2018 SELF-DRIVING SAFETY REPORT

GENERAL MOTORS

CREATING NEW TECHNOLOGY TO BRING NEW BENEFITS

Imagine a world with no car crashes. Our self-driving vehicles aim to eliminate human driver error — the primary cause of 94 percent of crashes — leading to fewer injuries and fatalities.

Imagine widespread use of electric-only vehicles, reducing vehicle emissions. Our self-driving vehicles will all be electric, contributing to a better environment.

Imagine not sitting in traffic for what feels like half your life. And imagine a crowded city not filled with congested roads and parking lots and structures but with efficiently moving traffic and more space. Nearly one of three cars on city streets at any given time is simply looking for parking. Our technology will create better use of time and space. For everyone.

Imagine the peace of mind knowing that whatever our age, our stage of life or our physical capabilities we have the freedom to go wherever we want to go. Our self-driving vehicles will improve access to mobility for those who currently cannot drive due to age, disability, or otherwise.

The pathway to get all of us to this world requires integrating the software expertise of Silicon Valley with the systems safety and manufacturing expertise of Detroit and our teams around the world. With safety at the core, we are ready to take the next step.

OUR VISION

At General Motors, we envision a future with zero crashes, zero emissions and zero congestion:

Zero crashes to save lives

Each year close to 1.25 million people die in car crashes around the world, 40,000 in the United States alone. More than 2 million people are injured. Human error is a major contributing factor in 94 percent of these crashes.

Zero emissions to leave our children a healthier planet

Vehicles release almost 2 billion tons of carbon dioxide into the atmosphere every year.

Zero congestion to give our customers back their precious time

In the United States, commuters spend about a week of their lives in traffic each and every year. That's a week not spent with those we love, doing what we want to do and being where we want to be.

OUR MISSION

General Motors' mission is to bring our vision of a world of zero crashes, zero emissions and zero congestion to life. Safely developing and deploying electric self-driving vehicles at scale will dramatically change our world.

MEET THE CRUISE AV: OUR ZERO EMISSION SELF-DRIVING VEHICLE

You might think it looks like any other vehicle, but the Cruise AV was built from the start to operate safely on its own, with no driver. We engineered safety into the vehicle in every single step of design, development, manufacturing, testing and validation.

Our self-driving vehicle is the result of intensely focused development, and countless hours of real-world testing and validation. It doesn't drink and drive, doesn't text and drive, doesn't get upset, doesn't get tired, never gets distracted and doesn't produce any emissions.

With its advanced sensor systems, the Cruise AV has the capability to see the environment around it, in 360 degrees, day and night. It is designed to identify pedestrians in a crosswalk, or an object darting suddenly into its path, and to respond accordingly. It can maneuver through construction cones, yield to emergency vehicles and react to avoid collisions.

By integrating our self-driving system into the vehicle from the beginning, and through close coordination between the hardware and software teams, we have evaluated potential failure modes for all systems, and addressed them throughout development to ensure a safe and reliable product. This comprehensive, integrated approach to safety, combined with testing in one of the most complex environments in the world, allows us to safely take the next step — elimination of the steering wheel, pedals and other manual controls — from the vehicle.

Our Cruise AV has the potential to provide a level of safety far beyond the capabilities of humans. As our experience and iterative improvements continue, we will advance closer to our zero crashes vision.

HOW WE DESIGN A SAFE VEHICLE

General Motors is committed to safety in everything we do.

With safety top of mind, our self-driving vehicle development process started by analyzing the act of driving itself. We broke down every action necessary to safely navigate from point A to point B and determined how to execute each action in different locations and conditions. We then challenged prototype after prototype through simulation and real-world testing to develop and refine how each of the vehicle's systems work together to result in predictable, safe driving.

We have designed and built a self-driving car to safely operate among aggressive drivers, jaywalkers, bicyclists, delivery trucks, construction, unprotected left turns, 4-way stop signs and countless other factors that arise when driving in the city.

To define and handle all these real-world interactions safely, we combined the best of Detroit, Silicon Valley and our teams around the world to continuously improve performance and safety throughout design, development and deployment.

We combined the best of Detroit, Silicon Valley and our teams around the world.

We developed our vehicle in one of the most complex environments possible — San Francisco — to ensure that our vehicle can drive safely even in the most unpredictable circumstances and conditions. This challenge helped us put our safety systems through rigorous tests.

Our fleet is growing by the day, and each vehicle contributes to a shared knowledge base so that each vehicle can learn from the collective experiences of the entire fleet. If one car sees that a road is closed, the others automatically avoid it. Or if there's a dangerous road hazard, a single car can notify thousands of others to avoid a potentially unsafe situation. This fleet learning capability is just one of many advantages our vehicles have over human drivers. This combined data is used to improve each individual car's performance and safety.

Our iterative design process doesn't stop with initial launch; we will deploy our self-driving vehicles in GM-operated fleets, enabling continuous improvement into the future.

We're not only learning from what our test fleet does on the road, we're also learning from what doesn't happen. We combine data gathered from our extensive testing with comprehensive safety analyses to identify additional potential challenges we may not have experienced on the road. Then we determine how best to respond to those unseen challenges as well. It's all in the name of our zero crashes vision.

We believe that a safe self-driving car must be built from the ground up, seamlessly integrating the self-driving system into the vehicle. That's exactly what we did, starting with our all-electric Chevrolet Bolt EV, a vehicle platform designed as a gateway to the future of transportation.

A COMPUTER "BRAIN" BUILT FROM TECHNOLOGIES AND SYSTEMS

At the center of our vehicle's self-driving capabilities are computers that perform the functions necessary to understand the world around the vehicle and make the driving decisions that safely transport passengers. No one technology makes this "brain" work. Instead, the computers use a combination of systems that work safely together, including:

Safety

Built into the decision-making for the computers' technologies and systems.

Behavioral Control

Uses information from Safety, Planning and Controls to provide safe and comfortable rides to customers with driving behavior that is predictable to other human road users.

Machine Learning

Rapidly advances the computers' capabilities, such as identification of certain objects and road infrastructure by Perception.

Simulation

Computerized system that facilitates rapid development to continuously improve vehicle performance.

Perception

"Sees" surrounding environment in three dimensions of space and over time, using information from vehicle's sensors and Mapping.

Localization

Knows the vehicle's location at all times.

Mapping

Uses high-definition maps of the roads upon which it will travel.

Planning

Knows how to navigate safely through its environment using information from Dispatch and Routing, Perception, Safety and Mapping.

Remote Assistance

Connects passengers with remote operators upon request, and in emergencies.

Controls

Turns the routes and decisions from Planning into commands sent through Networking to the vehicle actuators.

Dispatch and Routing

Connects to the operations center to obtain pick-up and drop-off locations, and uses Mapping and Planning data to determine routes.

Networking

Moves large amounts of data to the computers within the vehicle and to and from the operations center.

HOW THE CRUISE AV OPERATES

Let's look at three of these elements — **Perception**, **Planning** and **Controls** — to showcase how the Cruise AV senses its environment and makes driving decisions.

