Delivering Safety: Nuro's Approach

Introduction

We believe that great technology should benefit everyone. Self-driving vehicles promise to save lives, make our days easier, and help us connect to the people and things we love. At Nuro, we're pushing the boundaries of robotics to make those benefits available to anyone, anywhere, anytime.

Safety is our top priority. More than 1 million people die in car crashes around the world every year, and 94% are the result of human error.[1] Self-driving vehicles could prevent many of those accidents and save thousands of lives. To do that, they need to be designed, built, and operated with safety in mind, and made broadly accessible.

That's why we created the first fully self-driving, on-road vehicle designed to transport goods. We believe that self-driving delivery, and thus the resulting benefits, can be scaled sooner and more affordably, than self-driving passenger transportation. Our custom vehicle is engineered to make delivery of everything more accessible — from groceries to pet food, prescription drugs to dry cleaning.

With no driver or passengers to worry about, our vehicle can be built to keep what's outside even safer than what's inside. It's lighter, nimbler, and slower than a passenger car, and is equipped with state-of-the-art software and sensing capabilities that never get distracted. With its smaller size and manufacturing costs, we can make vehicles more rapidly. And because it's electric and fully self-driving, our vehicle can deliver life's needs at an affordable price. Overall, this means spending less time on errands, and more time on life.

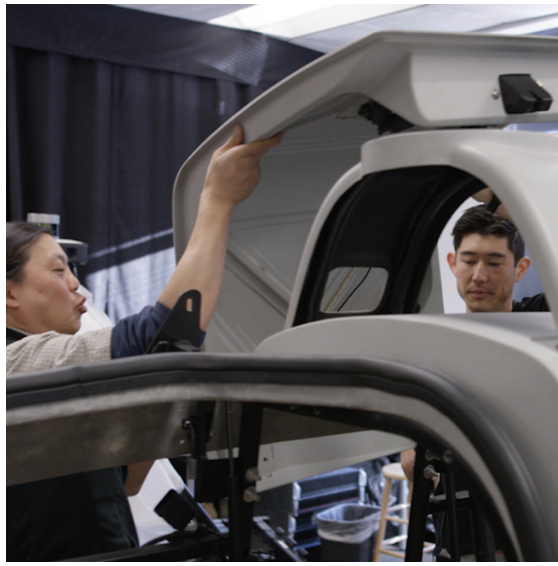
This Voluntary Safety Self-Assessment report outlines our approach to safety and the progress we have made so far. It is organized in two parts. Part 1 introduces Nuro, our vehicle, and our approach to safety. Part 2 explains how our vehicle fully addresses all 12 safety elements that the Department of Transportation's National Highway Traffic Safety Administration has outlined as critical areas of focus for self-driving vehicles.

PART 1

Overview of Nuro and our Approach to Safety

OUR MISSION

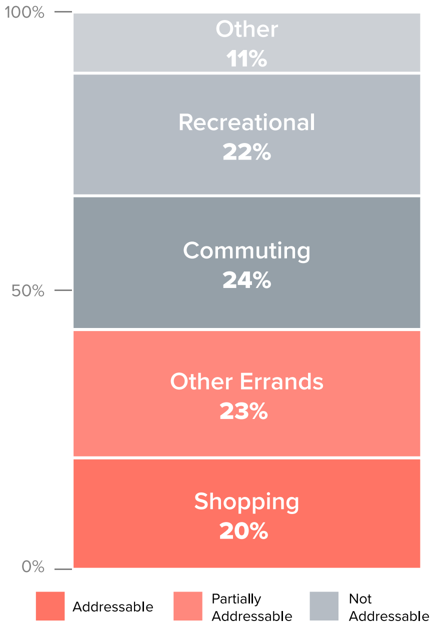
Accelerate the benefits of robotics for everyday life



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 some of the most innovative robotics systems. They saw the need for a new robotics company focused on making the technology available to everyone. The team has grown to include some of the very best minds from academia and industry. We are veterans of award-winning projects in robotics, consumer electronics, self-driving software, and automobiles.

Nuro’s vision for self-driving delivery



Percentage of daily trips taken by Americans.
Source: National Household Travel Survey

We envision a future where everything comes to you, on-demand, for free.

Today, we waste a lot of time running errands. Americans make a total of 220 billion vehicle trips a year. Of those, more than 20% are to shop or run errands. To put that figure in perspective, commuting makes up about the same share of trips.[2] That’s the equivalent of over 60 thousand lifetimes every year. Most of those trips use personal passenger cars, and expose drivers and passengers to the risk of an accident, generate pollution, and add to congestion.

What is required for people to stop spending time and making car trips to run errands? If everyone can get whatever they need as fast as (or faster than) going to the store themselves — and for a very low price — errands will become a thing of the past.

To make that a reality, we’ve set out to dramatically lower delivery costs through self-driving technology. We’ve built an entirely new type of self-driving vehicle designed purely for local goods transportation.

We are starting with groceries, working to make the convenience of grocery delivery accessible and affordable for customers everywhere. Customers can now place same-day delivery orders on the web or in a mobile app, and receive their orders at home from Nuro’s fleet of self-driving vehicles. Each order has the potential to replace one or more car trips — making our roads a little bit safer and less congested.

Our Vehicle

Nuro has designed, prototyped, and extensively tested a custom, low-speed, zero-emission, self-driving vehicle. It is engineered for short neighborhood trips and for the exclusive purpose of transporting and delivering goods. With a flexible interior design, our vehicle can handle errands of all kinds — from dinner to dry cleaning.

Even though it's a new type of vehicle, we designed it to be familiar to other road users — resembling many Neighborhood Electric Vehicles — so it can safely share the street. When you see our custom vehicle on the road, it will look like a narrow car, being driven by a safe, cautious driver.

Nuro's vehicle is designed to be fully self-driving, so it does not have space for a driver or passengers. Designing the vehicle, software, and service ourselves allows us to maximize reliability and find ways to build safety in at every step that wouldn't be possible if each piece was engineered in isolation. This novel approach has allowed us to introduce a range of new safety innovations with the potential to dramatically outperform the full-speed, passenger-laden, and heavier vehicles on the road today.

This is just the beginning for self-driving. This new technology holds great promise, but will also require extensive testing and refinement for self-driving vehicles to eventually be the safest on the road, provide a great experience for customers, and be seen as an asset to communities.

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

At Nuro, our goal is to produce robots that are as neighborly as they are helpful. Because we provide last-mile delivery to homes and businesses, our vehicles will be routinely visible to the consumer and accountable directly to the communities in which they operate — we will only be successful if they are regarded as safe and beneficial. That's why we designed our service to improve safety, expand economic opportunity, make home delivery affordable for everyone, and reduce pollution and congestion.

Safety

Core to Nuro's mission, and business model, is the production of a vehicle that is designed to be uniquely safe, leveraging the particular benefits of providing goods delivery to create innovations not possible with passenger vehicles.

This philosophy permeates the company's approach to engineering. Our vehicles are designed to be fully self-driving. Our technology continuously learns from every situation it sees, sharing that learning with every other vehicle we operate. It is programmed to always practice defensive driving, and unlike human drivers, it never gets distracted. In the US, more than 3,000 people died from distracted driving-related crashes in 2016, and more than 37,000 people died from all kinds of accidents.[3] 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 US, and more than a million worldwide.

Our vehicle is engineered to be safer than nearly any other — it is lighter than a passenger vehicle, narrower and more nimble, and operates at lower speeds. This approach gives us more time to react, shortens our stopping distance, and provides an additional safety buffer to the side of the vehicle. Together, these advantages help prevent accidents that standard vehicles cannot avoid, such as someone jumping out from between parked cars or swerving across the road.

