feasible way to physically road test vehicles in all these situations, nor is road testing sufficiently controllable, repeatable, exhaustive, or fast enough. The ability to test in a realistic simulation environment is essential to providing safe self-driving vehicles. Coupling actual road miles with simulated miles in the data center is the key to developing and validating AVs.

**NVIDIA DRIVE Constellation™** is a data center solution that enables developers to test and validate the actual hardware and software that will operate in an autonomous vehicle before it’s deployed on the road. The platform consists of two side-by-side servers, with the first using NVIDIA GPUs running DRIVE Sim™ software to simulate sensor data from cameras, radars, and lidars on a virtual car driving in a virtual world. The output of the simulator is fed into the second server containing the DRIVE AGX Pegasus AI car computer running the complete AV software stack and processing the simulated sensor data.

The driving decisions from DRIVE AGX Pegasus are fed back to the simulator 30 times every second, enabling hardware-in-the-loop testing. DRIVE Constellation and DRIVE Sim can simulate rare and dangerous scenarios at a scale simply not possible with on-road test drives. The platform is capable of simulating billions of miles in virtual reality, running repeatable regression tests, and validating the complete AV system.

DRIVE Sim is an open platform offering a programming interface that allows users or ecosystem partners to incorporate their environment models, vehicle models, sensor models, and traffic scenarios. By working with a variety of partners, the platform can generate comprehensive, diverse, and complex testing environments.
PILLAR 4
BEST-IN-CLASS PERVERSIVE SAFETY PROGRAM

Safety is our highest priority at every step of the research, development, and deployment process. It begins with a pervasive safety methodology that emphasizes diversity and redundancy in the design, validation, verification, and lifetime support of the entire autonomous system. We settle for nothing less than best-in-class solutions in our processes, products, and safety architecture. NVIDIA safety is designed for software-defined autonomy because it accepts, tackles, and leverages the complexity of autonomous vehicles.

To conceptualize our autonomous vehicle safety program, we follow recommendations by the U.S. Department of Transportation’s National Highway Traffic Safety Administration in its 2017-2018, and 2020 publications. Throughout our program, we benchmark ourselves against the automotive industry’s highest safety standards from the International Organization for Standardization (see sidebar). These are:

**Functional Safety and Safety of the Intended Functionality (SOTIF)**
Autonomous vehicles must be able to operate safely, even when a system fails. Functional safety focuses on measures to ensure risk is minimized when hardware, software, or systems fail to work as intended. Safety hazards can be present even if the system is functioning as designed, without a malfunction. SOTIF focuses on ensuring the absence of unreasonable risk due to hazards resulting from insufficiencies in the intended functionality or from reasonably foreseeable misuse.

**Federal and International Regulations and Standardization**
We also adhere to federal and international regulations, including global NCAP (New Car Assessment Program), Euro NCAP, and the United Nations Economic Commission for Europe. We influence, co-create, and follow standards of the International Standards Organization, the New Vehicle Assessment Program, and the Society of Automotive Engineers International, as well as standards from other industries.

We also contribute to standardization initiatives of the Institute of Electrical and Electronics Engineers (IEEE), such as IEEE P2846 (Assumptions for Models in Safety-Related Automated Vehicle Behavior) and IEEE P2851 (Exchange/Interoperability Format for Safety Analysis and Safety Verification of IP, SoC, and Mixed Signal). Beyond complying with federal and industry guidelines, we practice open disclosure and collaboration with industry experts to ensure that we remain up-to-date on all current and future safety issues. We also hold leadership positions in multiple safety working groups to drive the state-of-the-art and explore new research areas, such as safety for AI systems and explainable AI.

The NVIDIA DRIVE AGX architecture is designed to support Levels 2 through 5 of the SAE J3016 specification and includes support of NCAP.

\NATIONAL AND INTERNATIONAL SAFETY REGULATIONS AND RECOMMENDATIONS

NVIDIA adheres to national and international safety recommendations outlined here.