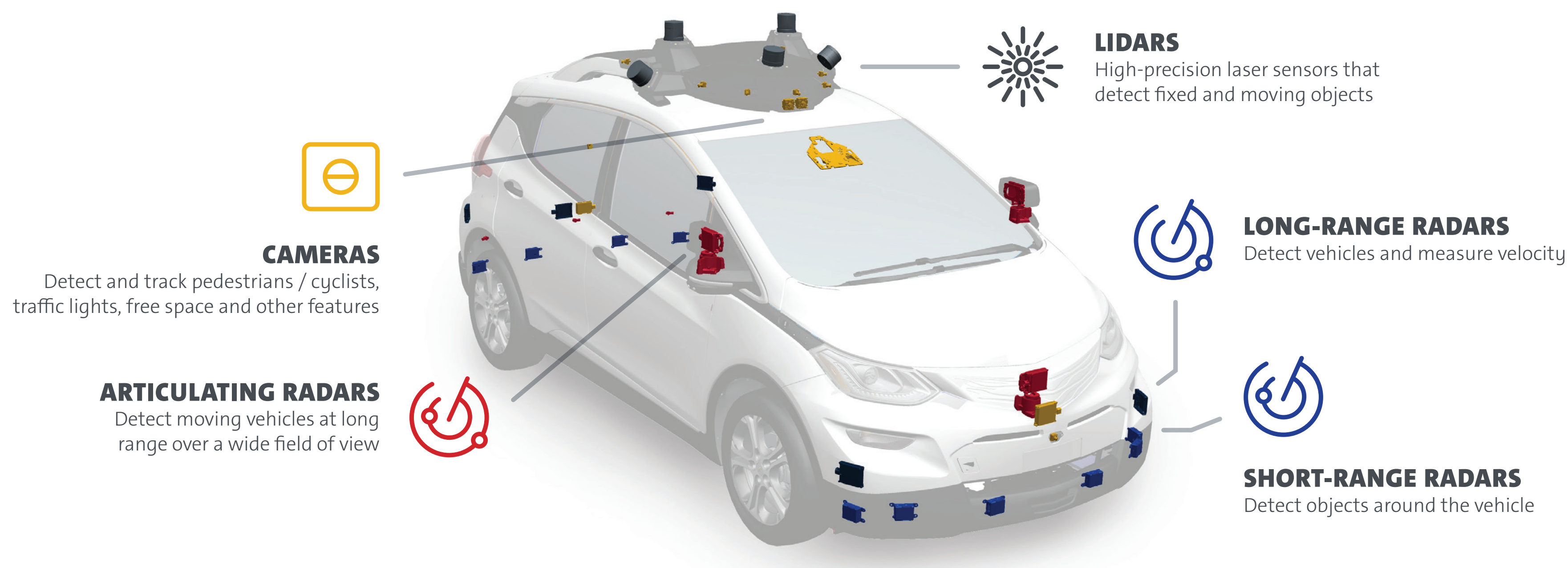
Allows safe operation based upon both what the sensors "see," as well as what may be hidden from view.

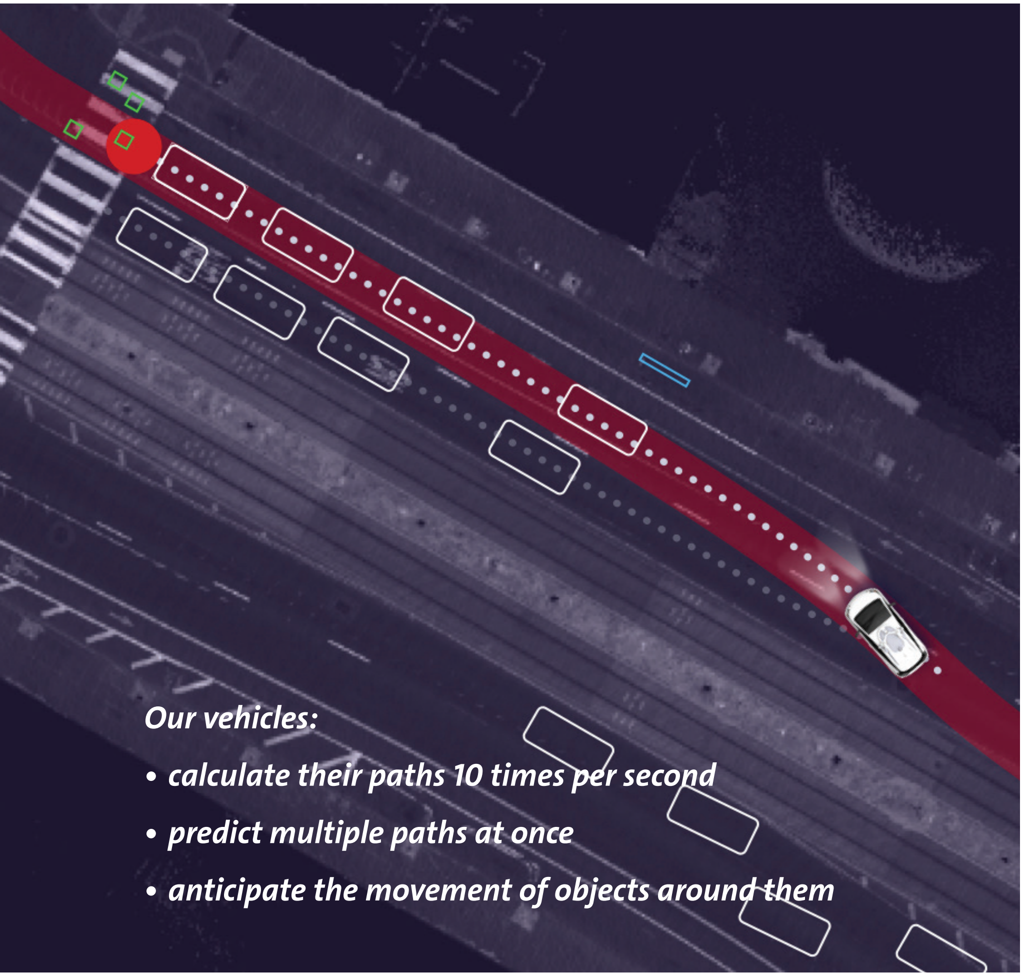
In our self-driving vehicle, **Perception** "sees" by using sensors to monitor its environment. The sensors feed information to the computer that combines the sensor data with high-definition map data to localize the vehicle. Perception detects and classifies objects, determines their location and provides their speed and direction. It builds a three-dimensional model of the world that keeps track of important objects. Perception also predicts the objects' future motion — pedestrians and trucks have different predicted movements. Using the three-dimensional model and map data, Perception determines free, drivable space around the vehicle.

Perception identifies other environmental uncertainties. For example, with knowledge of its location, Perception knows where it must look for moving objects. If its view is blocked, Perception will flag that area as unknown. If an object is hard to see because of rain or fog, or because it is hidden behind a truck, the computer brain knows that and adjusts its decision-making and performance accordingly.

This allows prudent decision-making and operation based upon both what the sensors "see," as well as what may be hidden from view.

To perform Perception functions, the vehicle has five LiDARs, 16 cameras and 21 radars. Their combined data provides sensor diversity allowing Perception to see complex environments. Our LiDARs, radars





and cameras all scan both long and short range with views 360 degrees around the vehicle. We start with LiDAR, which provides highly precise feedback using laser measurements for both fixed and moving objects. Radar is complementary to LiDAR because it uses electromagnetic pulse measurements and can see solid objects that have low light reflectivity. We use both LiDAR and radar inputs for measuring the speed of moving objects, allowing quick, confident determinations of speed. Cameras are also complementary to LiDAR because they measure the light intensity reflected off or emitted from objects, providing rich detail of the object. We combine LiDAR and camera data for classifying and tracking objects, making high-confidence determinations more quickly. This helps, for example, identify pedestrians, vehicle types and road details such as lane lines, construction zones and signage. Our complementary set of long-range sensors track high-speed objects, such as oncoming vehicles, and the short-range sensors provide detail about moving objects near the vehicle such as pedestrians and bicycles.