Nuro’s Safety Innovations

Nuro’s groundbreaking approach of building a vehicle without passengers let us reimagine the car. Our custom vehicle will introduce innovative ways to improve safety for other road users, so we can focus on keeping what’s outside safer than what’s inside.

1. Lower speed operation

Nuro’s vehicle is designed to operate exclusively at or below 25 miles per hour. That low speed gives us more time to react and prevent collisions. Having no passengers means we can take the extra time to drive carefully and always stay on the side of safety.

2. Lighter, narrower, and more nimble vehicle

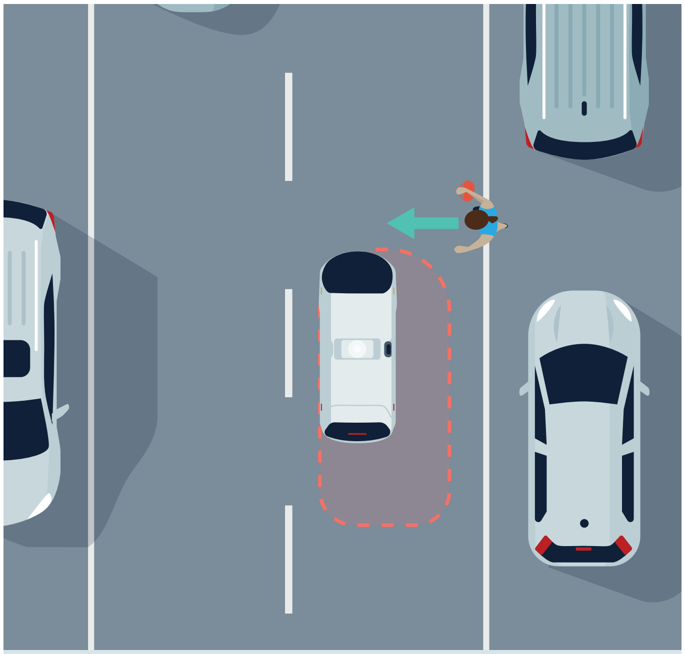
Without passengers, there’s no need for leather seats or stereos, a steering wheel or power windows. Removing all that equipment lets us use a much narrower frame — about half the width of a typical car — which gives our vehicle more space to navigate around obstructions and a few more feet of safety buffer to avoid a collision if someone were to suddenly pull out of a driveway or step out from between parked cars. It also reduces our weight to about half that of a typical car, further shortening the stopping distance.

3. Ability to self-sacrifice

In the unlikely case of a vehicle ever encountering an unavoidable collision scenario, a driverless, passengerless vehicle also has the unique opportunity to prioritize the safety of humans, other road users, and occupied vehicles over its contents.

4. Safety-enhanced vehicle front-end

We are engineering our vehicle with particular attention to minimizing the 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. Our reduced mass and low speed will reduce the force of any potential impact relative to a passenger car, and we also designed the vehicle to provide additional pedestrian protection. The overall rounded contouring is engineered such that objects coming into contact with the vehicle are more likely to glance off, rather than suffer a perpendicular strike. Unlike traditional vehicles, which are engineered to protect the passengers inside with hard, protective materials, we use softer materials for the front and rear panels, and a front-end design that acts as a “crumple zone” to minimize the potential for injury.



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.

We designed our vehicle to bring the highest performance components together with cutting edge software. From the standpoint of the vehicle's self-driving driving system, our custom hardware is among the industry's most advanced, incorporating 12 cameras providing high-definition, constant, and 360° views of the environment from various elevations and with overlapping vantages; top-mounted LIDAR to provide precise representations of the surrounding area and movements; radar for detecting objects and estimating their velocity even at long range; ultrasonics and audio sensors for additional sensing coverage and redundancy; and on-board computing power capable of running all aspects of driving onboard and without the limitations of network connectivity. All driving and safety-critical systems are redundant, including backups for computing, steering, power, sensing, throttle, and braking systems. The vehicle also checks for errors hundreds of times per second, ensuring all systems are operating safely. With respect to software, the system implements world-leading computer vision powered by advanced machine learning — capable of continual improvement.

Underlying this hardware and software is a precision-engineered, U.S.-built vehicle chassis that has — as a core design principle — a goal of not only meeting, but in many cases dramatically exceeding the specified safety requirements for a vehicle of our size and speed. For example, our vehicle features braking components with the power and performance of brakes that can stop full-speed passenger vehicles with twice our weight.

Our vehicles and their self-driving systems undergo extensive testing, including a wide range of critical safety scenarios that require immediate response to prevent harm. It is important to us that as we develop our technology and move closer to full self-driving, our testing itself is safe for the public. Before any Nuro vehicles operate in self-driving mode on public roads, we conduct extensive bench testing, computer modeling, simulated testing, and driving on private roads, all using hundreds of common and uncommon scenarios tested thousands of times. Our testing always uses highly-trained safety drivers as a backup.

Our approach to safety also emphasizes people-centric design, considering safety throughout the user experience. Each detail of the experience of picking up your groceries is designed to be not only easy but safe. For example, we designed the compartment's size and position with ergonomics in mind, so customers do not have to bend over to lift groceries. The doors open without swinging far out, enabling the vehicle to parallel park close to the curb and avoid blocking cars, while also allowing 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.

Creating economic opportunity, supporting local businesses, and making home delivery affordable to everyone

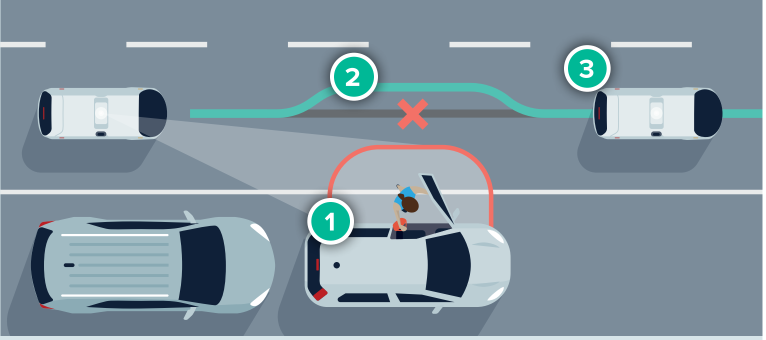
In some retail industries, only a single-digit fraction of goods purchases are delivered, despite consumer surveys indicating that up to 90 percent of customers would prefer delivery if it were offered at a nominal price. By partnering with Nuro, local businesses will be able to offer low-cost delivery without huge capital investments, enabling them to serve a bigger market and compete. Delivery also more evenly distributes operations throughout the day — meaning shorter wait times for goods, better planning for stores, and more reliable and predictable employment for workers. And numerous people participate in every delivery to pick-and-pack goods, supervise the vehicle fleet, and conduct maintenance. The dedicated staff that we and our partners need to support our operations will grow with demand, creating more jobs for local workers over time.

We also aim to make home delivery affordable for all Americans. For instance, Nuro's service has the potential to save busy parents a trip to the pharmacy, deliver fresh groceries more often, or drop off dry cleaning to a college student on their way to an interview — all at an accessible cost. That means that everyone can avoid trips to the store and spend more time doing the things they love. And the more people that can afford to use Nuro, the more car trips will be replaced by safe, self-driving transportation.

Environmental impact

The novelty of self-driving technology should not overshadow the major environmental benefits of Nuro's vehicle. We chose to develop a fully electric vehicle, instead of choosing a hybrid or conventionally-fueled option, because of the additional efficiency and social benefit that comes with battery-power. Each of these zero-emission vehicles will replace potentially hundreds of trips, the vast majority of which utilize conventionally-fueled personal cars. The electricity that powers our vehicles can come from a wide-variety of sources, including alternative fuels. With multiple compartments, our vehicle will also be able to combine trips, plotting the most efficient route from store to consumers, thereby lowering the energy and economic cost for last mile transportation. By reducing the need for vehicles to circle the block looking for parking or sit idling while someone runs into the store, we can also help reduce local air pollution and smog.

