nuro

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Delivering Safety

Introduction

Nuro's mission is to better everyday life through robotics.

We measure our success by how many people's lives are substantially improved by our products. That's why we created the first fully self-driving on-road vehicle designed to transport goods — quickly, safely, and affordably. With the help of robotics, we can significantly improve people's day-to-day lives, transform local commerce, and make our roads safer.

More than 1.3 million people die in car crashes every year worldwide, and 94% of those crashes are caused by human error.[1] Self-driving vehicles have the potential to save lives by preventing road accidents resulting from fatigue, distraction, failure to properly perceive the environment, overly aggressive driving, and other common mistakes.

To improve road safety most effectively, autonomous vehicles should be designed, built, and operated to conduct many of the trips people take today in manually driven vehicles. This means two things. First, common causes of car accidents can be reduced when autonomous technology handles more of the driving tasks. Second, many of the trips we take can and should be replaced entirely by self-driving vehicles that operate without people on board. Why? Nearly half of the trips we take in cars today are to run errands, such as picking things up from local stores. Rather than getting into the car to rush around town conducting all of these errands, we can stay safely off the roads while groceries, medicines, hot foods, and other goods are transported to us on demand.

Our newest model custom delivery vehicle, R2, is lighter, nimbler, narrower, and drives more slowly than a passenger car. And it's equipped with state-of-the-art software and sensing capabilities that never get distracted or fatigued. R2 is engineered to make delivery of everything more accessible—from groceries to packages, prescription drugs to pizza—and help all of us spend time on the things and people we care about the most.

With no driver or passengers inside, R2 is built to prioritize the wellbeing of other road users over the cargo carried inside. A recent study conducted by the transportation economist firm Steer concluded that during the initial period of 2025 to 2035, when services such as Nuro's are ramping up, autonomous driving could prevent 348,000 car crashes and save 4,800 lives in the United States alone.[2]

Nuro is the first company to operate an autonomous commercial delivery service open to the general public. We've been testing our AV technology since 2016 and have been conducting active on-demand home delivery operations for more than two years using our modified Prius vehicles with a safety driver and our first generation custom vehicle, R1. During the summer of 2018, we launched a delivery service in Scottsdale, Arizona, in partnership with Kroger, delivering groceries to local homes and businesses.

We then expanded to Houston, Texas, where we've operated a commercial local delivery service continuously since spring 2019 with our self-driving Priuses. These programs have included thousands of on-time deliveries, high customer satisfaction, and zero autonomy safety incidents. As we evolve both our commercial delivery service capabilities and our technology platforms, our self-driving Prius vehicles with safety drivers will be replaced with our custom-built, delivery-only vehicles, such as R2 and future models.

In December 2020, the California Department of Motor Vehicles granted Nuro the first California permit to deploy autonomous vehicles commercially on public roads. Ever since California adopted one of the first autonomous vehicle laws in the United States in 2012, the DMV has been working towards this milestone. The agency established a three-stage permitting process for companies to move from testing with a safety driver to driverless testing, and finally, to commercial deployment. The DMV requires a substantial record of data and information to be provided by companies seeking permits. It collects input from law enforcement, local communities, and stakeholders. As DMV Director Steve Gordon emphasized:

> "Issuing the first deployment permit is a significant milestone in the evolution of autonomous vehicles in California…We will continue to keep the safety of the motoring public in mind as this technology develops."[3]

We are proud to have completed the safety assurance processes needed to enable the first commercial self-driving operations in California.

Earlier in 2020, the US Department of Transportation granted Nuro the agency's first approved exemption for any autonomous vehicle that does not contain all of the same equipment required of a standard, manually-operated vehicle.[4] This exemption was granted for the R2, pursuant to a comprehensive and lengthy process, including public notice and comment, to demonstrate and answer questions regarding the safety of Nuro's vehicle design modifications and DOT's commitment to public safety. It followed three years of discussion with the agency, voluminous submissions of information on Nuro's technology, and supportive comments from leaders in the communities in which we operate, our long-standing partners, and our fellow citizens concerned about road safety.

When the COVID-19 pandemic hit, Nuro partnered with government agencies to establish contactless delivery services with R2 at temporary care facilities in California to carry food, water, and medical supplies to patients and doctors with the goal of decreasing points of contagion. In late 2020, we announced that R2 had conducted fully autonomous public roads testing in three states: Arizona, California, and Texas.[5]

This Voluntary Safety Self-Assessment report outlines our approach to safety and the progress we have made so far. It is organized in two parts.

PART 01

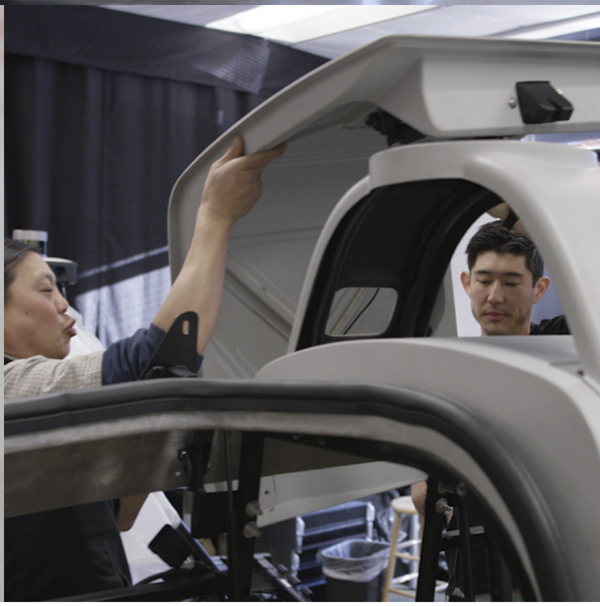
Introduces Nuro, our self-driving vehicles, and our approach to operations.

PART 02

Explains how we address the 12 safety elements that the Department of Transportation's National Highway Traffic Safety Administration has identified as critical areas of focus for self-driving vehicles.

PART 01

Nuro's Approach to Self-Driving Vehicles and Operations



About Nuro

Nuro was founded in 2016 by leaders in robotics and artificial intelligence with experience building some of the world's first self-driving vehicles and innovative robotics systems. They saw the need for a new robotics company focused on making this potentially life-saving technology available to society on a more accelerated timeline. Nuro's team has grown to include some of the best minds from academia and industry, including veterans of self-driving software, automobile design and manufacturing, consumer electronics, transportation and logistics services, and award-winning robotics projects.

Our Vehicle

Purpose-built zero-occupant delivery robot

Central to our long-term vision is a custom robot designed and produced exclusively for delivery and engineered from the ground up with safety in mind. To date, we have produced two models of this robot: the R1 and R2. Both are built-for-purpose vehicles and are designed never to accommodate a human driver or passengers. Instead, they are designed to be fully autonomous, driverless, and zero-occupant. In addition, Nuro is committed to a future of road transport that does not contribute to climate change with carbon emissions. That is why each of our custom vehicles—and all future models—are and will be zero-emission electric vehicles. In 2020, Nuro commissioned Steer to examine the economic, safety, and environmental impacts of our type of autonomous delivery service.

The study concluded that from 2025 to 2035, the proliferation of zero-emissions autonomous delivery services such as ours can prevent 407 million tons of CO_2 emissions.[6] For context, that would offset the emissions from powering every household in New York City, Los Angeles, Chicago, and Houston combined for ten years.