With an understanding of space and time, the car plans its path

Within the computers' operations, **Planning** determines the desired vehicle behavior. It accounts for road rules and plans routes for the car to travel from trip origin to destination. It chooses routes to optimize efficiency and safety and to route the car only on streets within its capabilities.

Planning operations are based upon vehicle location, other road users' predicted actions, traffic controls, road markings, rules of the road and other external factors. Planning identifies multiple paths per second, and constantly chooses the best one to meet changing road conditions and events.

If something unexpected happens, Planning has multiple backup plans. For example, while preparing to change lanes to turn right at an intersection, another vehicle may aggressively cut into the destination lane, making the lane change unsafe. Planning would already have an alternative route planned; for example, the vehicle could go around the block instead of blocking its current lane while waiting for an opening to change lanes.

The **Controls** function implements the final path from Planning, converting its commands for the actuators that control the steering, throttle, brake and drive unit. We've designed the Controls function to give the self-driving system full vehicle maneuverability complete with stability, traction and anti-lock brake systems fully active.

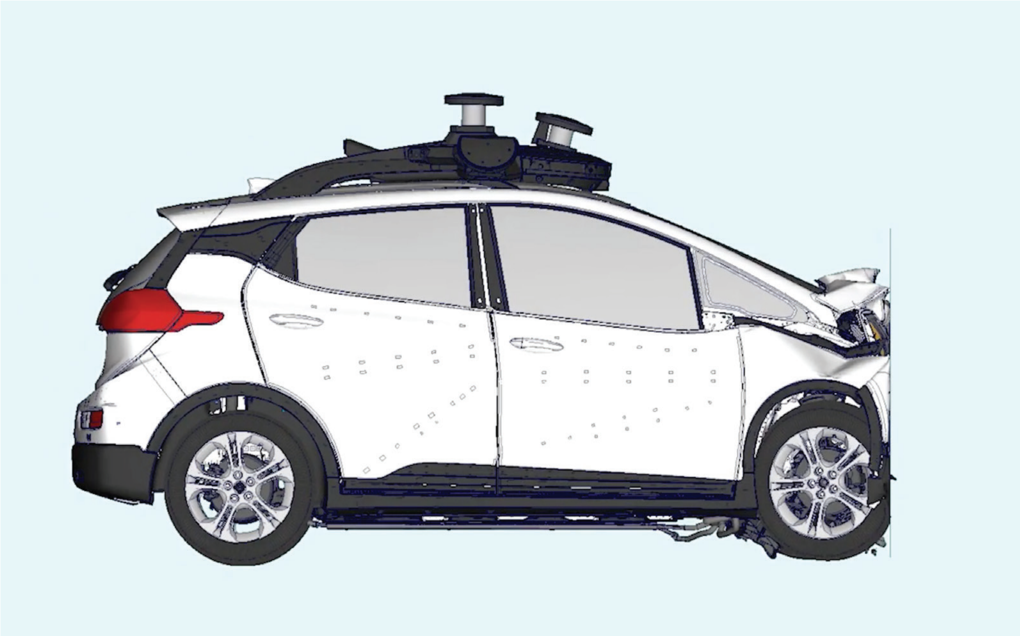
SAFETY AT EVERY STEP

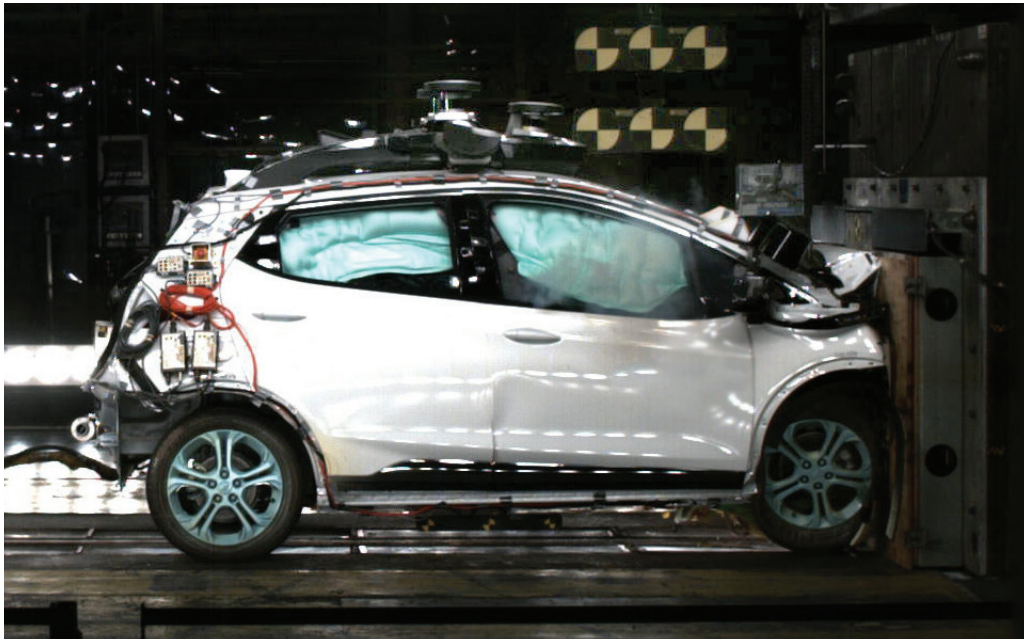
As we create and refine the technology that drives the car, we apply our comprehensive System Safety program throughout the design, development and validation of all the vehicle's systems — mechanical, electrical and compute — and we prioritize safety every step of the way.

Our System Safety program incorporates proven processes from engineering standards organizations, 100-plus years of our own experience, from other industries such as aerospace, pharmaceutical and medical, and from the military and defense industries. Self-driving vehicles require system diversity, robustness and redundancies similar to strategies used for the most advanced fighter planes and deep-space satellites.

We focus on the capabilities of each system to give the vehicle's computers full control of acceleration, braking and steering, and the ability to make the right decisions to drive safely on the road. This also requires thoroughly analyzing each system to identify the safety risks and challenges, and to eliminate or safely manage each one.

Our System Safety process has two key components that work together to allow us to create a safe vehicle design: Safety through Iterative Design, and Safety through Comprehensive Risk Management and Deep Integration.