While self-driving, fully-electric delivery vehicles won't solve these problems alone, they can help provide customers and non-customers alike with cleaner air, less noise pollution, and reduced traffic congestion — which makes everyone safer.



How Nuro's self-driving technology works

Nuro's self-driving technology operates in three steps: understanding the world around the vehicle and its position, planning how to safely get to a destination, and executing that plan — see, think, do.

1. See

Nuro's custom vehicle needs to understand where it 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 use the vehicles sensors, including 12 high-definition cameras, radar, LIDAR, ultrasonic sensors, and audio sensors to provide a 360-degree, live image of the surrounding area. This enables us to see what other road users are doing, observe traffic signals, and understand anything that's changed from our map.

2. Think

Our system then needs to plot its course. Our vehicle uses the maps and its understanding of its position to design multiple potential routes to the destination. The vehicle then combines that with observations of what's happening live around it, and its experience observing the behavior of different kinds of road users — understanding the behavior differences between a pedestrian and a cyclist, a truck and a coupe — to figure out which route is safest. The system continuously 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.

3. Do

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 Process

Our goal is to develop the safest vehicle on the road. That's why we have built a company focused on safety since its very earliest days — from the use case and design of the vehicle, to the testing process.

Our thinking about safety started with the conception of a fully self-driving vehicle for delivering goods. Because we design and own both the vehicle and its self-driving 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.

While our approach to delivering goods is novel, our safety process draws on long-established best practices from the automotive and aerospace industries, software engineering, and other sources. We break down the vehicle into each of its component systems and consider each potential fault, to ensure we have addressed potential issues before they happen and to prepare for contingencies. We use parts that have been shown to be reliable through extensive real-world use, and rigorously test every component. We've designed our hardware and software systems with numerous redundancies, including redundant computing, braking, throttle, sensing, power, and steering systems, to ensure our vehicle can safely pull over should anything go wrong. And we've partnered with tier-one automotive suppliers with decades of experience building high-performance vehicles to ensure safe, reliable production of our vehicles here in the United States.

An extensive testing program is at the heart of our safety efforts. Our guiding principle in testing is to avoid exposing the public to harm, so we take multiple steps to ensure our software and hardware are working safely before we put a self-driving vehicle on the road. We began by driving standard passenger vehicles equipped with sensors

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 using a laptop, 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.

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 and completing a safety-focused driving interview with a veteran safety driver who observes the candidate operating a passenger car.

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, and watching videos, but they spend the majority of time in vehicles training with veteran safety drivers. 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 of veteran safety drivers who are trained with hundreds of hours of self-driving vehicle operations experience. Instructors provide in-person instruction with real-life examples on both common and uncommon scenarios.

Testing

Trainees are tested and graded throughout the program. Tests are designed to measure the trainee's understanding of Nuro's software and operating systems, how to properly communicate the system's intent, and how to safely operate the system under both normal and adverse circumstances. Trainees must first pass all co-driver tests before they can begin driver training, and trainees must pass every test to complete the program.

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 and respond to the vehicle whenever it is out of park. We also apply a zero-tolerance policy for actions that create undue risks to the safety of trainees, colleagues, or the public, such as using a cell phone when the vehicle is not in park. Safety drivers are permitted to monitor or operate a vehicle without a co-driver only after they have demonstrated a substantial track record of safe driving and experience.

Continuous improvement

To help our safety drivers and co-drivers improve over time, we also provide regular coaching. We hold daily team debriefings on vehicle behavior and scenarios encountered to ensure that all drivers learn from every situation. We also leverage driver monitoring and assessment tools to generate a score for each driver based on how safely they drive, considering factors such as harsh braking, sudden steering, and throttle control. This technology also uses machine learning to constantly monitor driver attention and immediately report any distraction events to shift managers.

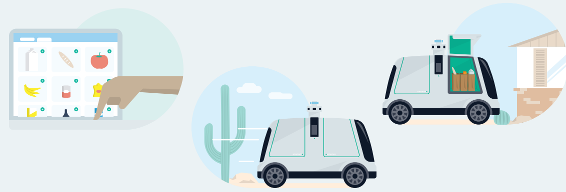
Remote operation training

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 with the same functional responsiveness as an in-person driver would experience. 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 operation requires operators to proceed through six steps of training, progressing through increasingly difficult courses. Training begins with self-driving, traditional vehicles 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 that is also able to remotely control the vehicle, 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.

By integrating cutting edge self-driving software with a built-for-purpose vehicle design, and using testing techniques to avoid exposing the public to harm, we are working to build a new generation of safer vehicles.

around city streets to collect data on real-world driving situations. We used this information, along with NHTSA scenarios and academic research, to develop and run our vehicles through a huge variety of computer simulations, including common challenges and unusual dangers. We then tested our vehicles on private roads to ensure the software works in practice. Before putting our custom vehicles on public streets, we modified passenger cars with the same sensors and self-driving software as our custom vehicle, and put teams of experienced and highly-trained safety drivers behind the wheel, to avoid exposing the public to risk while testing the self-driving software. These safety drivers can take over at any time, or even use a failsafe stop button to disconnect the self-driving system if needed. Once we deploy our fully self-driving, custom vehicles, we will use a remote operator as a backup, able to take control of the vehicles and navigate them to a safe position. Each step in this testing program helps the system learn and improve, and the vehicle must pass critical thresholds before it is allowed to go to the next step.

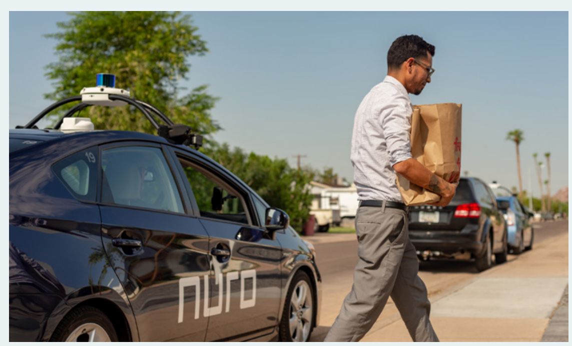


How self-driving delivery works

Nuro's same day delivery pilot in Scottsdale, Arizona

Self-driving delivery will feel familiar to anyone who has ordered a pizza or a package online. Simply place your order on the website or the mobile app, pick a delivery window, and then meet your vehicle at the curb. You will receive text message notifications when your order has departed the store and when it's arriving at your location. Similar to other delivery services, you can track your Nuro vehicle live on a map once it's on its way. As this will be many people's first time interacting with a self-driving vehicle, we also have live customer service representatives available to answer questions by phone or through the vehicle's touchscreen.

When the vehicle is about to arrive, you'll receive an access code that securely opens the compartment door. Simply enter the code and the compartment door opens. Once you're finished unloading your order, either tap "DONE" on the touchscreen or just walk away, and the door will close behind you.



This summer, we launched a pilot of our service with Kroger in Scottsdale, Arizona to allow customers to shop for groceries from any computer or smartphone and have them delivered the same day, affordably.

Learning motivated us to begin the pilot with our self-driving Prius fleet. It shares many software and hardware systems with our custom vehicle, which we plan to begin using this fall. In the meantime, the Priuses will be completing deliveries and helping us improve the overall service.

PART 2

Elements of Safety

Nuro's vehicles are designed for 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.[4] The following section covers each of the 12 elements of that guidance in turn.