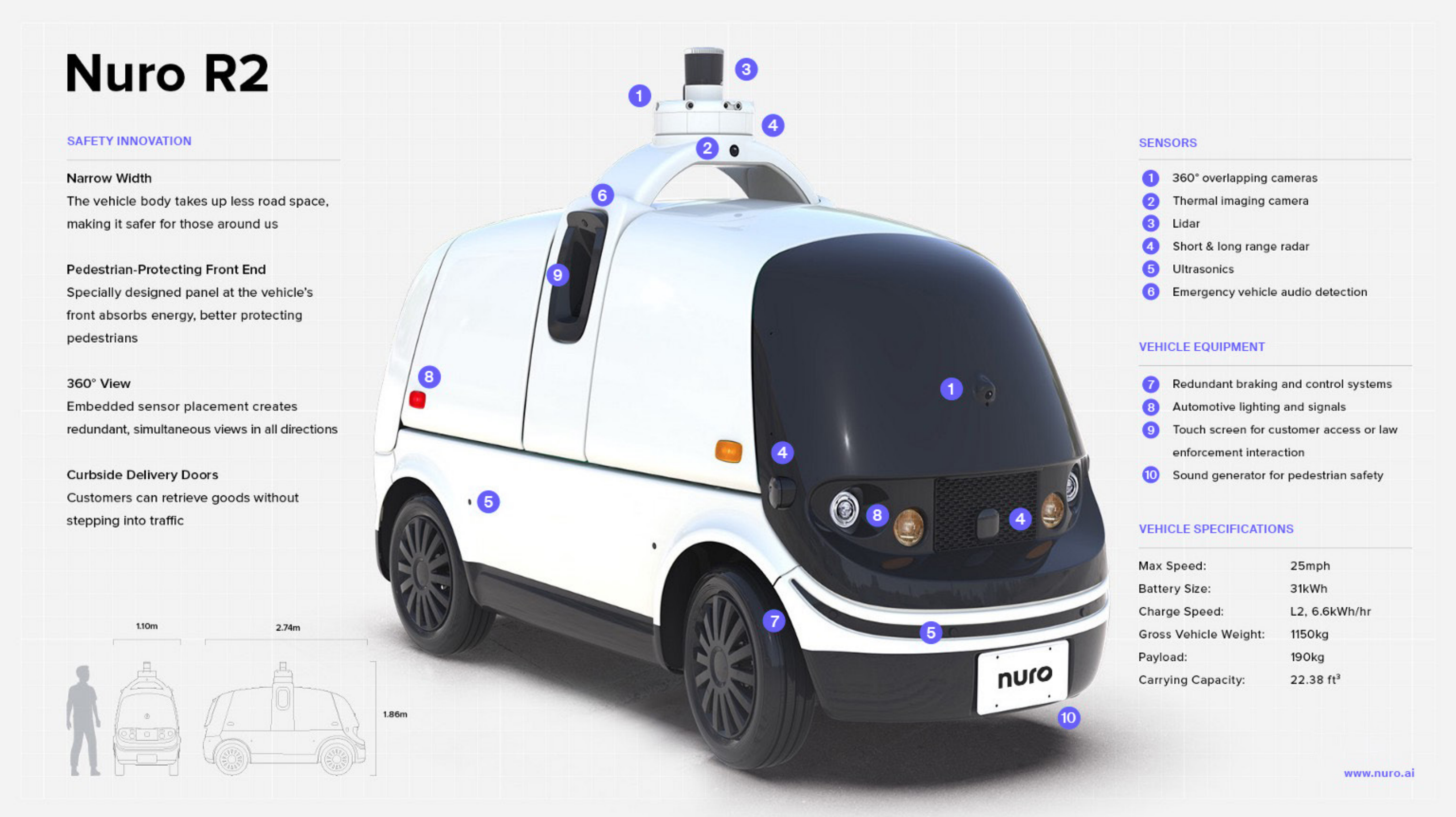
Our Community

Helping make the communities we serve safe, thriving, and environmentally healthy places

Our newest model vehicle, R2, is engineered for short neighborhood trips exclusively to transport and deliver goods. With a configurable interior cargo space, R2 can handle local shopping errands of all kinds to help customers spend fewer hours on the roads and minimize the potential for injuries. Even though R2 is a new type of vehicle, we designed it to be familiar to other road users—resembling Neighborhood Electric Vehicles (NEVs).

When you see R2 on the road, it will look like a small, narrow car being driven by a cautious driver.

R2 is lighter than a passenger vehicle, narrower and more nimble, and operates at lower speeds. This design and a cautious driving approach gives R2 more time to react, shortens its stopping distance, and provides additional maneuvering space to avoid objects on each side of the vehicle. Together, these advantages can help prevent crashes, such as by avoiding



Safety Innovations

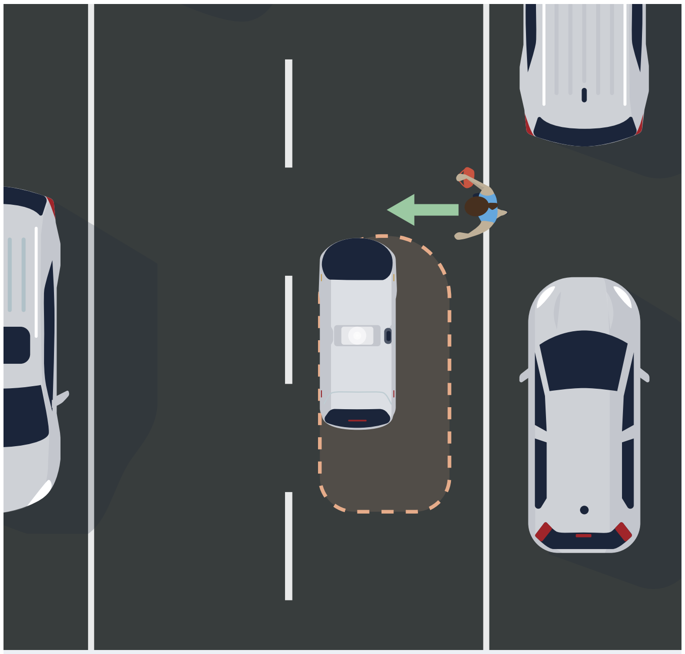
Zero-occupant vehicles reduce the number of people on the road, are narrower and lighter, and can be designed to protect pedestrians. A recent study from the Virginia Tech Transportation Institute showed that zero-occupant vehicles could reduce fatalities by 58% and injuries by 62% for every mile of driving in traditional vehicles that they replace.[7] These benefits from the base vehicle design are in addition to the safety benefits of software that avoids human errors, a low operating speed, and a business model that enables more conservative driving and routing.

Low speed and lightweight

R2 is classified as a Low-Speed Vehicle under the National Highway Traffic Safety Administration's (NHTSA) Federal Motor Vehicle Safety Standards, permitted to operate up to 25 miles per hour and weigh up to 3,000 pounds when fully loaded with goods. R2's empty weight is 2150 pounds. Because R2 will never have a driver or passengers, it has no need for comfortable leather seats or a stereo system, no steering wheel or other manual controls, and no dashboard filled with indicators and switches. Removing that equipment makes a much narrower frame possible, providing R2 more space to navigate around obstructions and avoid collisions if someone were to suddenly pull out of a driveway or step out from between parked cars. Given R2 is approximately half the weight of the average vehicle on the road, it has the potential to cause less damage to other traffic participants in case of any at-fault or not-at-fault collision.