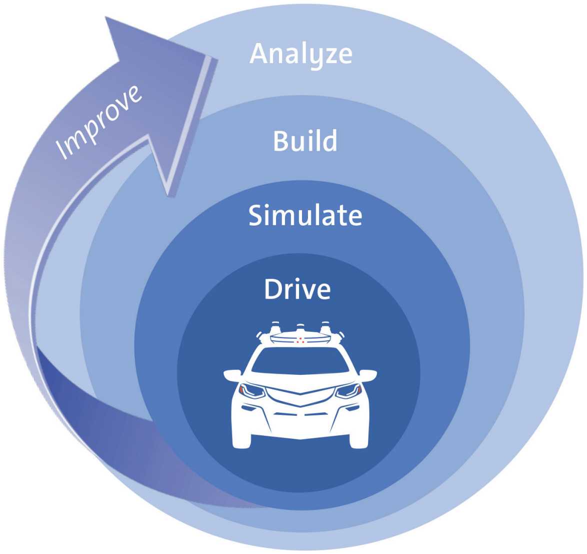




Safety through Iterative Design

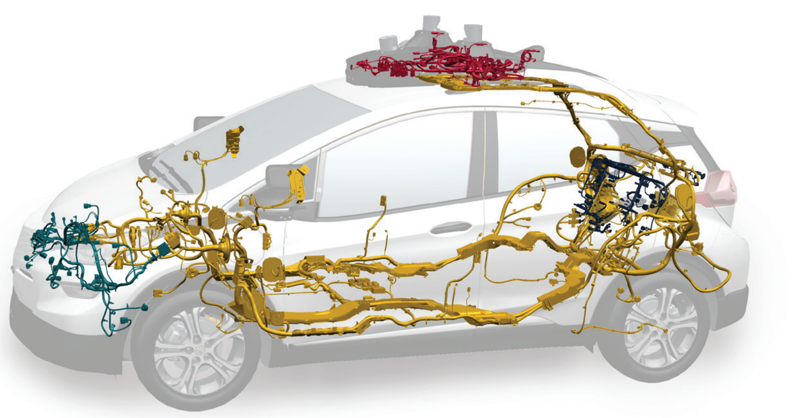
Our design continuously improves with each iteration of the vehicle and its systems. For example, the Cruise AV is the fourth generation of our self-driving vehicle. Our teams design and create technologies and systems, test them in the field and in simulations, and then feed the results back into the design process. This way we incorporate learnings, especially safety data, into future generations so they will be even safer. We do this over and over again, leading to new technologies and systems at the heart of our self-driving vehicle. This iterative design process is strengthened by our Deep Integration, which makes the self-driving system an integral part of the vehicle from the outset. This integrated approach enabled us to build our vehicle with diverse technology and redundant vehicle functionality.

Development Process



Safety through Comprehensive Risk Management and Deep Integration

We believe that a truly safe self-driving car cannot be built by simply adding a self-driving system onto an existing vehicle in a plug-and-play fashion. It must be built from the ground up, seamlessly integrating the self-driving system into the vehicle. The benefits of iterative design and comprehensive risk management are grounded in the vehicle's deep integration.



Comprehensive Risk Management is a key component of our System Safety process. Throughout the design, development and testing processes, our Comprehensive Risk Management approach thoroughly identifies and addresses risks, and validates solutions to address them. This is a constant element of our Systems Safety process, which prioritizes elimination, not just mitigation, of safety risks wherever possible.

Our self-driving vehicles, including all the hardware and systems necessary for self-driving operation, meet all our standards for performance, crash protection, reliability, serviceability, security and safety. That rigorous process means we manufacture our self-driving vehicles with the same high-quality standards as the millions of vehicles we build for our customers around the world each year.

SYSTEMS DIVERSITY AND REDUNDANCY

An important result of our Comprehensive Risk Management and Deep Integration process is systems diversity and redundancy, which are key drivers of the safety of the Cruise AV.

Self-Driving Computer

The Cruise AV has two main computer systems operating simultaneously, so if the primary computer has a problem, the secondary system is there to take over.

Vehicle Localization

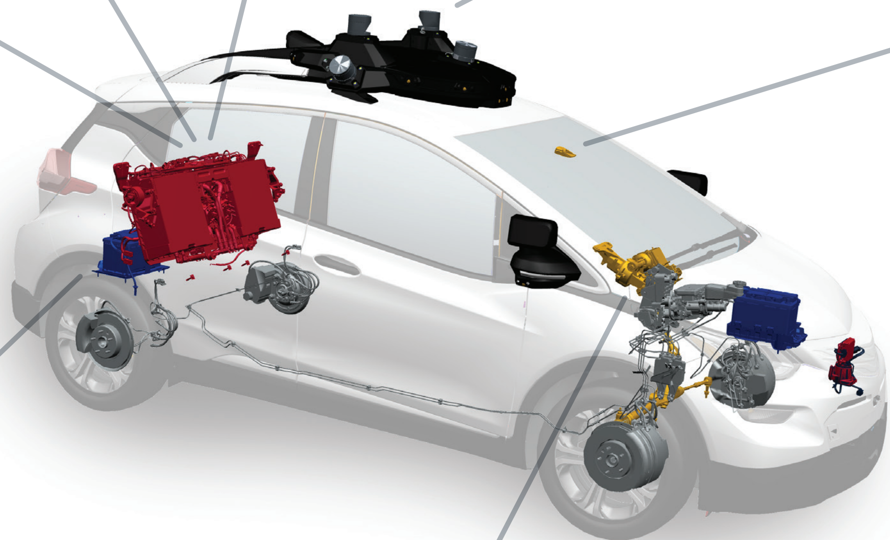
The vehicle's location is estimated by many different methods, which means that even if the localization information from one system becomes unavailable, the vehicle can use localization information generated by other sources, such as from LiDAR data or from our inertial tracking system.

Electrical Power

We have included redundant electrical power sources and power distribution for all important systems. Main power is provided through the high voltage electric vehicle battery. Should power from that battery fail, backup batteries will power all critical sensors, computers and actuators.

Signal Communications

Communications between computers, sensors and actuators have an alternate path if the primary fails.



Steering and Braking

On our self-driving vehicles, the steering and braking systems have redundant motor actuators, electrical power and computer electronics so the vehicle can respond safely and keep performing during a failure.

Perception Sensors

Sensor diversity provides confidence that the self-driving system can detect, track and classify objects around it. Field of view overlaps enable 360-degree vision even if a sensor fails.

Redundant Collision Detection

Our vehicle includes a crash-imminent braking system calibrated to work as a backup to the self-driving system that can apply the brakes to stop the car if necessary.

Integrated Vehicle Health Monitor

Keeps track of diagnostics for all self-driving systems in the vehicle and determines operating state of the vehicle.

System Robustness

All critical systems have been designed, tested and validated through intrusive testing, test track durability testing and extensive on-road mileage accumulation.

OUR PRODUCTION PROCESS SUPPORTS SAFETY

Our self-driving vehicles are built at our assembly plant in Orion Township, Michigan, which builds thousands of vehicles every year. Our employees there build our vehicles to established quality standards — we know that even the best self-driving vehicle will not gain customer trust or satisfaction if it is not built with quality. And our suppliers who manufacture other components make sure their quality meets our high standards.

Our assembly plants are state-of-the-art facilities. The Orion plant where we build our self-driving cars is a large facility, requiring the cooperation of more than 1,000 people and spanning the area of 75 football fields. There are hundreds of assembly vehicles on tracks that weave, rotate and climb through the facility, with equipment and processes that have been honed over decades.