**International Organization for Standardization (ISO)**

**Functional Safety**
ISO 26262 addresses functional safety in road vehicles. It focuses on avoiding failures that can be avoided, while detecting and responding appropriately to unavoidable failures due to malfunction. This is done through combinations of robust processes during development, production, and operation, as well as inclusion of diagnostics and other mitigations to manage random hardware failures. ISO 26262 can be applied at the vehicle, system, hardware, and software levels.

**Safety of the Intended Functionality (SOTIF)**
ISO/DIS 21448 addresses safety of the intended functionality in road vehicles. It reuses and extends the ISO 26262 development process to address SOTIF concerns. Safety hazards are evaluated for vehicle behavior and known system limitations and mitigations are defined, implemented, and verified during development. Before release, the safety of the vehicle system is validated to ensure that no unreasonable risk remains.

**National Highway Traffic Safety Administration (NHTSA)**
Safety guidelines for autonomous driving are covered in a publication released by NHTSA titled Voluntary Guidance for Automated Driving Systems. Because NVIDIA is not a vehicle manufacturer, a few of the safety elements, such as crashworthiness and whiplash/rear-end crash protection, are not explicitly covered in this report. Of the 12 safety elements representing industry consensus on safety for the use of automated driving systems on public roadways, 10 are the most relevant to NVIDIA:

- System Safety
- Operational Design Domain
- Object And Event Detection and Response
- Fallback (Minimal Risk Condition)
- Validation Methods
- Data Recording
- Human-Machine Interface (HMI)
- Vehicle Cybersecurity
- Consumer Education and Training
- Federal, State, and Local Laws

**Global NCAP**
Regional NCAPs adjust safety practices to their particular markets, and NVIDIA complies with all local NCAP versions. The European New Vehicle Assessment Program (Euro NCAP) provides consumers with an independent safety assessment of vehicles sold in Europe. Euro NCAP published its 2025 Roadmap, which presents a vision and strategy to emphasize primary, secondary, and tertiary vehicle safety. We are currently addressing these Euro NCAP recommendations:
The NVIDIA Solution – NHTSA Safety Element

SYSTEM SAFETY

NVIDIA has created a system safety program that integrates robust design and validation processes based on a systems-engineering approach with the goal of designing automated driving systems with the highest level of safety and free of unreasonable safety risks.

FALLBACK (MINIMAL RISK CONDITION)

Our products enable the vehicle to detect a system malfunction or breach of the operational design domain, and then transition the system to a safe or degraded mode of operation based on warning and degradation strategy. Every NVIDIA autonomous driving system includes a fallback strategy that enables the driver to regain proper control of the vehicle or allows the autonomous vehicle to return to a minimal risk condition independently.

Our HMI products can be used to notify the driver of a potentially dangerous event and return the vehicle to a minimal risk condition independently, or alert the driver to regain proper control. The minimal risk conditions vary according to the type and extent of a given failure.

VALIDATION METHODS

Validation methods establish confidence that the autonomous system can accomplish its expected functionalities. Our development process contains rigorous methods to verify and validate our products’ behavioral functionality and deployment. To demonstrate the expected performance of an autonomous vehicle for deployment on public roads, our test approaches include a combination of simulation, test track, and on-road testing. These methods expose the performance under widely variable conditions, such as when deploying fallback strategies.

The NVIDIA Solution – NHTSA Safety Element

OPERATIONAL DESIGN DOMAIN

NVIDIA has developed an extensive set of operational design domains as recommended by NHTSA. Each operational design domain includes the following information at a minimum to define the product’s capability boundaries: roadway types, geographic area and geo-region conditions, speed range, environmental conditions (weather, time of day, etc.), and other constraints.
NVIDIA designs the DRIVE AGX platform to ensure that the autonomous vehicle can operate safely within the operational design domain for which it's intended. In situations where the vehicle is outside its defined operational design domain or conditions dynamically change to fall outside it, our products enable the vehicle to return to a minimal risk condition (also known as a safe fallback state). For example, if an automated system detects a sudden change such as a heavy snowfall that affects the sensors and, therefore, the driving capability within its operational design domain, the system is designed to hand off control to the driver. If significant danger is detected, the system is designed to come to a safe stop.