Safety enhanced exterior enabled by NHTSA exemptions

We engineered R2 with particular attention to minimizing physical harm in the event of a pedestrian strike. While our top priority is to avoid collisions, we recognize it is possible that we could be involved in a collision at some point. In February 2020, NHTSA granted Nuro the industry's first exemption from certain equipment requirements otherwise required of Low-Speed Vehicles that are operated by human drivers: side mirrors, a



Pedestrians who walk out between two parked cars have up to a full meter of space between themselves and our robot, reducing the likelihood of an accident.

windshield, and turning off the backup camera when moving forward.

This allowed us to replace side mirrors relied on by human drivers with cameras and other sensors. We rounded the edges of the vehicle body to take up less road space and make it safer for those around us. Rather than a hard glass windshield, R2 is built with a specially designed front panel that absorbs energy, better protecting pedestrians in the unlikely event of an impact. The rounded front face of the vehicle is engineered to present objects coming into contact with the vehicle a more uniform surface, rather than suffer a perpendicular strike. Softer materials for the front and rear panels as well as a deformation space behind the front surface act as a cushion to mitigate the potential for injury.

In addition to our custom-built vehicles, we operate a fleet of FMVSS-certified Toyota Priuses outfitted with the same autonomous software, onboard computing, and sensor suite as we operate on the R2. The Prius has been an IIHS Top Safety Pick since Nuro began using the vehicles in our program.[8]

360° sensor capabilities

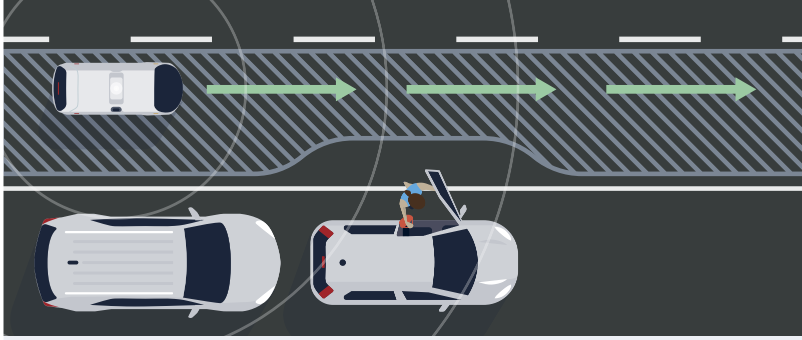
Our vehicle's self-driving system incorporates:

- 12 cameras designed to provide high-definition, constant, 360° views of the environment from various elevations and with overlapping vantages at both long range and next to the robot, facilitated by the NHTSA exemption
- 1 lidar mounted at the top of the robot to provide representations of the surrounding area and movements
- 14 radars for detecting objects and estimating their velocity at both near and far range
- 2 Inertial Measurement Units to determine positioning in the world
- Ultrasonics and audio sensors for additional sensing coverage and redundancy
- On-board computing power capable of running all aspects of driving

Customer safety and accessibility

Shopping and other errands are part of daily life for many drivers, but running these errands can be challenging for some people with disabilities. That's why we have considered people with disabilities in the design of our vehicle. We designed the goods compartments ergonomically to reduce the upper body strength and bending required for lifting and placing grocery bags. We also ensured that wheelchair users are able to reach the touchscreen and access the full compartment area. We look forward to continuing to make affordable goods delivery more accessible to people with physical, sensory, and/or cognitive disabilities in future generations of our vehicle.

Our approach to safety also emphasizes people-centric design for customer usability, considering safety throughout the user experience. Each detail of the experience of picking up groceries is designed to be not only easy but safe. In addition to compartments designed with ergonomics in mind, the doors open without swinging far out, enabling the vehicle to parallel park close to the curb and avoid blocking cars. This also allows customers to stand nearby without getting bumped by an opening compartment door. Safety was a big concern even on issues as fundamental as the vehicle's size—we wanted it to be easily seen by others on the road, but not block their view.



Autonomous Driving and Safety Testing

Nuro's autonomy software is designed to accomplish two core functions—sensing and behavior—to accomplish safe driving: understand the world around the vehicle and its position, then plan an appropriate path taking into account the robot's behavior and other road users.

Our autonomy software continuously learns and improves from its experiences on the road and propagates those learnings to every other vehicle we operate. It is programmed to practice defensive driving, and unlike human drivers, it never gets distracted. In the U.S., more than 3,000 people died from distracted driving-related crashes in 2019, and more than 36,000 people died from all kinds of accidents.[9] By avoiding the human errors that cause 94% of all accidents, self-driving vehicles like Nuro's have the potential to save thousands of lives every year in the U.S. alone.

How Nuro's self-driving technology works

Sensing

Nuro's software needs to understand where the vehicle is in the world and what surrounds it. GPS is only accurate to within a few meters, so our vehicle also uses its onboard sensors and computer to accurately calculate its location based on how it has moved relative to its previous position and to localize its position in the world down to the centimeter. To enable the vehicle to focus its sensors on what is changing around it, we use custom-built, high-definition 3D maps to mark road features such as curbs, lane centers and markers, traffic signs and lights, crosswalks, and speed bumps.

We perform sensor fusion and multi-object tracking to leverage all our near- and far-range sensors to track stationary and moving objects. This enables us to perceive what other road users are and what they are doing, including their kinematics, such as velocity and acceleration. In addition, we observe traffic signals and validate changes in the environment to make sure that we have a continually updated map.

Behavior

Our system then needs to predict how dynamic agents will move to plot a safe trajectory that reaches the desired destination. It combines intent with what's happening around the system and its experience observing the behavior of different kinds of road users—for instance, understanding the behavior differences between a pedestrian and a cyclist—to figure out which route is safest. The system continually updates its plan based on new information and will take preemptive action to, for example, ensure it has enough time to react if another car turns without signaling or a pedestrian enters the street from behind a parked bus. Each mile traveled makes the system smarter, remembering the location of every pothole in its path and learning more about how other road users behave.

To execute the plan, the vehicle's computer sends a signal to the relevant hardware systems, instructing them to steer, accelerate, brake, or signal a turn. Our vehicle can take advantage of performance hardware and a narrower frame to maneuver safely around potential obstructions.

Nuro's safety driver training program

Operating safely on public roads is the highest priority for our team. One of the ways we test and improve the self-driving software is by operating passenger cars equipped with the same self-driving software and sensing hardware as our custom vehicles on private and public roads, and we use safety drivers and co-drivers to monitor the vehicle's operation. Safety drivers are responsible for protecting themselves and the public through safe, conservative driving, and when needed, disengaging appropriately from self-driving mode. The co-driver is responsible for monitoring the system, calling out any potential issues, providing detailed feedback to help developers improve software quality, and acting as a second pair of eyes for the driver. The co-driver may be in the passenger seat of the vehicle or in some cases may be a remote operator.

Nuro takes a holistic approach to training safety drivers and co-drivers, with safety as a core value from hiring to exit.

Hiring and onboarding

Nuro's safety drivers and co-drivers go through an intensive onboarding and training process designed to create a culture and practice of safe vehicle operations. Before they can begin training, we thoroughly screen candidates, including performing a background check on every individual's driving history.