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 vehicle as a whole operates safely, and can keep people safe even if something goes wrong with one of the parts. 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 are able to avoid any risk to people inside the vehicle, dramatically 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. We incorporated this kind of broad, outside-the-box thinking about safety in every step of our design, development, and testing process, allowing us to produce a custom vehicle with several safety innovations.

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, the draft standard ISO 21448 for Safety of the Intended Functionality (SOTIF), and other best practice sources, including MIL specs, IEC 61508, NHTSA, RAND, and federal, state, and local regulations.

Requirements analysis

Our process begins by defining the requirements for the vehicle. We laid out each of the steps in the process of driving and determined what our system needs to be able to do, ranging from general behaviors, like stopping at stop signs or detecting obstacles in its path, to the specific capabilities of individual components, like the localizing system being able to monitor itself for failures or the steering system being able to turn the vehicle at a certain angle. We also identify any requirements imposed by law or regulation in the areas we operate. To inform what requirements we need and what level of performance we should aim for in each system, we looked at how people drive today and data on the leading causes of accidents, and always strove to set a high standard. For instance, we may require that our vehicle drive slower than the posted speed limit around certain crowded areas, such as near bars at night where there are often many pedestrians, or give more clearance on the right to closely parked cars, to accommodate the potential for a pedestrian to walk out. These requirements become our benchmark, and the design and validation process is designed to show that our vehicle is consistently meeting them.

Hazard analysis

A key part of system safety is proactively anticipating issues. We analyze how each part of the driving system could cause a collision, and for each potential hazard, we list possible causes, along with the severity and frequency.

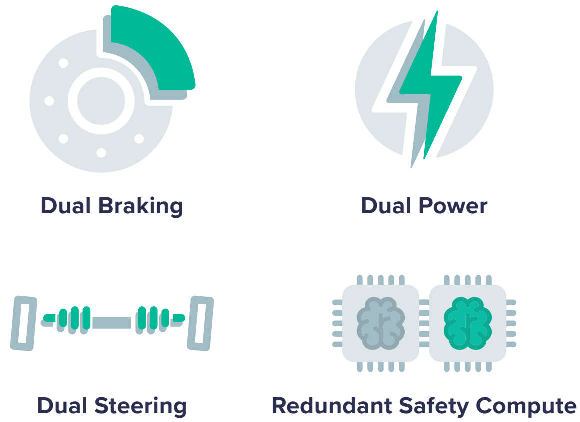
For the software systems that enable the vehicle's self-driving, we also consider ways that they could perform as designed, but still create risks if the software's learned response is not appropriate to the situation — an approach called Safety of the Intended Functionality (SOTIF). For example, if the software learns that it should stop for objects in the road, it might incorrectly stop for a temporary covering for a pothole, instead of driving over the cover. We use SOTIF to design software development, testing, and hazard analysis processes that address these kinds of cases and consistently take a conservative approach.

Active and passive safety mitigations

For each hazard, we designed 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. By making all critical systems redundant, we ensure that even if a component malfunctions, another is still functioning. In the unlikely event the steering system were to fail, for example, backup steering would enable the vehicle to 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.[5] This is a big part of many cities' Vision Zero efforts, which focus on bringing the number of traffic fatalities down to zero.



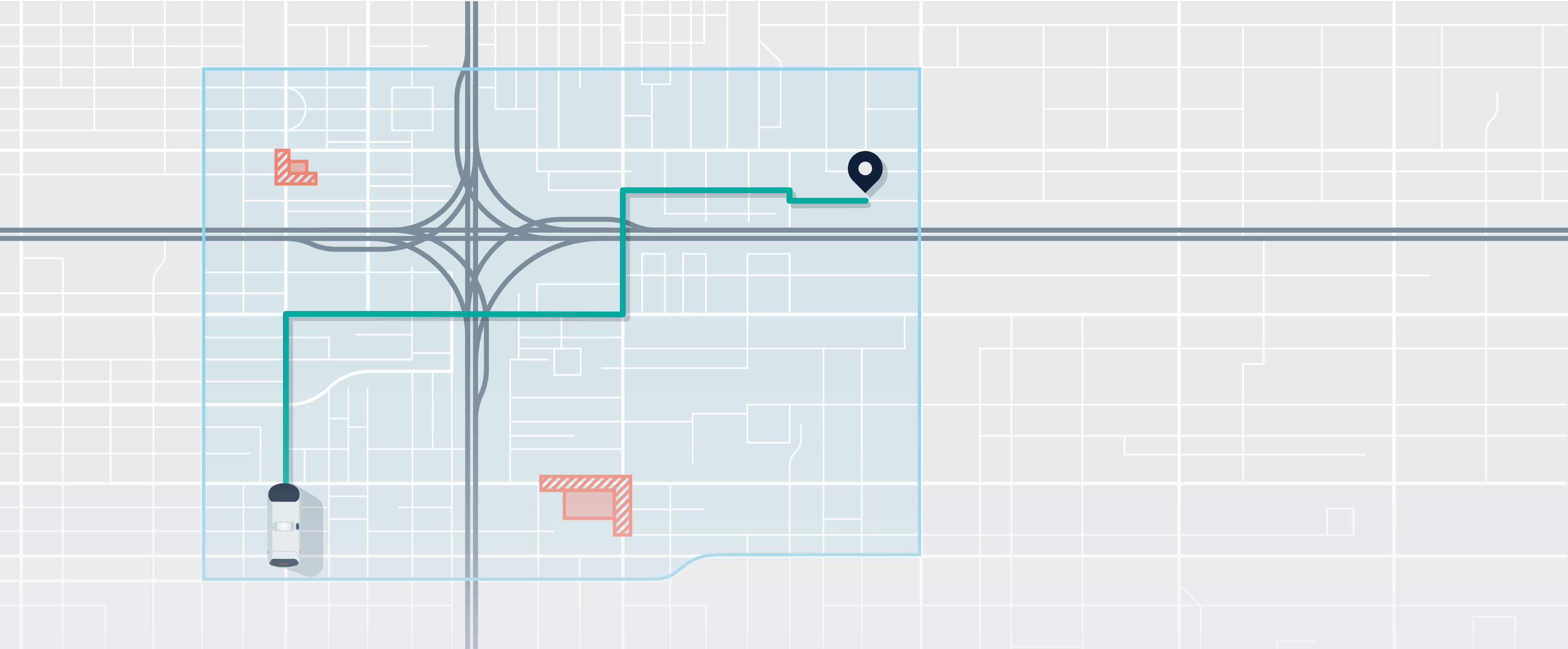
That's why we're investing in engineering a safety-enhanced front-end and lowering our vehicle's weight. The design both reduces the vehicle's force and absorbs energy, helping reduce injuries from pedestrians impacting the ground or other objects.

Fallback

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 use our highly trained safety drivers to take over operation, or follow a pre-defined trajectory stored on our high-reliability computer to pull over safely.

Validation

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. While Nuro's vehicles can sense in 360-degrees at all times, this approach allows the vehicle to focus on what's changing around it and gives us an extra layer of fallback should something go wrong with one of the sensing systems.