NVIDIA follows the V-model (including verification and validation) at every stage of DRIVE development. We also perform detailed analyses of our products’ functionality and related hazards to develop safety goals for the product. For each identified hazard, we create safety goals to mitigate risk, each rated with an Automotive Safety Integrity Level (ASIL). ASIL levels of A, B, C, or D indicate the level of risk mitigation needed, with ASIL D representing the safest (the highest level of risk reduction). Meeting these safety goals is the top-level requirement for our design. By applying the safety goals to a functional design description, we create more detailed functional safety requirements.

At the system-development level, we refine the safety design by applying the functional safety requirements to a specific system architecture. Technical analyses—such as failure mode and effects analysis (FMEA), fault tree analysis (FTA), and dependent failure analysis (DFA)—are applied iteratively to identify weak points and improve the design. Resulting technical safety requirements are delivered to the hardware and software teams for development at the next level. We’ve also designed redundant and diverse functionality into our autonomous vehicle system to make it as resilient as possible. This ensures that the vehicle will continue to operate safely when a fault is detected or reconfigure itself to compensate for a fault.

At the hardware-development level, we refine the overall design by applying technical safety requirements to the hardware designs of the board and the chip (SoC or GPU). Technical analyses are used to identify any weak points and improve the hardware design. Analysis of the final hardware design is used to verify that hardware failure related risks are sufficiently mitigated.

At the software-development level, we consider both software and firmware. We refine the overall design by applying technical safety requirements to the software architecture. We also perform code inspection, reviews, automated code structural testing, and code functional testing at both unit and integration levels. Software-specific failure mode and effects analysis are used to design better software. In addition, we design test cases for interface, requirements-based, fault-injection, and resource-usage validation methods.

When we have all necessary hardware and software components complete, we integrate and start our verification and validation processes on the system level. In addition to the autonomous vehicle simulation described under Simulation, we also perform end-to-end system testing and validation.

\[SAFETY\ FOR\ SOFTWARE-DEFINED\ AUTONOMY\]

Our safety approach is architected for software-defined autonomy. Compared to safety approaches for traditional systems, NVIDIA’s safety strategy is:

- Designed for dynamic system configurations
- A flexible platform for hardware and software richness
- Optimized for a growing number of functions
- Ecosystem-friendly with open system boundaries
- Designed for AI hardware, software, and tools
- Expandable with new algorithms
- Supporting of decomposable safety concepts
- Compatible with millions of lines of code
- Easily updatable
- Continuously and over-the-air upgradable
- Function-aware, data-oriented, and validated end-to-end
- Hardware-firmware-software harmonized
END-TO-END: AI TRAINING, SIMULATION, AND TESTING

NVIDIA’s infrastructure platform includes a data factory to label millions of images, the NVIDIA DGX SaturnV supercomputer for training DNNs, DRIVE Constellation for hardware-in-the-loop simulation, and other tools to complete our end-to-end system. Autonomous vehicle software development begins with collecting huge amounts of data from vehicles in globally diverse environments and situations. Multiple teams across many geographies access this data for labeling, indexing, archiving, and management before it can be used for AI model training and validation. We call this first step of the autonomous vehicle workflow the “data factory.”

AI model training starts when the labeled data is used to train the models for perception and other self-driving functions. This is an iterative process; the initial models are used by the data factory to select the next set of data to be labeled. Deep learning engineers adjust model parameters as needed, and then re-train the DNN, at which point the next set of labeled data is added to the training set. This process continues until the desired model performance and accuracy is achieved.

Self-driving technology must be evaluated again and again during development in a vast array of driving conditions to ensure that the vehicles are far safer than human-driven vehicles. Simulation runs test-drive scenarios in a virtual world, providing rendered sensor data to the driving stack and carrying out driving commands from the driving stack. Re-simulation plays back previously recorded sensor data to the driving stack. The AI model is finally validated against a large and growing collection of test data.