Training curriculum

In our training program, we use a variety of methods to ensure each trainee becomes intimately familiar and comfortable with our vehicles, processes, policies, and standards. Throughout the month-long training program, trainees participate in active observation, classroom learning, reading and understanding manuals, watching videos, and hands-on instruction, with Nuro vehicles or systems. They learn about how the technology works, how to ensure the vehicle is ready for testing, and how to safely operate and monitor the systems. Instruction is led by a selected group with hundreds of hours of self-driving vehicle operations experience.

Testing

Trainees are tested and graded throughout the program. Tests are designed to measure the trainee's understanding of Nuro's systems, how to properly communicate the system's intent, and how to safely operate the system under both normal and adverse circumstances.

Remote operation training

Some of our most experienced safety drivers are also trained in how to perform remote operation. Our custom vehicle has no driver's seat, but we are able to operate it remotely as a backup. After additional training, including hours of practice on private roads, these safety drivers are able to remotely monitor a vehicle and take over if required.

The training program for remote operators proceeds through six steps of training, progressing through increasingly difficult courses. Training begins with supervising our autonomous passenger cars on private roads and parking lots, with a safety driver in the vehicle as well, able to take over in case of any issues. The remote operators must repeatedly pass defined tests at each stage before moving forward or training on public roads. After remote operators have mastered safe driving of our modified passenger cars, they move onto remote operation of our custom vehicle, still with the additional backup of a car closely following, ensuring safety during training. Remote operators must show they are able to monitor vehicles without distraction, promptly take control of the vehicle when needed, and operate safely in a variety of situations before they complete the training.

Continuous improvement

To help our safety drivers and co-drivers improve over time, we also provide regular coaching. Team briefings on changes made to the software, hardware, or processes are held to ensure safety drivers have the most up to date information and are continuously learning. Operators also receive release notes, which includes important information on the software and expected vehicle behavior and performance. We also leverage driver monitoring and assessment tools to generate fatigue and distraction metrics in addition to operator driving profiles from on-road data. We also monitor driver attention and report distraction events to shift managers.

Ongoing policy compliance

Once training is complete, safety drivers and co-drivers must consistently follow all of Nuro's policies, designed to ensure that they are always prepared to take control of the vehicle. Nuro has a zero-tolerance policy for actions that create undue risks to the safety of the public, trainees, or colleagues, such as using a cell phone or other electronic device when the vehicle is not in park, use of alcohol or drugs, or eating or drinking when driving. Safety drivers are permitted to monitor or operate a vehicle without a co-driver physically present in the vehicle, but with a remote co-driver, only after they have demonstrated a substantial track record of safe driving and experience and have been through additional training.

PART 02

Elements of Safety

This section of the report covers how we addressed each of the 12 topics that the National Highway Traffic Safety Administration has outlined as focus areas for self-driving vehicle companies in its guidance, Automated Driving Systems 2.0: A Vision for Safety.[10]

Nuro's culture of safety is the foundation of preventing undue harm to our employees, customers, and members of the public. Ultimately, product and employee safety require each of us to demonstrate integrity, sound judgement, and competence. Keeping people safe is critical to the long-term success of Nuro.

Nuro's safety culture involves several elements: engineering rigor and competence, individual and group values, clear responsibilities and accountability, a culture of feedback and willingness to take corrective actions, and patterns of behavior. We recognize that we have a remarkable opportunity to develop products that will benefit society in profound ways, and capitalizing on that opportunity requires us to make choices each and every day to advance our goal of creating safe products that better everyday life through robotics.

Our thinking about safety started with the conception of a fully autonomous vehicle for delivering goods. Because we design and own both the vehicle and its autonomous technology, we can choose to focus on a business model — goods delivery — that avoids risk for passengers and drivers entirely. We then translated that into the design of a new type of vehicle: nimbler, lighter, slower, and more pedestrian-protecting than most cars on the road. We incorporate safety thinking in every part of the business.

System Safety

The design and validation process, based on a systems-engineering approach, with the goal of designing self-driving vehicles free of unreasonable safety risks

A System Safety approach goes beyond just ensuring each piece of hardware is sound and the self-driving software works, or looking at past accidents and understanding what went wrong. It requires a systemic approach to ensuring the automated vehicle as a whole and all its constituent parts operates safely, and is designed to avoid or reduce harm even if something goes wrong. It also requires being proactive about identifying potential issues and planning how to address them.

Nuro adopted a System Safety approach that encompasses every aspect of our vehicle, including its intended operating environment and use. By starting with a delivery service model, we eliminate risk to people inside the vehicle, lowering overall risk and allowing us to focus on making other road users safe. Similarly, by limiting vehicle operation to low speeds, we give our vehicle and others around us more time to react to all kinds of situations.

The safety approach that produced this design, and that we use to improve the vehicle over time, draws on well established processes and techniques in the safety field. We incorporate best practices from several sources, including ISO 26262 for Functional Safety, ISO 21448 for Safety of the Intended Functionality (SOTIF), and federal, state, and local regulations.

A key part of system safety is anticipating and addressing how the driving system could cause a collision. For each hazard identified, we design safety mitigations to reduce the likelihood and severity of any potential incident. The set of mitigations we design includes both active and passive safety features. Active safety prevents crashes and passive safety reduces their severity.

One of the most important active safety strategies we use is redundancy. We've designed our hardware and software systems with numerous redundancies, including redundant computing, braking, steering, power, and sensor systems to ensure our vehicle can safely come to a stop should anything go wrong. By making critical systems redundant, even if a component malfunctions, another can remain functioning. In the unlikely event the steering system were to fail, for example, backup steering would enable the vehicle to autonomously fail-over to a minimum risk condition or in some instances pull over safely.

When designing passive safety features, we looked specifically into the most common accidents today in the environments where we operate — low-speed, urban and suburban neighborhood roads — and found that pedestrian collisions are a major concern.[11] This is a big part of many cities' Vision Zero efforts, which focus on bringing the number of traffic fatalities down to zero. That's why we're investing in engineering a safety-enhanced front-end and lowering our vehicle's weight. The design both reduces the vehicle's force and absorbs energy, helping to mitigate pedestrian injuries.

Part of our overall system safety approach is detecting failures and responding safely. As detailed below, if we detect a fault, we are able to rely on several layers of fallback strategies. The self-driving system is designed to respond to the specific issue based on the circumstances, considering factors like the status of its backup systems, the proximity of following vehicles, and the size of the road's shoulder. We can autonomously fail-over to a minimum risk condition or in some instances safely pull over using our highly trained safety drivers to take over operation.

To ensure the design meets our requirements, we conduct extensive testing during the software development process, on each hardware component, and on the integrated system. We take the benchmarks defined during the requirements phase and compare them to our performance during testing to validate that the vehicle is meeting all specifications. We also use this data to continually refine our design and improve the software. As described further below, we use simulation, private test track driving, and public road testing with safety drivers to ensure we consistently reach our milestones.

Operational Design Domain

The specific conditions under which the vehicle operates autonomously

Like human drivers, certain road conditions are easier for our vehicle to navigate than others — snow and black ice or high-speed roadways present additional risk for a self-driving vehicle just as they do for humans. However, unlike a human driver that might choose to take on greater risk, we designed all Nuro vehicles to only operate autonomously in areas where we have high confidence that we are able to operate safely. The software is specifically programmed to only choose routes that are within the safe domain, and if weather conditions suddenly change, to pull over every time rather than operate in a dangerous environment.