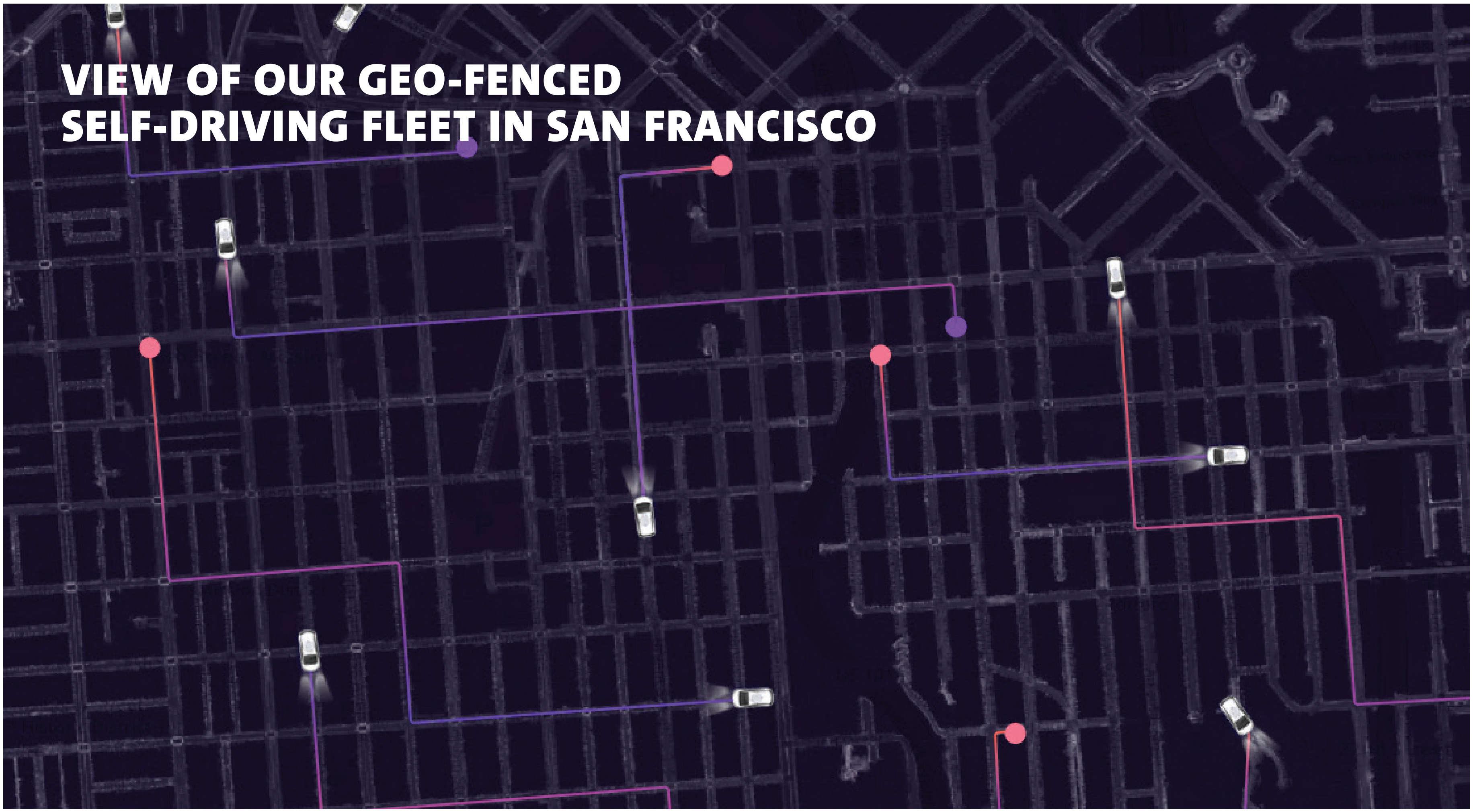
This fully integrated AV manufacturing process is the best way to build safe and reliably performing self-driving vehicles.

OUR DEPLOYMENT WILL SUPPORT SAFETY AND CONTINUE RAPID IMPROVEMENT

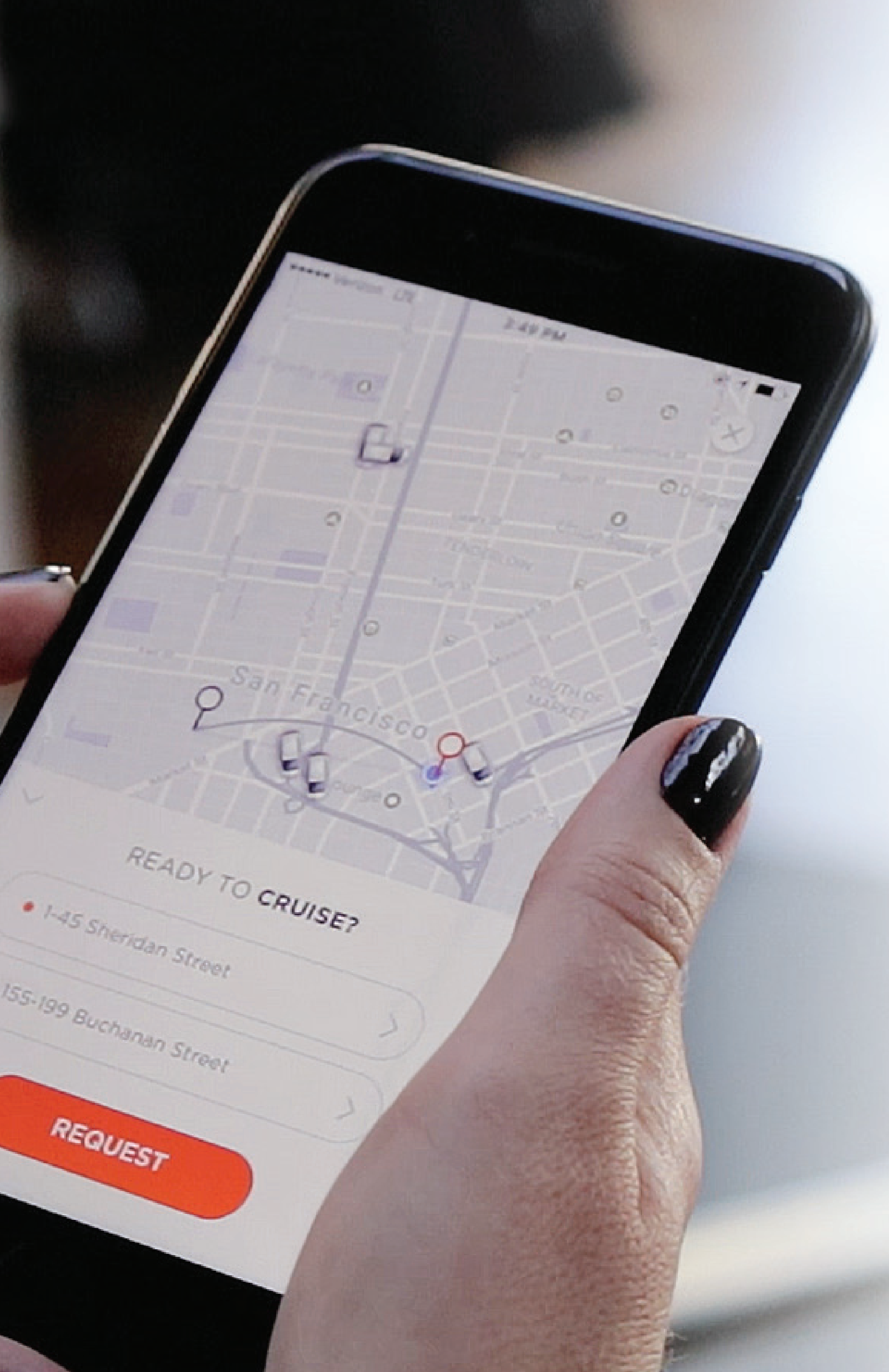
We believe that our self-driving vehicle represents a giant leap forward for advanced auto safety, toward our vision of a world of zero crashes. The first step toward achieving that goal is deploying these vehicles in a ride-share service to help the public become more familiar with this technology. This will allow any consumer — from the early adopter to the skeptic — to experience our self-driving vehicle technology firsthand. Many will also experience their first ride in an all-electric vehicle as well, and they'll see how well-suited electric vehicles are for self-driving ride-share.