The NVIDIA Solution – NHTSA Safety Element

OBJECT AND EVENT DETECTION AND RESPONSE

Object and event detection and response refers to the detection of any circumstance that’s relevant to the immediate driving task, and the appropriate driver or system response to this circumstance. The NVIDIA DRIVE AV module is responsible for detecting and responding to environmental stimuli, both on and off the road. The NVIDIA DRIVE IX module helps monitors the driver and take mitigation actions when they’re required.

HARDWARE

The NVIDIA DRIVE AGX hardware architecture is scalable, covering everything from entry-level advanced driver assistance systems to fully autonomous robotics. The current generation NVIDIA Xavier SoC’s safety architecture was developed over several years by more than 300 architects, designers, and safety experts based on analysis of more than 150 safety-related modules. It enables systems to achieve ASIL D, the highest functional safety rating.

NVIDIA Xavier has continuously shattered MLPerf AI inference benchmarks—the only consortium-based and peer-reviewed inference performance tests.

The Xavier SoC will transition to the next-generation NVIDIA Orin, which contains 17 billion transistors to process incredible amounts of data. Sixteen lanes of GMSL (gigabit multimedia serial link) high-speed input/output and 4x 10 Gb Ethernet ports connect Orin to the largest array of lidar, radar, and camera sensors of any chip ever built, with an aggregate ingress capability of 204 Gbps.

Six types of processors work together inside Orin: an image signal processor, a video processing unit, a programmable vision accelerator, a deep learning accelerator, a CUDA GPU, and a CPU. Together, they process more than 256-trillion operations per second (TOPS)—an 8x performance increase from the previous generation—for deep learning alone.

These autonomous driving SoCs include many types of hardware diagnostics. Key areas of logic are duplicated and tested in parallel using lockstep comparators and error-correcting codes on memories to detect faults and improve availability. A unique built-in self-test helps to find faults in the diagnostics, wherever they may be on the chip.
SOFTWARE

The NVIDIA DRIVE AV software stack consists of three major software modules: Perception, Mapping, and Planning. The **Perception module** takes sensor data and uses a combination of deep learning and traditional computer vision to determine an understanding of the vehicle’s environment, referred to as the World Model. Once the environment is understood, the **Planning module** uses this information to determine and score a set of trajectories and determine the best route. The Vehicle Dynamics Control module can then score a set of trajectories for the best route.

**DRIVE AV** currently uses more than 20 DNN models running simultaneously, in addition to a large suite of computer vision and robotics algorithms. However, the number of DNNs and the capabilities they cover is continually growing. For example, a dedicated DNN controls the detection and response to pedestrians and cyclists around the vehicle, running simultaneously with a DNN dedicated to traffic lights. We also expand the use of our DNNs to support features like automatic emergency steering and autonomous emergency braking, providing redundancy to these functionalities.

VEHICLES & SENSORS

**DRIVE Hyperion™** is a hardware implementation of the DRIVE platform to enable self-driving development, data campaign processing, verification, validation, and ground-truth data collection across automation levels. In addition, **DRIVE Hyperion** provides a path to productization of AV and AI cockpit technology. The platform leverages multiple sensor modules—including cameras, radars, IMUs, and ultrasonic sensors—and is deployable to a variety of vehicle types.

Each major function—such as sensor processing, AI-based perception, localization, trajectory planning, and mapping—is performed with multiple redundant and diverse methods to achieve the highest level of safety. For example, **DRIVE AV** uses embedded modules for detecting and handling obstacles and drivable space. For traffic lights, stop signs, intersections, and stop lines. For paths, we detect lane edges and drivable paths. This detection is happening over multiple frames, and objects are tracked over time. We also layer diversity by using multiple sensor types (radar, camera, and lidar). The triple combination of diverse DNNs, tracking of objects over multiple frames, and presence of different sensor types ensures safe operation within the operational design domain. Additionally, the integrated functional safety mechanisms enable safe operation in the event of a system fault.
DATA CENTER

After collecting sensor data, we process it and, in the case of camera data, select images to be labeled for training the AI. The whole process is continuously validated. We label not only objects and images within captured frames, but also scenarios and conditions in video sequences. The more diverse and unbiased data we have, the safer the DNNs become. We also define key performance metrics to measure the collected data quality and add synthetic data into our training datasets. The ultimate goal is to continuously add training data to build a comprehensive matrix of locations, conditions, and scenarios. Performance of neural network models is validated against the data and retested as new data is collected.