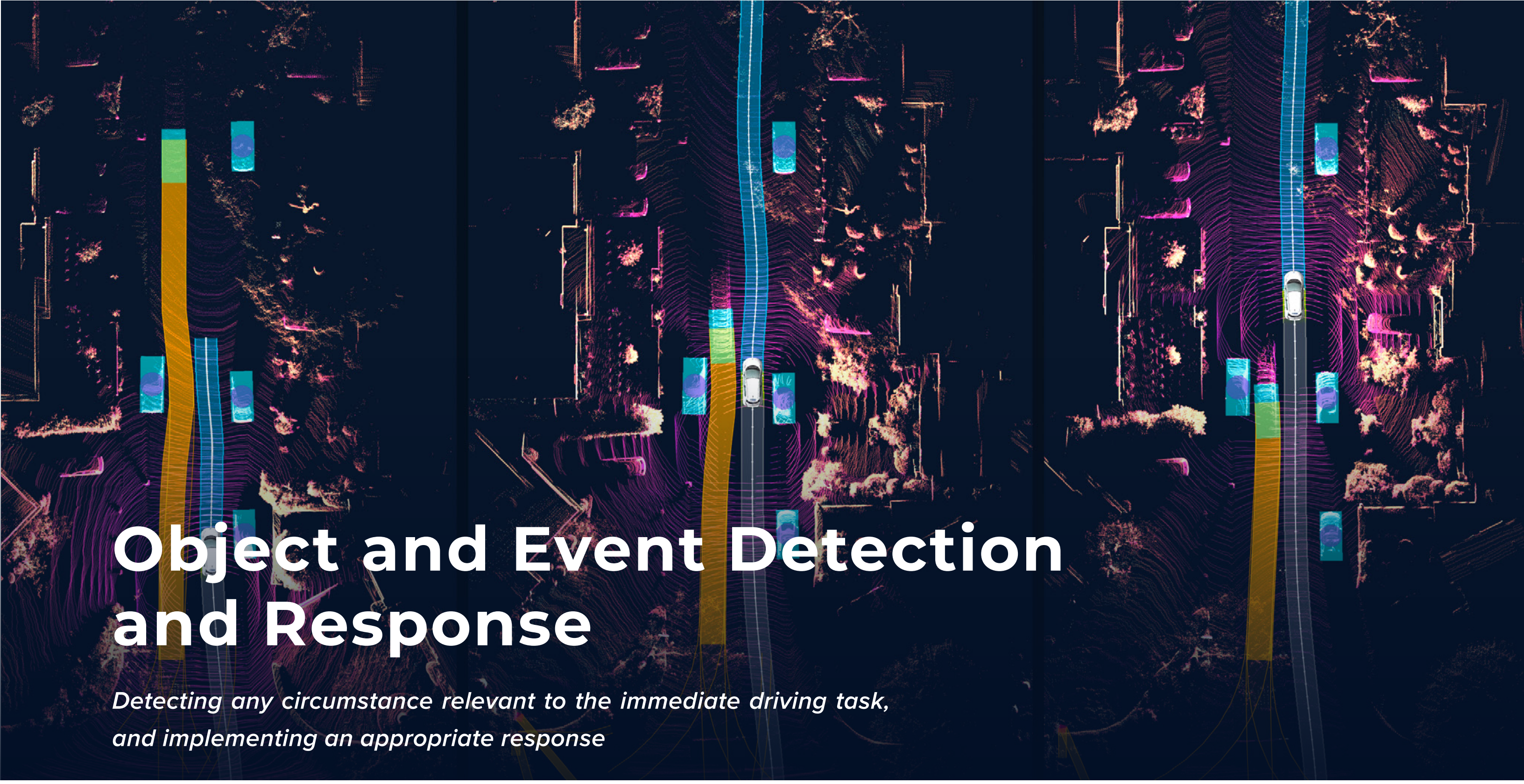
Next, we've designed our vehicles for lower speeds, and have limited their maximum speed to 25 miles per hour. That gives the vehicle more time to react to other drivers, cyclists, and pedestrians, shortens the stopping distance, and reduces the impact of any potential collision. That also means that 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. They can also operate night or day. 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 safety drivers or remote operators to closely monitor or operate the vehicle.

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

Before the operational design domain is expanded, we conduct extensive simulated and private road testing and ensure critical safety milestones are met.



Object and Event Detection and Response

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

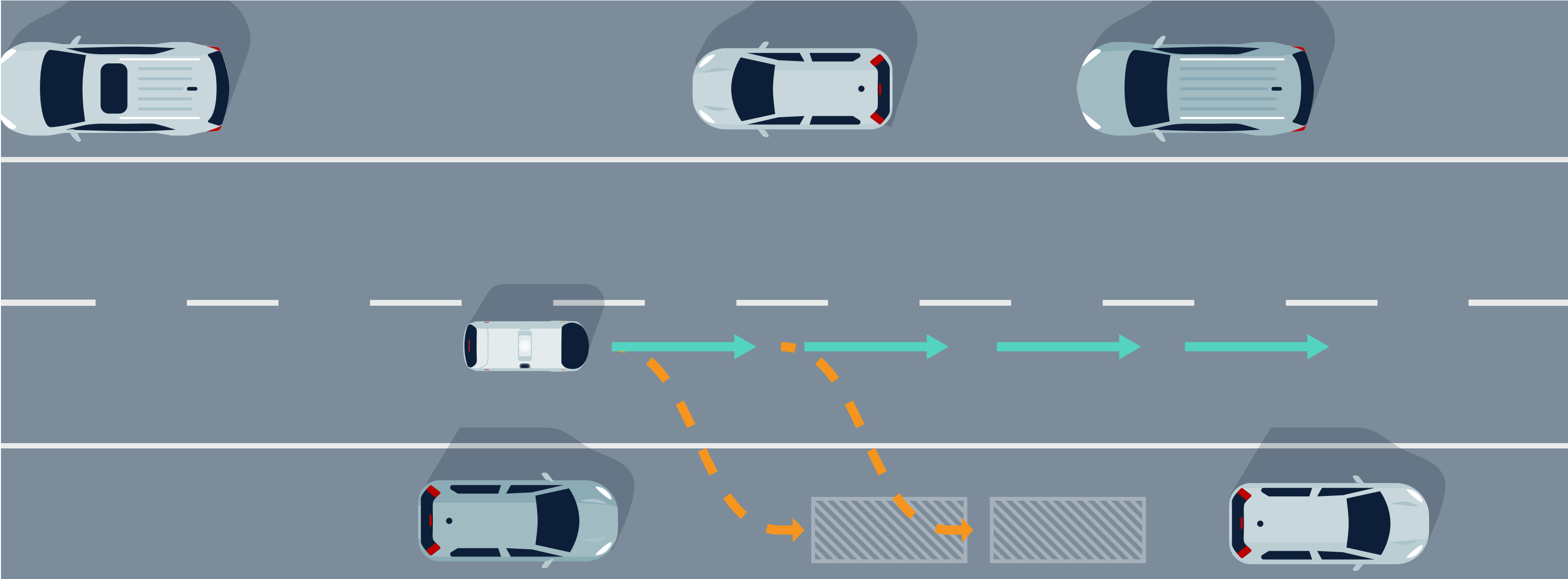
To drive safely around a neighborhood, our vehicles need to be able to spot objects around them, understand their potential behavior, decide on the best course of action, and implement that decision. Detecting and responding to objects draws on each of the See, Think, Do aspects of the self-driving system.

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 top-mounted LIDAR, which bounces light off of objects in every direction to provide precise representations of the surrounding area, including objects' movement direction and speed. We supplement this with radar to provide additional information about range and velocity. To identify what an object is and track its movement, we combine input from the LIDAR and radar with 12 high-definition cameras that provide 360° views of the environment from various elevations and with overlapping vantages. 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 it is and how it's likely to behave. 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.

Our vehicle estimates what each object is likely to do, based on the situation, and creates multiple potential paths for itself through the world. Each path is based on what other road users may do, and is continuously updated based on additional information on their behavior, and how it compares to Nuro's full history of observations. 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 above. Every critical system is redundant, in some cases even triple-redundant. 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 safety and await repair. As an additional layer of backup, the system would be able to as a last-resort 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 manned vehicle, a safety driver may take over operation. All manned vehicles have safety driver teams or one of our very experienced safety drivers, and we utilize dash cams and extensive training to avoid driver distraction. In the event of a system malfunction, warning lights and sounds on the dash and computer monitor 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 repair, as the situation requires.