Our first requirement is that we have carefully mapped the road and simulated driving on it and select ODDs that we have confidently validated. Before the operational design domain is expanded, we conduct extensive simulated and private road testing and ensure critical safety milestones are met. Given we do not have passengers we can optimize for safety at the expense of slightly longer routes and more challenging routes (e.g. high speed traffic or complex intersections) need not be within our deployment ODD.

Next, we've designed our vehicles for lower speeds. Operating at lower speeds gives the vehicle more time to react to other drivers, cyclists, and pedestrians, shortens the stopping distance, and reduces the severity of any potential collision. It also means that our vehicles generally drive on neighborhood roads and do not go on highways.

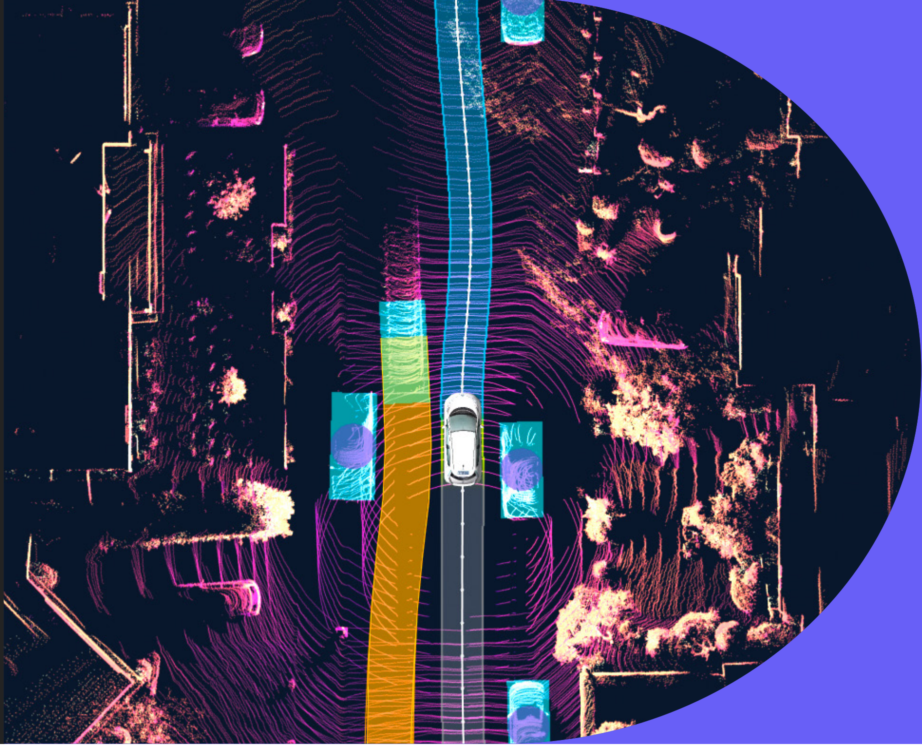
Our vehicles currently can use their self-driving capability in fair weather conditions. For example, that typically includes dry or wet pavement or asphalt, including light rain, and light to moderate fog. We therefore choose to operate in areas that typically have fair weather, and we do not operate in self-driving mode when the weather falls outside of these parameters. Our on-site operations team's pre-trip checklist includes assessing the weather before beginning a self-driving trip, and our safety drivers and remote operators continuously monitor conditions to determine if it's safer to pull over and wait for severe weather to pass.

Finally, in certain complex situations such as a partial road closure due to construction or an accident, we may rely on remote operators to closely monitor or operate the vehicle.

When these conditions are met, our vehicles operate autonomously without any expectation that a person will respond to a request to intervene, meeting the Society of Automotive Engineers' definition of Level 4 autonomy.

Object and Event Detection and Response

Detecting any circumstance relevant to the immediate driving task, and implementing an appropriate response



To drive safely around a neighborhood, our vehicles need to be able to spot objects around them, understand their potential behavior, decide on the best course of action, and implement that decision.

There are many potential objects a driver needs to detect, including cars, trucks, school buses, cyclists, pedestrians, animals, construction materials, street signs, traffic lights, objects that have fallen or blown into the road, and more. To spot these objects, we use a comprehensive suite of sensors. First, we use 12 high definition cameras that provide a 360° view of the environment for our machine learning to understand the state of the world. We then take our top-mounted lidar, which bounces light off of objects in every direction, to provide precise representations of distance of all objects in the surrounding area, which includes such objects' movement direction and speed. We supplement our camera and lidar with radar to provide redundant range and additional velocity information. To identify what an object is and track its movement, we combine all of the inputs of the sensors mentioned above to enhance the 360° views of the environment from various elevations and with overlapping advantages. Our design supplements this with other sensors, including audio and ultrasonic sensors for additional coverage and redundancy.

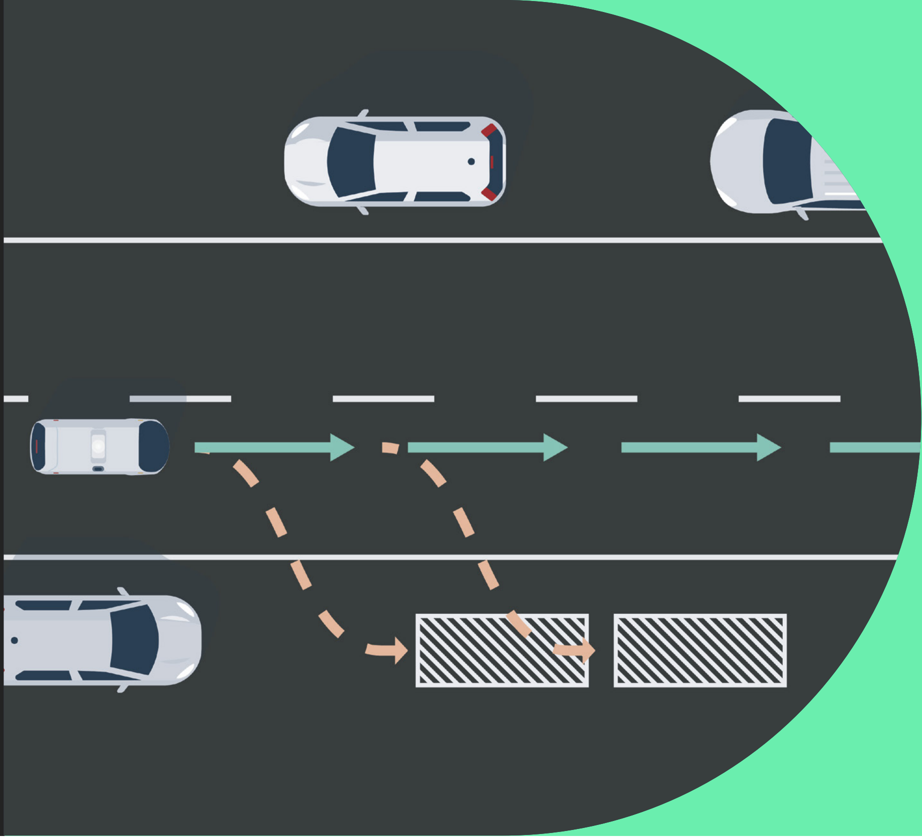
Beyond just detecting an object, our vehicle needs to understand what the object is and predict how it's likely to behave in the future. This is critical, because the expected behavior of a pedestrian will be different than a cyclist, and our system needs to anticipate how a child might move at a different speed than an adult pedestrian or could be more likely to dart into traffic. Because our vehicle does not have passengers, we also have the ability to be more conservative in our expectation of other agents' behavior.