MAPPING

A robust mapping and localization process allows a self-driving vehicle to determine its location with precision, discern potential hazards, and then determine exactly where it can safely drive. NVIDIA DRIVE enables vehicle manufacturers to use maps from various global providers while also allowing the vehicle to build and update a map using sensors available on the car. We localize the vehicle to high-definition maps of every traditional map provider and perform exhaustive simulations to build in proper functional safety.

The NVIDIA DRIVE platform has many monitoring processes to diagnose and mitigate the effects of map failures in real-time. First, map quality and validation checks are implemented in each step of the map generation and delivery pipeline to assure its integrity. Next, before a map is used in the vehicle for autonomous driving, a background process determines its accuracy by comparing key attributes to perception results. Using the map for autonomy is enabled only after these checks have been successfully completed.

Autonomous vehicles operate in environments that require maps be continually updated as changes to the road infrastructure and environment are discovered. The NVIDIA DRIVE platform maintains the freshness of its maps by continuously sending any discrepancies that are found between the map and live perception results to the map publisher. These results are aggregated and an updated map is sent to the vehicle after successful completion of the validation process.

NVIDIA collaborates with mapping companies all over the world, including AutoNavi, Baidu, HERE, KingWayTek, NavInfo, TomTom, Zenrin, and many others. Our application-programming interface allows NVIDIA systems to communicate and calibrate our high-precision localization system with their high-definition maps.

In addition to labeling the objects in an image, we label the conditions under which data was collected. This provides a matrix of conditions we can use as a training dataset to test the performance of our DNN models against a wide range of scenarios, weather conditions, and times of day. When performance doesn’t meet key indicators, we collect and process more data for validation.

GPUs in the data center are used extensively to investigate new DNNs with diverse datasets, continually train neural network models, analyze the results of workflows, and test and validate outcomes using large-scale systems for simulation in virtual worlds and re-simulation of collected data.
Occurrences of dangerous incidents experienced by a single test vehicle are extremely rare, making it hard to accurately assess safety or compare different designs. For example, U.S. drivers experience a police-reported collision approximately once every 500,000 miles. To statistically demonstrate that a self-driving system has a lower collision rate than human drivers requires a sizable test fleet driving around the clock. As a result, it’s very difficult to verify and validate vehicle self-driving capabilities solely using on-road testing.

DRIVE Constellation bridges this verification and validation gap. It’s designed for maximum flexibility, throughput, and risk elimination and relies on high-fidelity simulation. It also uses the computing horsepower of two different servers to deliver a cloud-based computing platform capable of generating billions of virtual miles of autonomous vehicle testing.

**SIMULATION**

In the image above, the first server in DRIVE Constellation runs DRIVE Sim software to simulate the multiple sensors of a self-driving vehicle and vehicle dynamics. Powerful GPUs accurately render sensor data streams that represent a wide range of environments and scenarios. This allows engineers to test rare conditions, such as rainstorms, or sharp glare at different times of the day and night. Each scenario can be tested repeatedly, adjusting multiple variables such as road surfaces and surroundings, weather conditions, other traffic, and time of day.

The second server contains a DRIVE AGX Pegasus vehicle computer that runs the complete autonomous vehicle software stack (DRIVE AV) that operates inside an autonomous vehicle. It processes the simulated data as if it were coming from the sensors of a vehicle driving on the road, and sends actuation commands back to the simulator.

**REPLAY**

In addition to simulation, NVIDIA utilizes re-simulation, or replay—playing back previously recorded sensor data or synthetic data—to test the driving software stack. For example, we incorporate actual sensor data from automatic emergency braking scenarios using replay to help eliminate false positives.