In our controlled deployment, our self-driving vehicles will drive only in known geo-fenced boundaries, and only on roads for which we have developed high-definition map data. They will also drive only under known operational conditions and constraints that apply to the entire fleet. We will make sure they are serviced and maintained so that the vehicles' critical systems remain operational and support safe driving.

We will monitor the vehicles and collect data on their performance. As this data is used to identify opportunities for improvements in self-driving operation, we will update the software in all the vehicles — so the entire fleet will continue to get better, and so will future generations of our self-driving vehicles. When one car experiences something new, that data is sent back to the operations center and every other vehicle in our fleet learns from it.



VIEW OF OUR GEO-FENCED SELF-DRIVING FLEET IN SAN FRANCISCO



THE RIDE

When we deploy our self-driving vehicles, customers will use a mobile app to request a ride, just like they use ride-sharing today. The only difference is that customers will control the experience — their customized climate control and radio station settings will be sent to the vehicle ahead of when they access their ride. Our fleet operations will send a vehicle to a customer's location for pickup and transport to the desired destination. Inside the vehicle, passengers will find touch screen tablets to access real-time status information about the ride. The tablets will also remind passengers to close all doors and fasten their seat belts.

Passengers will be able to communicate with remote support personnel with the press of a button. There's another button for passengers to press if they want to end a ride because of an emergency. Support personnel may also initiate contact with vehicle passengers in certain circumstances where assistance may be needed, or if a passenger forgets an item in the vehicle after the end of a ride. Once the ride is over, if passengers forget to close the doors, the vehicle can close them itself and move on to the next customer.

ELEMENTS OF SAFETY

As discussed below, our development of our self-driving vehicle, together with our intended deployment of these vehicles in GM-controlled ride-share fleets, fully addresses all 12 safety elements in NHTSA's voluntary guidance, Automated Driving Systems 2.0 – A Vision for Safety.

SYSTEM SAFETY

Robust design and validation processes based on a systems-engineering approach support the goal of designing self-driving operation free of unreasonable safety risks.

We engineer safety into the design, development and validation of our self-driving vehicle through rigorous application of System Safety processes.

Here is a summary of how the System Safety process works:

Designing a capable system and thoroughly analyzing safety performance

To build our self-driving vehicle, we design, develop and validate the comprehensive capabilities described previously in this report. During these processes, our System Safety process asks two questions that help develop safety performance. How does the vehicle maintain safe operation if a component or system breaks or malfunctions? And, even if nothing breaks or malfunctions, how does the vehicle establish safe-driving capabilities on the roads, and with the traffic and weather, that it will face? From the very beginning, we applied rigorous risk analyses to these questions, studying them from multiple angles and using a variety of tools to resolve them. We applied both top-down hazard assessment such as HAZOP and fault tree analysis, and bottom-up assessment such as design failure mode analysis. With this approach, we identified the risks of self-driving operation and developed requirements to address them.

Using the right engineering tools

As we implement requirements to address identified risks, we use a variety of System Safety engineering tools to track performance against those requirements. This process applies to all parts of the vehicle's self-driving system. Different types of mechanical and electrical components and systems require different kinds of analytical tools. And analyzing and tracking performance of the complex operations of self-driving software require tools different from those used to analyze mechanical and electrical components and systems.

Below we highlight some of those tools and how we use them:

- *Deductive analysis* includes a fault tree analysis (FTA), which connects potential hazards to their direct causes.
- *Inductive analysis* includes design and process failure mode and effects analysis (DFMEA/PFMEA), which is a step-by-step approach to identifying all possible hazards in a design.
- *Exploratory analysis* includes hazard and operability study (HAZOP), which identifies potential risks by analyzing the functions of a complex system.

- *Implementation into the product development process* includes using process hazard analysis at the concept stage to assess potential hazards, software HAZOP, system FTA and DFMEA during design, system functional interface analysis (SFIA) and DFMEA during requirements definition, and DFMEA during implementation phases.

- *Requirements Traceability Analysis* manages the relationships between engineered systems and the safety goals and attendant requirements.

Using these tools, we maintain a consistent approach of identifying risks, implementing solutions and verifying their effectiveness.

Applying the development processes to the self-driving vehicle

Following our proven engineering and development standards, along with applicable military standards for system safety, we focus on eliminating risks where possible. If we cannot eliminate them, we minimize them to maintain a safe state. And we include in our design requirements these two key safety performance thresholds: First, our vehicle will operate safely even if there is a single-point-, plausible dual-point-, or common-cause-malfunction; and second, our vehicle will demonstrate safe driving behavior in the defined driving environment through a statistically meaningful experience.

The first key safety performance threshold:
Our vehicle can keep operating properly even if there is a failure in a critical system (fail-operational functionality). Fail-operational functionality is enabled by the vehicle's backup systems for all critical operations (system redundancy). We built redundancy into the self-driving vehicle's computers, critical networks, critical actuators and critical actuator controllers. For example, if the vehicle's main steering actuator fails, there is another steering actuator in a redundant system to take over, reducing the likelihood the vehicle will need to initiate a fallback safe-stop maneuver. And in the unlikely event that both primary and backup systems fail, the vehicle can bring itself to a safe stop (fail-safe functionality).

The second key safety performance threshold:
We evaluate the operations of all critical self-driving functions. This analysis includes both qualitative and quantitative evaluation of those functions. This approach is called "safety of the intended function," or SOTIF. Through this process, we establish that the computer's brain will safely handle the unpredictable circumstances that it will face on public roads. For example, before we put the vehicle into driverless operation in a city that has six-way stops, our vehicle will have demonstrated its ability to navigate the six-way stops many times, in all expected traffic, lighting and weather conditions. This training, as well as closed course and simulation activities, addresses safety challenges associated with navigating six-way stops.

Manufacturing supports system safety

We use our "built-in quality" method to identify defects that may arise during manufacturing, just as we do with each of our other production vehicles. We have assembly line quality checks for the components we build, for the subsystems we build, and when assembling the vehicles. These checks help us find components not built to our specifications and eliminate possible defects.

System safety through city testing and proving safe driving through experience

In our on-road testing, we currently use a fleet of self-driving vehicles that each have a steering wheel, brake pedal and accelerator pedal. These vehicles are monitored by trained human drivers (Autonomous

Vehicle Trainer, or AVT). During on-road testing, the AVT can take over control from the self-driving system when necessary or appropriate to be safe. Our vehicle's data logger records the driver takeover events. We analyze data from the logger to assess the vehicle's self-driving performance and to decide whether to update the software. When we update the software, we test it in simulations to confirm that it accounts for the conditions and circumstances leading to the takeover event and that it drives better than the previous software. We then test the updated software in our on-road testing program.