Our software estimates what each object is likely to do, based on the situation, and creates multiple potential paths for the vehicle. Each path is based on what other road users may do, and is continuously updated based on additional information on their behavior. Once the best path forward is designed, the vehicle's onboard computer transmits this information to the relevant driving system. When necessary, our vehicle is able to leverage its performance design and narrow frame to brake quickly or swerve around a fast moving object.

Each of these perception and response systems are extensively tested and validated to ensure they work in a wide variety of situations, as described below.

Fallback (Minimal Risk Condition)

The ability to safely respond to a problem that prevents the vehicle from safely operating autonomously



If some component in the vehicle is not operating as intended, we must be able to detect it and respond safely. Our approach is to use redundancy and layered fallback safety strategies, so that we can maximize safety even if something goes wrong under challenging circumstances. Nuro's onboard systems check for faults hundreds of times per second, ensuring all systems are operating safely, and take action if needed.

Critical to enabling our fallback strategies is the system redundancy described earlier. This means that should any component go offline, there is at least one backup in place to automatically take over. This redundancy works together with the fallback approach so that, for example, in the event of an outage or damage of any camera in any position, the system can immediately flag this fault to both its internal automation system and Nuro's remote operations center. In such an event, the system is designed to rely first upon other cameras' significantly overlapping field of view; the lidar system's distance-and-motion tracking; and near-range radar — each providing 360° coverage — to navigate to a minimal risk position and await repair. As an additional layer of backup, the system would be able to rely on extensive inch-by-inch mapping data of the operational environment kept onboard, as well as recent image memory in storage, to navigate to safety and await repair.

Should a system fail in a crewed vehicle, a safety driver is trained to take over operations. All crewed vehicles have a safety driver and we utilize dash cams and extensive training to avoid driver distraction. In the event of a system malfunction, audio and visual cues notify the safety driver to take over, and they can use one of several means to take control. The driver then operates the vehicle like a traditional car, or pulls over immediately for root cause analysis, as the situation requires.

For our custom vehicles, we monitor these systems remotely and can likewise take over operations. Their control is enabled through redundant wireless connections and all transmissions are encrypted.

Beyond safety drivers, we have also developed a layered system fallback strategy that can support full self-driving in our vehicles, without requiring human intervention. At all times, our onboard computer calculates multiple potential stopping trajectories that would be safe to take should a system fail. This approach is resilient to a loss of connectivity or a computer malfunction as the trajectories are preplanned and sent to our high reliability computer frequently. The system can choose to execute one of many fail-safe trajectories that can either immediately stop the robot or have a remote operator pullover depending on the situation and what fault was detected. Preparing for multiple potential scenarios with increasing layers of severity allows the vehicle to choose the option that is safest under the circumstances.

To ensure our layered fallback strategies function as intended, we validate the system's performance by simulating various system failures (sensors, steering, compute, etc.).

Validation Methods

Approach to demonstrating that the vehicle performs as intended in normal, crash-avoidance, and system failure situations

After implementing best practices in system safety, systems engineering, and vehicle design and manufacturing, it is critical to conduct an extensive testing program to validate the overall system. The purpose of validation is to ensure the various system elements have adequate performance to sufficiently mitigate risk to the public.

For any autonomous driving system, real-world performance characterization is critical. However, more vehicles on the road can also mean more exposure for the public. Nuro's incremental testing and fleet scaling strategy seeks to balance the competing demands of building confidence in the accuracy of our performance assessment, while keeping the public exposure to risk at a safe level. That is why our testing moves through stages, including simulation, private-road testing, and real-world driving. At each stage, we take precautions to ensure the testing itself minimizes risk, such as by employing experienced safety drivers to oversee test vehicle operations.

Validation seeks to show that the vehicle reliably meets performance requirements and handles hazards as designed when exposed to these situations in practice. We validate the performance of both the self-driving software and the vehicle hardware, following industry best practices and quality assurance principles.

Software Releases

One of the great advantages of autonomy is that the vehicle can always keep improving, learning from the unusual experiences of the most recent drive. One vehicle's experience can also benefit every robot in the fleet, so there's no need to make the same mistake twice.

This means the software regularly evolves. Validation is about ensuring that the latest version of the software is better than the last, and is always meeting our performance standards to sufficiently mitigate risk to the public. That also means testing and validation is never finished.

Although Nuro's autonomy system is developed using techniques such as machine learning, the improvements are not automatically deployed while the vehicle drives. Instead, improvements are developed and tested "off-board," on systems isolated from the vehicles, and then go through a rigorous, multi-step software release process before being used across the fleet.

Simulated Driving

The first step in validating the autonomy system or a new release is simulation. Before deploying uncrewed vehicles on public roads, the autonomous software must reliably meet our performance requirements in simulation and private-road testing. Simulation enables us to validate performance at scale, without exposing the public to risk.

Using manually-driven and crewed autonomous vehicles in three states, we have built up a large set of logged data of real-world driving conditions. By simulating autonomous driving on all the logged data, we evaluate both the current performance of the system and the safety of incremental changes. Nuro uses simulation in a variety of ways to evaluate and improve.

Perception/prediction evaluation: One example of how we use simulation is to evaluate the perception and prediction systems. Software operations specialists review hundreds of hours of footage from on-road log data, exhaustively labeling agents and obstacles in each scene, and marking them in 3D space. We compare this “ground truth” data with the ability of the autonomy software to correctly detect and classify objects in the same footage. This enables us to evaluate perception performance and progress. The size of our dataset allows us to exhaustively test performance across many permutations: for instance, our ability to detect pedestrians traveling at faster or slower speeds and at different distances. Using the same tools, we also automatically test our ability to predict that pedestrian’s subsequent behavior, which we then evaluate against what that pedestrian ultimately chose to do in real life.

Logged scenarios: We also use simulation to track improvement against logged scenarios. Our vehicles have seen many interesting and challenging scenarios over the past several years; they could be debris in the road, a challenging turn with oncoming traffic, a double parked car, or an animal darting out. From these logs, we regularly extract a portion of the most important and difficult scenes to create “benchmark test sets.” A test set includes either known “challenge” situations (scenarios that involve situations or behaviors that have been challenging for our autonomous vehicles in the past, such as tricky pedestrian situations or handling emergency vehicles) or "ODD -specific” situations (scenarios that occur in specific Operational Design Domains, enabling us to assess the software on an individual ODD basis). As we encounter new challenge situations or add ODDs to our system scope, we continue to add test sets to our benchmark sets, test our software against the expanded list, and measure our improvement.

Simulated equipment failures: We also simulate equipment failures, such as a camera outage, to ensure the vehicle would come to a minimal risk condition.

Synthetic testing: Synthetic testing allows developers to modify real data to give us more scenes than we’ve actually seen in the world, allowing for targeted testing of specific software attributes without having to conduct thousands of extra miles of driving until we see that rare case. For example, we can vary the speed of the road, the amount of oncoming traffic, or how much room we have to maneuver on a narrower street, or even add groups of joggers — all without taking a vehicle out of the depot.