**A TECHNICAL PERSPECTIVE ON VALIDATION AND VERIFICATION SERVICES**

DRIVE Sim is engineered for safety validation and is the centerpiece of NVIDIA’s autonomous vehicle validation and verification methodology. It’s used for testing vehicle software at all integration levels (units, integration, and system) and at all abstraction levels (model, software, and hardware-in-the-loop). It comprises all components of the self-driving vehicle experience, accounting for sensor data, pedestrians, drivers, roads, signs, vehicle dynamics, etc.

**The NVIDIA Solution – NHTSA Safety Element**

DATA RECORDING

NVIDIA replay enables real data from sensors placed on test vehicles that are driving on the public roads to be fed into the simulation. To maximize the safety of self-driving vehicles, NVIDIA offers a combination of simulated data to test dangerous road scenarios coupled with real-world data from replay.
ON-ROAD TESTING

NVIDIA created the DRIVE Road Test Operating Handbook to ensure a safe, standardized on-road testing process. This document specifies what must be done before, during, and upon completion of every road test. As recommended in the U.S. DOT report Preparing for the Future of Transportation: Automated Vehicles 3.0, NVIDIA’s process is modeled on the FAA-certified Pilot’s Operating Handbook that must be carried in-flight with every general aviation aircraft in the United States.

On-road testing is always performed with a highly trained safety driver continuously monitoring the vehicle’s behavior and ready to immediately intervene when necessary. A co-pilot monitors the self-driving software—like checking that the objects detected by the car correspond to those viewed live—and that the vehicle’s path is valid for current road conditions.

We modify our processes as necessary, such as during the COVID-19 pandemic, when it’s not possible to test in-person. Our DRIVE RC remote control teleoperation system and DRIVE Sim virtual testing platform make it possible to safely and securely test vehicles from home.

Prior to allowing software to be tested on-road, it’s extensively tested using unit tests and system simulation. The diagram on page 25 explains what steps need to be taken before the autonomous vehicle is permitted to drive on public roads.

Human-Machine Interface and Driver Monitoring

Before widespread deployment of AVs becomes a reality, driver monitoring technology can help make human drivers safer today. Incorporating AI into the vehicle cockpit can add a robust layer of safety, ensuring that drivers stay alert or taking action if they’re not paying attention.

The DRIVE IX software stack lets vehicle manufacturers develop in-vehicle driver-monitoring AI in a variety of ways. Similar to the way deep-learning algorithms are trained on driving data to operate a vehicle, the algorithms built on DRIVE IX can be trained to identify certain behaviors and step in whenever needed. For example, tracking a driver’s head and eyes lets the system understand when they’re paying attention, and blink frequency monitoring can assess drowsiness. Depending on a manufacturer’s preferences, the system can alert the driver using audio, visual, or haptic warnings to return their focus to the road.

DRIVE IX can also monitor the environment outside the vehicle. If a driver is about to exit the vehicle without looking as a bicyclist approaches alongside, DRIVE IX can provide an alert or prevent the door from opening until the bicyclist has safely passed.

DRIVE IX extends AI capability to detect individual passengers in a vehicle and let riders use voice commands for actions like temperature control or rolling down a window. Passenger detection also enables DRIVE IX to alert the driver if a child or pet has been accidentally left in the back seat, addressing the NCAP requirement to detect a child present in the vehicle15.

The platform is designed to be expandable with custom modules. Gesture, gaze, and eye openness detections are performed using DNNs that work with integrated third-party modules to predict emotion.
Every driver is qualified through an end-to-end process that includes commercial driving experience, AV licensing, and up to 70 hours of training. Each car has a driver and a co-pilot for monitoring, communication, and redundancy.

Software must pass both simulation and closed-course tests before going to the road.

Every car has a five-star safety rating, ADAS capabilities, and sensors used for automatic emergency braking (AEB).

Feedback from the test drives is provided to the readiness phases to help improve crew, software, and vehicle performance in the next trip.

A remote operations controller monitors all ongoing vehicle movements through internal and external cameras and GPS from a centralized control center.

Before going to the road, a car must pass an FAA-fashioned safety checklist.

At NVIDIA, developing self-driving cars is about more than just technological innovation and a vision for the future. It's driven by a singular dedication to safety. For every driver, every road, and every community in which these cars drive.