Testing in San Francisco allows us to develop the vehicle's self-driving skills more comprehensively than testing in a suburban location alone. Cities like San Francisco contain more people, cars and cyclists that our self-driving vehicles must be aware of at any given time. This rich environment tests our object detection, prediction and response functions. Stacked predictions — such as predicting that the car in front of our vehicle will brake because it is about to get cut off by a cyclist, or that a car making a left turn in front of us will yield to a pedestrian in a crosswalk — are not unusual. Similarly, stacked maneuvers — managing multiple road challenges together or in quick succession — are often necessary.

While we also test vehicles in Phoenix, our San Francisco vehicles predict an average of 32 times as many possible interactions as those in Phoenix. Thus, San Francisco challenges our self-driving system more because, as the number of objects increase, there are exponentially more possible interactions with objects that the self-driving system must consider.

Maneuver / Scenario	**San Francisco**	**Phoenix Suburbs**	**Ratio**
Left turn	1462	919	1.6:1
Lane change	772	143	5.4:1
Construction blocking lane	184	10	19.1:1
Pass using opposing lane	422	17	24.3:1
Construction navigation	152	4	39.4:1
Emergency vehicle	270	6	46.6:1

Per 1,000 miles of autonomous driving

OPERATIONAL DESIGN DOMAIN

The operational design domain (ODD) refers to the environment, including location, weather and speeds, in which the self-driving vehicle is designed to operate.

We will only deploy self-driving vehicles in environments where the vehicle can meet our performance thresholds. We determine the appropriate environments and conditions using our System Safety engineering process.

We rigorously test and validate our self-driving vehicles so that they have the skills and experience to navigate the environment safely. Through our test drives, we identify potential challenges in our proposed ODD. We then identify, track and implement solutions to those challenges. This process continuously improves the self-driving system's capabilities. We test and validate our self-driving vehicles in the wide variety of environmental conditions that the vehicle might face in its operational design domain — from driving scenarios the vehicle would face daily to the rare edge cases.

Our vehicle's ODD will include the streets in the cities where the vehicle will operate, and operation at all times of day and night, and in light-to-moderate inclement weather (e.g., fog or rain). The vehicles will remain within designated, premapped areas. The vehicle's computers treat these mapped areas as a strict boundary, or geo-fence, for the vehicle. As a result, the vehicle will choose only routes that fall entirely within the mapped area — every turn, every trip. Within the mapped areas, the vehicles will be capable of complying with all applicable traffic laws.

When the vehicle detects rapid or abnormal changes in weather conditions, it will adjust how it operates to accommodate the weather and how other road users are behaving, such as when traffic slows during heavy rain. At all times, our fleet will communicate with a centralized fleet operations center. This helps our vehicles avoid locations and conditions outside of their ODD.

As our development and validation continues and proves safe performance, we will expand the ODD to new cities and a wider variety of weather and speed conditions.

OBJECT AND EVENT DETECTION AND RESPONSE

Object and Event Detection and Response (OEDR) refers to the self-driving system's detection of, and appropriate response to, conditions and circumstances relevant to the immediate driving task.

Through our System Safety and extensive validation processes, our vehicle has robust capabilities to detect and respond to the range of conditions and circumstances it may encounter.

When our vehicle sees and understands the space around the vehicle, it exercises object and event detection capabilities. And when our vehicle plans its path, it exercises object and event response capabilities. There is more to the story.

Our vehicle's OEDR capabilities include detecting the environment around the vehicle, understanding the surrounding space, tracking objects in that space, safely planning its driving path through that space, and executing crash-avoidance maneuvers.

Our rigorous on-road testing in dynamic, real-world environments allows the vehicle to gain experience detecting and responding to circumstances that even human drivers find challenging — such as adjusting to jaywalking pedestrians and turning cyclists. To validate the vehicle's operational and crash avoidance capabilities, we analyze how the vehicle detects and responds in normal on-road test drives as well as in staged and edge case scenarios. Because our self-driving vehicle was designed to be automated from day one, we could build the vehicle to optimize how it detects and responds to conditions that arise. For example, we were able to optimize the number, type and location of sensors to enable the vehicle to perceive the environment with maximum clarity and precision. Our integrated design process also enables the vehicle to fully utilize its control system to respond to an event. For example, if another vehicle or person suddenly enters the lane in front of our vehicle, the vehicle can apply the full braking capability of the vehicle brake system to quickly stop the vehicle.

As discussed above, our self-driving vehicles use redundant systems to provide backup functionality. In a human-driven vehicle, if a system fails, we rely on an attentive human driver to serve as the backup. For example, if the power brakes fail in a conventional hydraulic brake system, the human can stop the vehicle by pressing the brake with more force than would normally be needed. In our self-driving vehicle, redundant systems provide the backup. For example, if the vehicle detects a potential crash and the primary brake actuator were to malfunction, the computers still have the ability to execute a crash avoidance maneuver by activating the backup brake actuator.

FALLBACK (MINIMAL RISK CONDITION)

Fallback is transition to a minimal risk condition (safe state) in the event of a problem with the self-driving system that prevents continued safe operation without the transition.

Our self-driving vehicles have features enabling transitions to safe states when necessary, including fail-operational functionality, system redundancy, fail-safe functionality and integrated diagnostics. The Cruise AV has diagnostics that continuously monitor the state of all critical self-driving systems as well as other vehicle systems necessary for safe operation.

The vehicle has two main sets of computers, one primary and one backup. They operate independently and simultaneously for self-driving decision-making. The vehicle includes separate and redundant networks to connect the computers, and a comprehensive set of diagnostic monitoring capabilities. Each set of computers has its own diagnostics, providing the ability for each computer to diagnose other computers and other parts of the self-driving system. In addition, critical functions such as steering and braking have separate and redundant controllers and actuators.

Should a malfunction occur, the diagnostics system determines whether the appropriate response is a fail-operational state or a fail-safe state, and transitions the vehicle to the corresponding safe state. When required, the self-driving system will operate the vehicle at a reduced speed or pull to the side of the road and execute a safe stop, as appropriate. In all events, the vehicle's state is continuously transmitted to the computers within the self-driving system, and Planning uses that information to plan an appropriate path and action.

Consistent with our System Safety approach, our fallback measures account for residual risks that we identified through risk analyses. Following the principles of military systems safety standards to eliminate risks wherever possible, we designed our systems to withstand many conditions that would otherwise require fallback measures that would reduce performance.

A primary reason we applied robust redundancy is so that our vehicle's fallback state allows safe continued operation as often as possible. This is the best approach for our customers.

VALIDATION METHODS

Validation methods verify that the self-driving system appropriately minimizes risks during operation.

Our System Safety process supports robust validation of our vehicle's structural systems, functional systems, self-driving skills and self-driving performance through experience.

As we design and develop our vehicle, our System Safety process provides a comprehensive approach to identifying safety risks and their potential root causes. With that information, we identify the design requirements for our vehicle to meet our safety performance thresholds. During development, we track how those requirements addressed risks. And we validate the end result so that the self-driving system performs its defined functions and does so reliably.

Validation includes track testing, staged encounters, test cases and simulations to test our self-driving vehicle itself against a variety of objective tests and performance requirements. We also validate with on-road performance testing, where we are collecting millions of miles of test data to show on a statistically significant basis that our vehicle is a safe driver.

In addition to these efforts, we are performing extensive research regarding human driving behavior. Our research includes analysis of existing driver behavior studies and conducting new driver behavior studies to expand the existing data set. These studies help us define and analyze self-driving system performance requirements.