For our custom vehicles, we monitor these systems remotely and can likewise take over operations. Our trained operators can operate the vehicle if its critical systems are still operating, or pull over safely. Their control is enabled through redundant wireless connections and all transmissions are encrypted.

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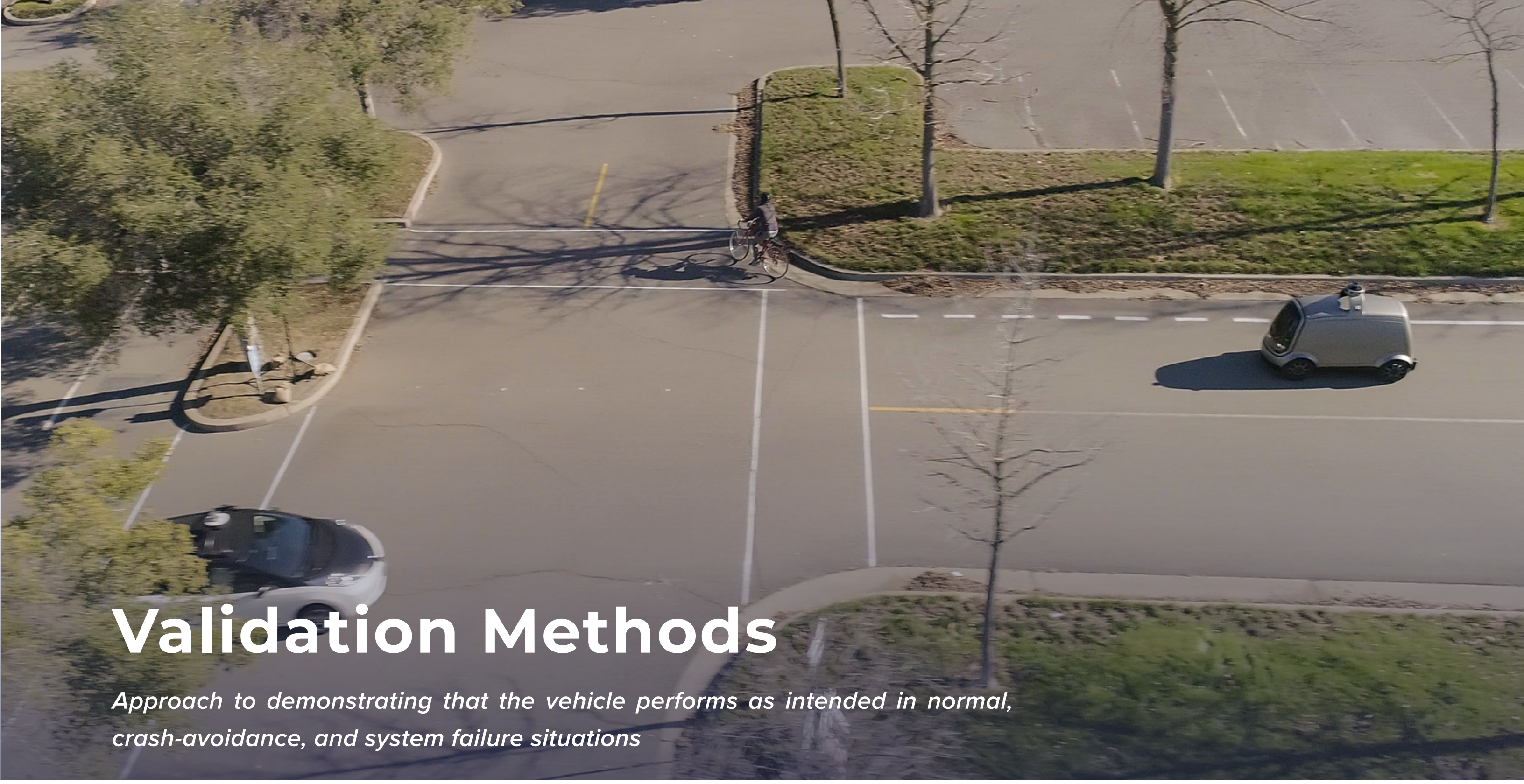
Beyond safety drivers, we have also developed a layered system fallback strategy that can support full self-driving in our vehicles, without requiring human intervention. At all times, our onboard, high-reliability computer calculates multiple potential trajectories that would be safe to take should a system fail. If, for example, a sensor were to malfunction, our vehicle could safely pull over to the side of the road or lane using a trajectory calculated before the malfunction, when the system had full information. Because the calculations are performed onboard and on multiple computers, this approach is resilient to a loss of connectivity or a computer malfunction. Which of the failsafe trajectories the system chooses depends on the situation and what fault was detected. For example, in some situations it may be safer to pull off the road 50 meters ahead, where there is a larger shoulder, while other times it might be best to pull over immediately or even slam the brakes. 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.), and even collisions.



Validation Methods

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

At the start of our System Safety approach, we identified a set of performance requirements and potential hazards our vehicles may face. Validation seeks to show that the vehicle reliably meets those 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.

Our approach to validating the Nuro self-driving technology is rooted in our philosophy that we should avoid exposing the public to harm during the development and testing process. Therefore, we use a several step process, including simulation, private-road testing, real-world driving, and accelerated testing. Before deploying unmanned vehicles on public roads, the software must reliably meet our performance requirements in simulation and private-road testing.

Simulating the performance of the self-driving system enables us to validate performance at scale, without exposing the public to risk. Using manned vehicles, we have built up a large set of logged data of real-world driving conditions that we can use to evaluate the performance of our system (and any incremental changes made to the system) by simulating self-driving on all the logged data. We do this both in a large-scale manner, where we use as much data as possible to ensure reliability, and in targeted scenario simulations (accelerated testing, described below), to ensure the vehicle can navigate difficult situations or simulated equipment failures. We then compare the performance against our benchmarks to ensure we are meeting our requirements and advancing towards our goal of being the safest vehicle on the road.

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's 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 unusu-

al 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 driveways, 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 self-driving 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.

Before testing our custom vehicle on public roads, we first operate the self-driving Prius and Leaf vehicles on the public roads with a safety driver team. We have been performing this public roads testing with the Prius and Leaf vehicles both in California and Arizona to see a range of weather conditions and road types, continually improving the software. Once we begin testing the custom vehicle on public roads, we will use our remote operators as a backup. At times, we will also use a safety chase vehicle in convoy, following closely behind the custom vehicle. This chase vehicle functions and appears like a normal passenger vehicle, but is specially equipped to serve as a mobile monitoring, evaluation, and backup control platform, and trained operators in the chase vehicle actively monitor the custom vehicle's behavior.

Testing on public roads in addition to private roads is essential because we use advanced machine learning capable of continual improvement; the self-driving vehicle improves its operation and performance by "experiencing" diverse situations. Testing on public roads exposes the vehicles 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, controlled, yet public environment.