The FAA-fashioned safety checklist is also used at the conclusion of every trip.
An autonomous vehicle platform can't be considered safe without cybersecurity. Without solid security engineering practices and development, it becomes impossible to deliver on the functional and actual safety required for automotive. Security breaches can compromise a system's ability to deliver on fundamental safety goals. To deliver a best-in-class automotive security platform with high consumer confidence, we've built a world-class security team and aligned with government and international standards and regulations. We've also built strong partner relationships to remediate security incidents and serve as a good steward in protecting customer data privacy.

NVIDIA follows international and national standards for hardware and software implementations of security functionality, including cryptographic principles. Plus, we adhere to standards set by the National Institute of Standards and Technology and General Data Protection Regulations to protect the data and privacy of all individuals.

Our cybersecurity team works with the Automotive Information Sharing and Analysis Center (Auto-ISAC), NHTSA, SAE, and the Bureau of Industry and Security (Department of Commerce). We also contribute to the Automatic Identification System (Department of Homeland Security), Federal Information Processing Standards (Federal Information Security Management Act), and Common Criteria standards or specifications. In addition, we use the SAE J3061 cybersecurity process as a guiding principle and leverage processes and practices from other cybersecurity-sensitive industries. Plus, we participate in the ISO/SAE 21434 standard development, which ensures the necessary building blocks for cybersecurity are implemented at the hardware chip level. And we review platform code for security conformance and use static and dynamic code analysis techniques.

NVIDIA employs a rigorous security development lifecycle into our system design and hazard analysis processes, including threat models that cover the entire autonomous driving system—hardware, software, manufacturing, and IT infrastructure. The NVIDIA DRIVE platform has multiple layers of defense that provide resiliency against a sustained attack.

NVIDIA also maintains a dedicated Product Security Incident Response Team that manages, investigates, and coordinates security vulnerability information internally and with our partners. This allows us to contain and remediate any immediate threats while openly working with our partners to recover from security incidents.

We work with our suppliers to ensure the components that make up the whole of an autonomous driving platform provide the necessary security features. Proper cybersecurity of complex platforms becomes assured when all the links in the chain from raw data to processed input to control actions meet security requirements. In addition, NVIDIA works with our vendors to ensure they have a cybersecurity reaction capability for new or unfound threats.

Finally, as vehicle systems have a longer in-use lifespan than many other types of computing systems, we use advanced machine learning techniques to detect anomalies in the vehicle communications and behaviors and provide additional monitoring capabilities for zero-day attacks.

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**DEVELOPER TRAINING AND EDUCATION**

NVIDIA is committed to making AI education easily accessible, helping both experts and students learn more about these breakthrough technologies. The NVIDIA Deep Learning Institute offers multiple courses on how to design, train, and deploy DNNs for autonomous vehicles, and we produce a wide range of content to answer common questions. We now have over 2 million registered developers in eight different domains, such as deep learning, accelerated computing, autonomous machines, and self-driving cars.

In addition, NVIDIA hosts the GPU Technology Conference series around the world to help educate students, developers, and executives on accelerated computing, AI, and autonomous vehicles.
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VEHICLE CYBERSECURITY

NVIDIA implements foundational best practices in multiple cybersecurity actions and processes.

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CONSUMER EDUCATION AND TRAINING

We continually develop, document, and maintain material to educate our employees, suppliers, customers, and end consumers. We offer multiple AI courses under our Deep Learning Institute and we report about new knowledge and developments at the NVIDIA GPU Technology Conferences around the world. We also collaborate with the research organizations to invent improved approaches to autonomy and maintain the highest integrity level to co-create world-class thought leadership in the autonomous vehicle domain.

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FEDERAL, STATE, AND LOCAL LAW

We operate under the principle that safety is the first priority and comply with international, federal, state, and local regulations, and all safety and functional safety standards. We also frequently communicate with regulators to ensure that our technology exceeds all safety standards and expectations. We are active in standardization organizations to advance the future of autonomous driving.