Once we transform a single scene into more than a dozen variations, we can further modify each variant using a technique called “fuzzing” to generate hundreds of variations of a challenging scene. The goal of fuzzing synthetic scenes is to robustly test behavior in certain situations: we want to be more certain that the software is not safely navigating a scene by chance, but rather that our software is robust enough to handle it, and introducing slight variations gives us confidence on this score.

Problem solving: Nuro uses simulation to understand the cause of disengagements, rapidly address the root causes, and validate our fixes. Software Engineers also have the ability to create their own custom test sets that meet certain criteria (e.g., a test set that only consists of animals darting into the road) for more targeted testing.

Large Scale Simulation: Simulating in a large-scale manner, where we use as much data as possible, ensures reliability. Every night, our vehicles replay the most difficult situations we’ve encountered or dreamt up. We then compare the performance against our benchmarks to ensure we are improving and operating safely.

Private Road Driving

Real-world driving validates the accuracy of the simulation, collects data on how the entire vehicle performs under the conditions it will eventually need to handle on its own, and finds additional complex cases to challenge and improve our software. To protect public safety, this test is first done on private roads, including at our private test facility in California. This facility, spanning nearly 110 acres, is custom configured to enable a broad range of driving environments and both common and challenging situations, including higher-speed stretches, intersections, traffic lights, pedestrian crossings, cul-de-sacs, bicycle lanes, unprotected turns, and more.

It is critical to validate that the system reliably responds both to everyday occurrences that our vehicles will encounter frequently, such as keeping the vehicle in a lane and following reasonable road etiquette, as well as unusual edge cases. Ordinary urban and suburban driving might not normally give enough exposure to rare but dangerous situations like pedestrians standing next to vehicles, cars pulling out of hidden alleys, or other road users running stop signs, so we also do accelerated testing. In accelerated testing, we stage variations of cases like these at our private test facility and give the autonomy system an opportunity to practice navigating them safely, and then repeat and refine using simulation. We use our observations from recording regular driving along with analysis of crash rate data and NHTSA pre-crash scenarios to design these structured tests.

Public Roads Driving

Testing on public roads exposes our software to a greater variety of real-world situations than can be achieved in simulation or imagined by our engineers, provides valuable insight into how other road users respond to Nuro’s unique design, and gives us new information on how best to maximize the safety advantage of the vehicle’s narrower width and improved maneuverability. To continually improve, it is critical to test the vehicle in a suitable public environment.

When testing a new release or in a new environment, we first use our staffed autonomous vehicles with a safety driver team. We have been performing this public roads testing in Arizona, California, and Texas to validate our ability to operate in diverse weather conditions and road types, and to continually improve the software.

To mitigate risk during this testing, we have experienced and highly-trained safety drivers behind the wheel. These safety drivers can take over at any time, or use a fail-safe stop button to disconnect the autonomy system if needed.

Vehicle and Hardware Testing

We bring the same rigor to testing each hardware component and vehicle system, to ensure the design is effective and the manufacturing is reliable. We work with leading automotive suppliers to build in performance-grade hardware that is often used in much heavier and faster vehicles. We use a wide variety of tests based on proven, industry-standard techniques.

Vehicle Testing: Before Nuro vehicles began on-road operations, we ran our systems through a variety of safety reviews. For each vehicle platform, we undertook a set of standard automotive vehicle tests at test grounds and closed-course tracks.

Sensor Testing & Calibration: Sensor configuration is first tested on our Prius vehicle. Once the configuration is finalized, those sensors are placed onto R2. Sensors are calibrated on each vehicle prior to autonomous driving.

Simulated Failure: One of the most important types of software testing is simulated failure, also known as fault injection. In these tests, conducted both in computer simulations and on the vehicle on private roads, we artificially tell the autonomy software that a component has failed, and ensure that our vehicle is able to still bring itself to a safe stop using its redundant brakes and steering. We perform this simulated failure testing on a significant number of vehicle components, including critical driving system components like braking, steering, and powertrain.

Once the hardware and software are assembled together, we also test the integration to ensure appropriate responses when a redundant system goes offline and that all interfaces function appropriately.

Human Machine Interface

The interaction between the vehicle and the driver and other road users

Nuro's approach of creating a vehicle without a driver or passengers allows us to focus on making our vehicle's behavior intuitive. We chose an overall vehicle shape and design that will be familiar to other road users, so our custom vehicles can safely share the street, while also seeking to further our vision of improved road safety. For example, most cars on the road today have a hard, glass windshield designed to protect those inside the vehicle, but it can also cause injury to a pedestrian in the event of a collision. Because windshields provide a rough visual indication of the front of a vehicle, giving a useful visual cue to other drivers as to potential behavior, we use a soft, deformable plate mimicking the visual appearance of a windshield; the result is a design that provides cues to other road users as to the vehicle's behavior, while reducing the risk of bodily harm. We also include a sound generator to help make pedestrians, including the visually impaired, aware of our presence.

Likewise, we aim to create a simple user experience for anyone using our delivery service. A great experience, low price, and a broad set of users is critical to ensuring widespread access to the benefits of self-driving delivery. We're working to build an experience that is fast and frictionless, transparent, and reliable, to address what customers tell us they care about most.

The vehicle itself is designed to be friendly and approachable: through its colors, form, and even the sounds it makes. We've spent time on many of the small details — for example, ensuring the doors open slowly, so a customer isn't startled, and stop moving if someone is in their path. Unloading is simple overall: find your vehicle, enter an access code to an onboard touchscreen, get your items, and you're on your way. It can all be done in less than a minute. The compartments are ergonomically designed to make lifting and placing heavy bags safe and easy to do without bending over. And to help make our service more broadly accessible, we ensured that wheelchair users are able to reach the touchscreen and access the full compartment area.

When operating uncrewed vehicles, we know it is also important that our remote operators are able to understand their status at all times. They can see whether the vehicle is functioning properly; operating in manual or self-driving mode; "unavailable" for some reason or experiencing a malfunction; or whether the self-driving system is indicating that it would be safer for the remote operator to take control. These operators are able to address issues that come up while the vehicle is driving, parked, or delivering. If necessary, the operators can perform a full wireless command override, and the vehicle hosts a number of other camera-based security features designed to minimize any dangerous intervention in its operation.

Vehicle Cybersecurity

Protecting against unauthorized access of the vehicle and responding to threats

Cybersecurity safeguards are critically important to protecting vehicles from malicious attacks. We take steps to protect our vehicle, self-driving software, and enterprise, with a special focus on threats that could impact safety on the roads.

We take significant steps to protect the safety-critical systems on our vehicle, including the self-driving software. All communication between Nuro and the vehicle is encrypted to enable secure remote operations. We also use several techniques to protect our software supply chain so that malicious software cannot be implanted, including isolating certain components and strictly controlling access for changes to the self-driving software.

Company-wide, Nuro's approach to enterprise cybersecurity is informed both by industry best practice and best practices from NIST's Cybersecurity Framework.

Crashworthiness

Protecting vehicle occupants in the event of a crash

One of the most significant safety advantages of Nuro's custom vehicle is that it has no driver and passengers. That means that for every trip to the store that Nuro replaces, one more family is safe from the risk of harm in the event of a collision — safer than any conventional car could promise, no matter its crashworthiness engineering.