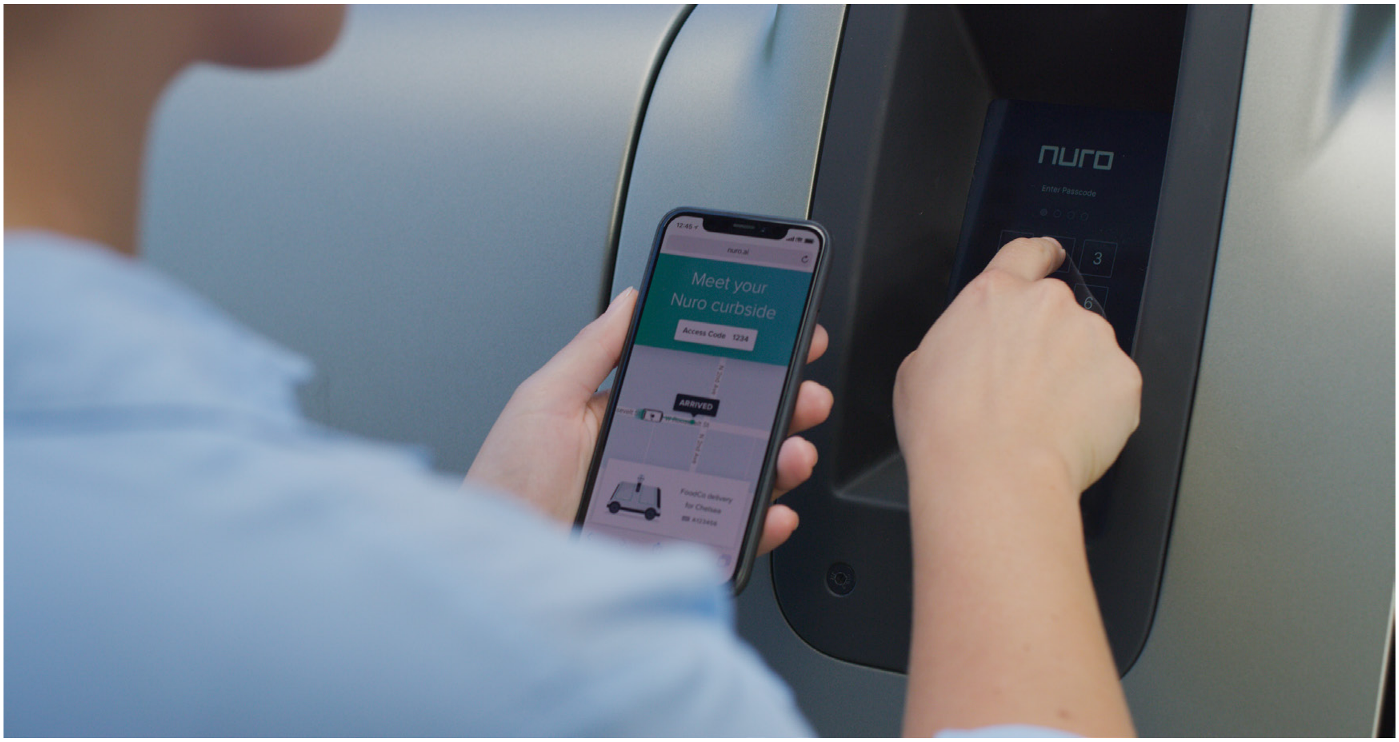
We bring the same rigor to testing each hardware component and system to ensure the design is effective and the manufacturing is reliable. We work with leading automotive suppliers to build in performance-grade hardware that is often used in much heavier and faster vehicles. We use a wide variety of tests based on proven, industry-standard techniques. One of the most important types of testing is simulated failure. In these tests, conducted both in computer simulations and on the vehicle, we tell the 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. 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 novel 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 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 to others. Although not currently required by federal regulations, we are also building in a sound generator to help make pedestrians, including the visually impaired, aware of our presence. Going forward, we will be designing additional systems to notify other road users, particularly pedestrians, of the presence (and potentially future behavior) of our vehicle.

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 ordering process that is fast and frictionless, transparent, and reliable, to address what customers tell us they care most about in their shopping experience.



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 opening 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 unmanned vehicles, we know it's also important that our remote operators are able to understand their status at all times. They can see whether it 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 any 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.

Our approach to cybersecurity is rooted in our overall System Safety approach. We apply “security by design,” which means we build in security as a requirement for all of our systems, proactively consider cyber hazards, and plan specific mitigations. This systems engineering approach ensures we think holistically about cybersecurity rather than simply address the latest threat.

We take significant steps to protect the safety-critical systems on our vehicle, including the self-driving software. All communication with the vehicle is encrypted to enable secure remote operations. We also use several techniques to protect the custom vehicle physically so that malicious software cannot be implanted, including isolating certain components and strictly controlling access for changes to the self-driving software. On an ongoing basis, we use immutable logs to protect log integrity and capture anomalies, and we analyze attempted intrusions, detecting and responding to attempts at unauthorized access.

Attackers continue to evolve, and we use a variety of techniques to address their latest threats. One of the most recent and difficult to confront attacks against machine learning systems is “adversarial examples.” This involves an attacker using manipulated images to train a computer to misidentify an object, potentially leading to dangerous results — for example, tricking an AI into classifying a stop sign as a yield sign. We are working to address this threat through extensive behavioral validation and other techniques, and we then test and improve our robustness by running the adversarial examples against our own models to ensure we are not vulnerable against them.

Company-wide, Nuro’s approach to enterprise cybersecurity is informed by best practices from NIST’s Cybersecurity Framework. We use industry-leading techniques such as 2048-bit encryption and rapidly expiring credentials instead of passwords to protect data and prevent unauthorized network access. In our application development, we also have high standards governing security for our third-party libraries.

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.

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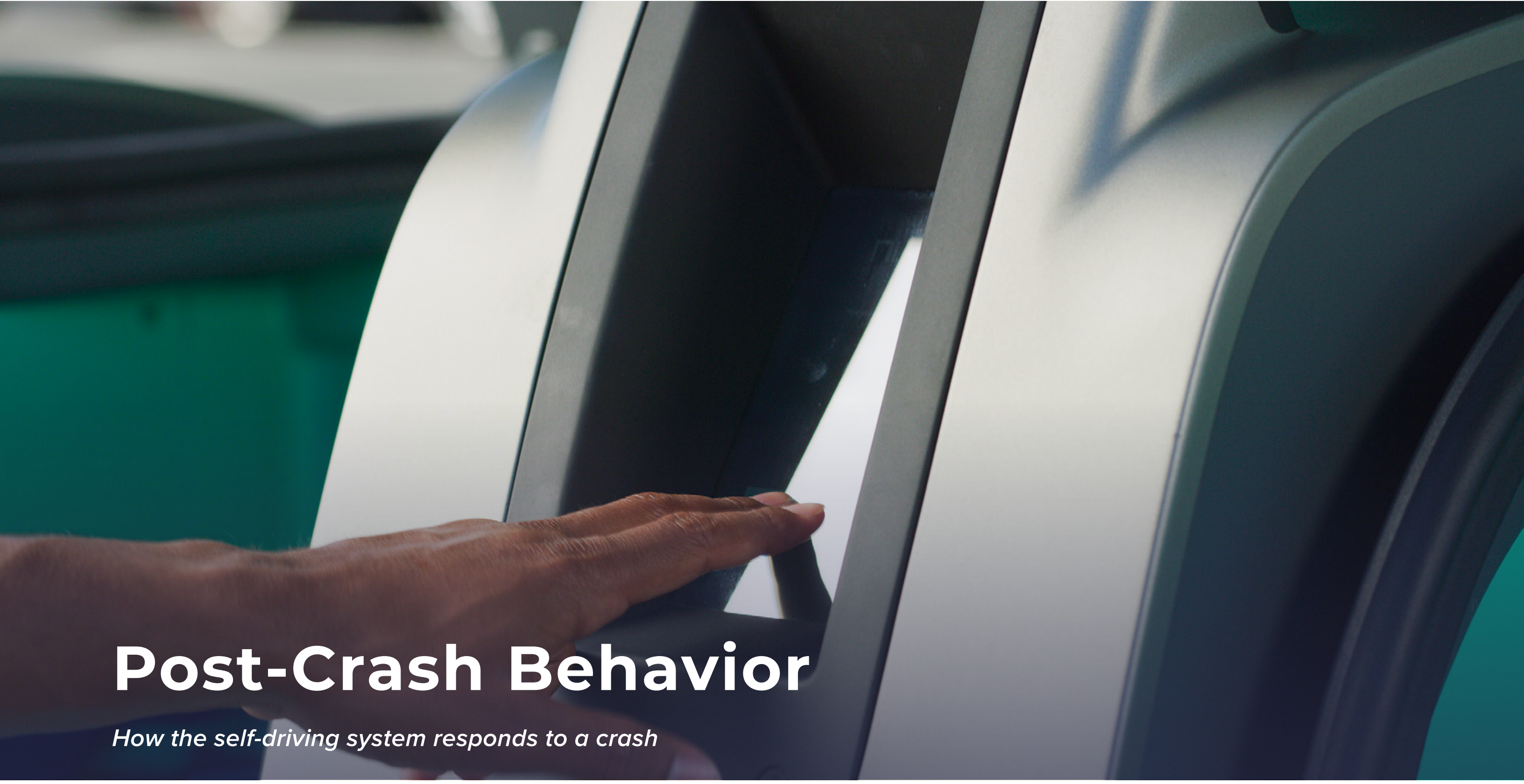
The passengerless model also allowed us to design a vehicle that is much less likely to get into an accident in the first place — the fundamental goal of our self-driving technology, low speed, and narrow, nimble design. And we have sought to minimize risk of harm to others in the event of an accident 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 and Nissan Leaf, equipped with our suite of sensors, self-driving software, and a team of safety drivers. Both vehicles are certified by Toyota and Nissan as fully meeting all safety standards and received 5 star safety ratings from Euro NCAP. The Prius was also rated as a 2018 Top Safety Pick by the Insurance Institute for Highway Safety, as it has been every year since 2010.