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NVIDIA ACTIVITY IN EXPERT GROUPS

NVIDIA is respected as an organization of experts in selected fields. Some of the working groups benefiting from our expertise include:

- ISO TC 22/SC 32/WG 8, “Functional Safety,” international level
  - U.S. working group chairman
  - ISO 26262 Part 10 leader
  - ISO 26262 Part 11 leader
- ISO TC 22, “Road Vehicles,” US delegate
- ISO TR 6846, “Road vehicles — Safety and cybersecurity for automated driving systems — Design, verification and validation methods,” IT delegate
- ISO/PAS 19651, project leader
- 2 of 7 U.S. delegates to international working group
- U.S. leader for ISO 26262 Part 5, hardware development
- Euro NCAP technical expert through the European Association of Automotive Suppliers
- UNECE Working Groups on Functional Requirements for Automated Vehicles (FRAV) and Validation Methods for Automated Driving (VMAD)
- SAE Automotive Functional Safety Committee
- Multiple worldwide R&D consortia, technical reviewer committees, and R&D chair roles

NVIDIA is unique in its role of providing underpinning technologies for the design, development, and manufacture of safe, reliable software-defined autonomous vehicles. Our ability to combine the power of visual and high-performance computing with artificial intelligence and proven software development makes us an invaluable partner to vehicle manufacturers and transportation companies around the world.

We adhere to the industry’s most rigorous safety standards in the design and implementation of the powerful NVIDIA DRIVE platform, and we collaborate with industry experts to address current and future safety issues. Our platform aligns with and supports the safety goals of the major autonomous vehicle manufacturers and robotaxi companies.

Building safe autonomous vehicle technology is one of the largest, most complex endeavors our company has ever undertaken. We’ve invested billions of dollars in research and development, and many thousands of engineers throughout the company are dedicated to this goal. During the past six years, more than 1,300 engineer-years have been invested in our automotive safety process. There are currently more than 60 AV companies who have nearly 1,500 automated and autonomous test vehicles on the road powered by NVIDIA technology. They recognize that greater compute in the vehicle enables redundant and diverse software algorithms to deliver increased safety on the road.

Safety is the focus at every step—from designing, to testing, and, ultimately, deploying a self-driving vehicle on the road.

We fundamentally believe that self-driving vehicles will bring transformative benefits to society. By eventually removing human error from the driving equation, we can prevent the vast majority of accidents and minimize the impact of those that do occur. We can also increase roadway efficiencies and curtail vehicle emissions. Finally, those that may not have the ability to drive a car will gain the freedom of mobility when they can easily summon a self-driving vehicle.

The autonomous vehicle industry is still young, but it’s maturing quickly. NVIDIA holds a key role in the development of AVs that will revolutionize the transportation industry over the next several decades. Nothing is more exciting to us than overcoming technology challenges and making people’s lives better. We invite you to join us on this ride of a lifetime.

SUMMARY

NVIDIA is unique in its role of providing underpinning technologies for the design, development, and manufacture of safe, reliable software-defined autonomous vehicles. Our ability to combine the power of visual and high-performance computing with artificial intelligence and proven software development makes us an invaluable partner to vehicle manufacturers and transportation companies around the world.

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ACRONYMS

ASIL Automotive Safety Integrity Level
CUDA Compute Unified Device Architecture
DFA Dependent Failure Analysis
DLA Deep Learning Accelerator
DLI Deep Learning Institute
DNN Deep Neural Network
FMEA Failure Modes and Effects Analysis
FTA Fault Tree Analysis
GNSS Global Navigation Satellite System
HAZD Hazard and Operability Analysis
HMI Human-Machine Interface
IMU Inertial Measurement Unit
ISO International Organization for Standardization
MISRA The Motor Industry Software Reliability Association
NCAP New Car Assessment Program
NHTSA National Highway Traffic Safety Administration
ODD Operational Design Domain
PLC Product Life Cycle
PVA Programmable Vision Accelerators
SAE Society of Automotive Engineers
SDK Software Development Kit
SoC System-on-a-Chip
SEoC Safety Element Out of Context
SOTIF Safety of the Intended Functionality
TOPS Trillion Operations Per Second
V&V Verification and Validation

APPENDICES