The fundamental goal of our self-driving technology is low speed, and a narrow, nimble design. We have sought to minimize risk of harm to others in the event of a collision by reducing vehicle mass and creating a safety-enhanced front-end.

While we test and validate our technology, we are also using the Toyota Prius, equipped with our suite of sensors, self-driving software, and a team of safety drivers. Toyota certified these vehicles as fully meeting all safety standards, and received the top rating of 5 stars in NHTSA crash testing for four of the last five model years.

Post-Crash Behavior

How the self-driving system responds to a crash

Before operating in an area, Nuro meets with first responders to provide a documented Law Enforcement Interaction Plan covering potential situations where they may come into contact with a Nuro vehicle, including after a crash. This plan incorporates feedback from State and Local law enforcement and other first responders. In addition to spelling out these procedures, Nuro provides contact details for a dedicated first responders hotline, and offers training to interested officers.

In the event of a collision, our vehicle will typically use the brakes to immediately come to a safe stop, relying on the redundant braking and steering systems to autonomously fail-over to a minimum risk condition or, in some instances, safely pull over should anything go wrong. Hazard lights will also be activated.

For uncrewed vehicles, after a collision a Nuro Operations Specialist follows an established Emergency Action Plan protocol. They will immediately contact the relevant law enforcement authorities and Nuro Central Dispatch per protocol, and use the vehicle's two-way communication system to ask if those nearby need help. Nuro's Fleet team will communicate with first responders when they arrive on the scene. Before resuming operations, they will request law enforcement approval to recover and extract the vehicle, and communicate information on how to deactivate the electric battery (this information is also provided to law enforcement in advance). Central Dispatch can also provide insurance information and required details. During Prius testing on public roads, safety drivers will be present and available to assist first responders or other members of the community.

We have also established a fleet-wide response plan in the event of any significant adverse incident involving a Nuro self-driving vehicle, including crashes causing injury. We believe it is critical to be prepared and have documented procedures in the event of an incident. The response will be based on the situation but will prioritize public safety, prompt action, thorough investigation, and following all state and local regulations, including reporting procedures.

Data Recording

Capturing information on trips and surroundings for use in continually improving the self-driving system

Recording what is happening in and around our vehicles powers the machine learning that enables continuous improvement of the self-driving software. By capturing details from our real-world drives, we can evaluate system performance and build simulations to practice challenging situations, ultimately building a more capable self-driving vehicle. Nuro can then apply the learnings from any one of these vehicles to the entire fleet to improve safety and efficiency.

Similarly, we capture data during testing on hardware performance and analyze it to ensure all systems are meeting our specifications. For example, we examine the power supply system to ensure its voltage stays within our tolerances, and if the computing system detects a deviation; this gives us the opportunity to investigate and improve the design.

We gather detailed data from onboard sensors, the driving systems, and all software systems throughout every trip, enabling us to recreate key events. Were a collision to occur, we could use these data points to understand how the vehicle was moving, what it was perceiving, and what movement it had planned. To ensure we have access to critical logs even if there is damage to computing systems, we also have a high-reliability computer onboard, with secure, redundant data storage devices — our equivalent to an airplane's "black box."

Consumer Education and Training

Informing the public about the expected behavior of the self-driving vehicle

While fully self-driving delivery vehicles are novel, we believe the best way to enable consumers to safely interact with them is to make the user experience intuitive. Ordering will feel familiar to anyone who has bought something online before, and unloading is straightforward. We worked with focus groups to design an interface that is simple and easy to use when the custom vehicle pulls up to the curb — a single touch-screen ready to receive a PIN code, and when entered, the correct door automatically opens. When they're done unloading, customers can tap "DONE" or just walk away and the door will close behind them. At every step of the way, online instructions and text reminders help new users understand what to expect and let them know they'll need to meet their delivery at the curb. They can also call Nuro with any questions.

We provide additional information online through our website (http://www.nuro.ai), on our blog (nuro.ai/blog), and on Twitter (@nurobots). We also participate in industry efforts to educate the public about autonomous vehicle technology, such as through Partners for Autonomous Vehicle Education (https://pavecampaign.org/) and as an original participant in NHTSA's AV TEST Initiative, which provides information on our current operations across the U.S. to the public.

When we launch in a new community, we always place a significant emphasis on engaging local citizens and leaders, including law enforcement, before we launch operations and on an ongoing basis. Feedback from local leaders is critical to making sure we are building the right service that fits in with each neighborhood we operate in. Some of our key activities in community engagement typically include:

- Attending local neighborhood meetings and major outdoor community events to provide information and address questions;
- Providing a community feedback number and email on our website (1-833-NURO-BOT or feedback@nuro.ai, or nurolistens.com for anonymous reporting), and responding quickly to all relevant questions or concerns;
- Answering questions posed to our vehicle operators by neighbors, and providing a handout that addresses frequently asked questions;
- Working with city officials and other local organizations to share information about Nuro and how to submit questions;
- Hosting students for demonstrations of the technology and supporting efforts to encourage careers in STEM.

Federal, State, and Local Laws

Ensuring compliance with all applicable laws

Our vehicles are designed from the outset to meet all Federal, State, and Local laws — or in some cases, to exceed government design standards. From our vehicle design to self-driving operation, it is important to us to be good partners with regulators in creating a vehicle that can make our roads safer.

Our vehicle design meets all the requirements of the Federal Motor Vehicle Safety Standards. Even though the lower speed of our custom vehicle provides enhanced safety and a different set of federal design requirements than some passenger cars, in many cases we have used performance-grade components suitable for vehicles that operate at greater speeds and weigh twice as much, to enhance safety. In 2020, the U.S. Department of Transportation approved the first autonomous vehicle exemption for R2, allowing us to design the vehicle without side-view mirrors or a windshield, and to keep our rearview camera active when in forward motion, because the Department found that this equipment was not necessary for the safety of a vehicle that does not carry human occupants. And because it is all-electric, our vehicle exceeds federal fuel efficiency and emission standards.

It is also critical that we follow all state and local laws. This not only protects public safety but ensures our driving behavior is familiar to other road users, appearing as a safe, law-abiding, and conservative driver. One of the advantages of a self-driving vehicle like ours is that it is programmed to never speed or run a red light, and our zero-occupant design means no one inside our custom vehicles can get impatient or distracted. Nuro also has received all relevant state permits for our operations, including the first permit to deploy a commercial service in California.

To ensure we follow all applicable laws in a jurisdiction, we research the laws for that locality and state, including the rules of the road that all motor vehicles must follow and any regulations specific to self-driving. For example, to operate in Scottsdale, we adapted for the specific local rules on everything from flashing yellow lights to “Do Not Enter When Flooded” signs. Before beginning to operate self-driving vehicles in an area, we also use human-driven vehicles to map all local road signs and markings so we can always be in compliance with the local speed limit, stop lines, and other rules.

Thank You

At Nuro, we work closely with federal, state, and local governments, law enforcement, and communities to ensure we are meeting regulatory requirements and safety expectations. We welcome feedback from residents in the areas we operate on how we can do better. We will continue to meet with leaders and potential customers in other areas where we are considering launching our service to provide information on Nuro and understand how we can best serve communities. We are here to make things better — less driving and more thriving.

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