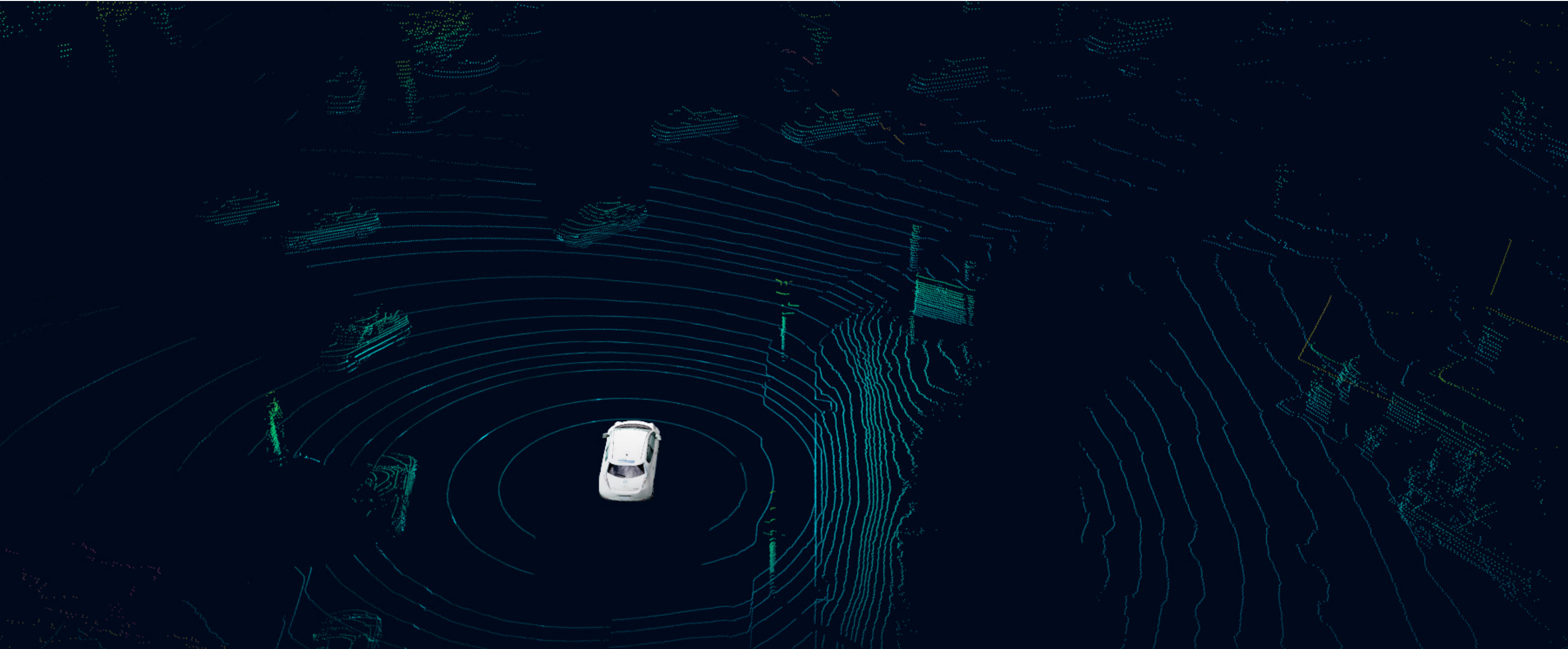
Post-Crash Behavior

How the self-driving system responds to a crash

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 move out of the flow of traffic if possible. Hazard lights will also be activated.

For unmanned vehicles, after a collision a Nuro Operations Specialist follows an established protocol. They will immediately contact the relevant law enforcement authorities and use the vehicle's two-way communication system to ask if those nearby need help. First responders can also communicate with Nuro upon arriving on the scene: before beginning to operate unmanned vehicles in an area, Nuro provides contact details for a dedicated first responders hotline to the authorities. As needed, the Operations Specialist also can arrange for towing, communicate information on how to deactivate the electric battery (this information is also provided to law enforcement in advance), and provide ownership and insurance information. During testing on public roads, safety drivers in the Prius or following the custom vehicle in a chase car 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 always 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 test and real-world drives, we can build simulations to practice challenging situations or evaluate a system's performance, 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 can use these data 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 onboard a high-reliability computer with secure, redundant data storage devices — our equivalent to the airplane's "black box." To protect customer privacy, we also do not personally attribute onboard data.

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 touchscreen 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.

By providing quick, safe, and affordable delivery with a great user experience, we hope to familiarize more people with self-driving vehicles, learn how to make our service better, and bring the safety benefits to more communities.

Through our pilot program in Scottsdale, Arizona, we're learning what's most helpful for customers and refining the experience. As we understand more, we will provide additional information online through our website (**www.nuro.ai**), on our blog (**www.nuro.ai/blog**), and on Twitter (**@nurobots**).

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. For our next-generation custom vehicle, we are also working to add further safety enhancements that take advantage of our passengerless design to reduce the risk of injury to pedestrians and other road users; where those enhancements are not allowed by current regulations that were originally intended for traditional vehicles with a human driver and passengers, we are requesting exemptions from NHTSA.

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 passengerless design means no one inside our custom vehicles can get impatient or distracted.

To ensure we follow all applicable laws in a jurisdiction, the requirements setting stage of our System Safety approach lays out all 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, which we then build into the software. For example, to operate in Scottsdale, we adapted the design for the specific local rules on everything from flashing yellow lights to “Do Not Enter When Flooded” signs to dust storms. 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.

We work closely with communities to ensure we are meeting their unique needs. Before we kicked off our pilot in Scottsdale, we met with state and local leaders, a variety of regulatory agencies, local law enforcement and first responders, and community groups, to build a service that met customer’s needs and could be delivered safely. We welcome feedback from people in the areas we operate on how we can do better, and we intend to 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 that community.

Conclusion

Nuro's mission is to accelerate the benefits of robotics for everyday life. 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.

Endnotes

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