We are presently collecting self-driving vehicle on-road performance data, including miles driven, crashes and take-over events, to build a statistically significant analysis of the vehicle's performance for comparison to human drivers in the same relevant driving environment. Over the course of millions of miles of testing in the relevant operating domain, these comparisons will allow us to demonstrate the safety of the self-driving vehicle within the ODD.

Our combination of conventional system validation with SOTIF validation of self-driving capabilities thoroughly verifies system safety. Here are examples of how we implement both approaches.

Examples of our conventional validation processes include:

- Vehicle-, system-, subsystem- and component-level performance tests
- Requirements-based validation of system, subsystem and components
- Fault injection testing of safety-critical control input, outputs, computation and communication

- Validation of fail-over (transitioning to a secondary control path when the primary path malfunctions) and safe state transitions within the fault tolerant time interval
- Intrusive testing, such as electromagnetic interference and electromagnetic compatibility testing, as well as other environmental element exposure tests (includes temperature, humidity, RF, light energy)
- Durability tests
- Regression and simulation-based software validation

Examples of our SOTIF validation processes include:

- Systematic exposure of the self-driving system to performance requirements of the Operating Design Domain
- Identifying and iteratively testing driving scenarios and edge cases that challenge the self-driving system
- Exercising the Object and Event Detection and Response capabilities of the vehicle and its ability to identify environmental objects and situations that require a safe behavior response
- Evaluation of self-driving behavior against safe driving standards with both qualitative and quantitative criteria

HUMAN MACHINE INTERFACE

The human machine interface (HMI) is the interaction between the vehicle and persons inside and outside the vehicle.

We designed our HMI to be intuitive and helpful to customers riding in our vehicles. This is true whether or not customers are technology savvy or they need hearing or visual accommodations. As part of our approach, we identify and address challenges that could arise from the interaction of the vehicle with passengers, or with road users external to the vehicle.

Interfacing with vehicle occupants

Customers will begin their interaction with our self-driving vehicle before they get in the vehicle by using a mobile application to request a ride. Once inside the vehicle, the customers will use touch-screen tablets with an intuitive interface allowing riders to control the HVAC and radio, access general information about the vehicle, and receive real-time status information pertinent to the current ride. Before the ride begins, the tablets will provide helpful safety reminders, such as to close all doors and fasten seat belts.

With the press of a button, passengers can ask any questions they may have. The vehicles will also have OnStar Automatic Crash Response. With more than 20 years of connected vehicle experience, OnStar can respond effectively in the event of a crash. Built-in sensors can automatically alert an OnStar Advisor and predict the severity of injuries. An Advisor is immediately connected into the vehicle to see if passengers need help, even if they can't ask for it. In addition, a push of the red OnStar emergency button gives passengers a priority connection to an OnStar Advisor who can direct emergency services to the vehicle's exact location and stay in communication with passengers until help arrives.

After customers enter the vehicle and meet all preconditions, such as closing the doors and pressing the begin ride button, the vehicle will start to move. At any point, a customer having an emergency may end the ride by making a stop request, and the vehicle will pull to the side of the road at the next available safe place. If the vehicle has a malfunction, it will provide explanatory information to the passengers, as well as offer communications with a remote operator.

Accessibility: The vehicles will accommodate hearing and visually impaired individuals so they can experience our self-driving vehicle services. These accommodations will be available in the mobile app and for the in-vehicle experience, including the in-vehicle tablets and communications with our remote operators. With these accommodations, our self-driving vehicles will provide mobility for many people who cannot drive themselves.

Interfacing with other road users

Our self-driving vehicle is designed to interact with other road users in a manner expected of typical human drivers engaged in safe driving practices. Our System Safety approach requires the Cruise AV to understand the behavior of other road users, including pedestrians, bicyclists and motorcyclists, and to account for those behaviors so it can operate safely. Our approach also drives requirements to understand and follow laws associated with other road users.

Interfacing with first responders

We have a long history of working with public safety and first responders when introducing new technology. Our OnStar business has for years worked with law enforcement and other first responders to educate them and obtain their input on the OnStar experience. When we introduced our revolutionary Chevrolet Volt, we conducted nationwide safety tours. We talked to the NationalFire Protection Agency, the International Association of Fire Fighters, the International Association of Fire Chiefs, the Association of Public-Safety Communications Officials, fire chiefs, police chiefs and 911 call centers. We trained over 15,000 people across the nation on safety protocols related to the Volt. Our established relationships, commitment to safety and experience in training on new technologies prepare us well for introducing self-driving vehicles. As we advance this new safety technology, we will inform, seek feedback from, and otherwise assist public safety officials and first responders so they are prepared when these vehicles are deployed.

In addition, our self-driving vehicles will have two-way communications capabilities allowing first responders to communicate with our remote advisors if needed.

VEHICLE CYBERSECURITY

Cybersecurity protects the vehicle control systems and customer information from unauthorized access.

Cybersecurity protects the operation of the self-driving system and other critical vehicle systems from malicious interference and supports high customer confidence in our vehicle's operation and use.

Our dedicated cybersecurity specialists are integrated with the rest of the self-driving vehicle development team to build cybersecurity into our Systems Safety engineering process. This team analyzes and addresses cybersecurity for all in-vehicle control systems, as well as any self-driving vehicle connected services (such as OnStar), mobile apps and in-vehicle apps created for the self-driving experience. The development team uses integrated systems security engineering practices, and a "security-by-design" strategy, to address security requirements for the entire self-driving vehicle ecosystem.

As with other areas of the vehicle, thorough use of analysis and evaluation tools, such as software scans and threat models, drive design features that respond to the risks of cybersecurity. These features, based on a "defense-in-depth" approach, include a variety of mitigating controls, such as device registration, message authentication, secure programming and diagnostics, and intrusion detection and prevention systems. During implementation and validation, we use additional tools, such as penetration testing, to verify that implementation meets our goals of eliminating and minimizing risks. In addition, our active fleet management process will allow service technicians to regularly monitor vehicles for security-related abnormalities. If needed during deployment, we have robust incident response capabilities to monitor and address potential new cyber risks.

We work with many third parties to maintain and advance our cybersecurity capabilities, implement and advance cybersecurity guidelines and standards, and support the growth of industry cybersecurity practices. These activities include working with our suppliers, joint ventures, various automotive and security consortia, government agencies, the security research community and the Auto-ISAC. In addition, we regularly assess our security practices against guidance from NHTSA, NIST, Auto-ISAC and other industry experts.

CRASHWORTHINESS

Protecting occupants in the event of a crash (e.g., when another vehicle crashes into the self-driving vehicle).

The best protection against crashes is to avoid them. Our Object and Event Detection and Response system is designed to do just that.

For crashes that do occur, our engineering and validation of the vehicle's occupant protection system performance accounts for the self-driving system integrated into the vehicle. Our performance testing (including crash testing) encompasses the performance of the entire vehicle with the self-driving system included.

Our self-driving vehicle structure is based on the Chevrolet Bolt EV. We analyzed structural integrity to account for the addition of several new key systems (for example, the sensor roof module, sensor cleaning and drying system, power backup system and data management system) to the vehicle. This work supported our integrated structure crashworthiness strategy starting in the early stages of the program to include:

- Engineered load paths to manage crash forces to protect occupant space during frontal, side, rear and rollover crashes;
- A battery housing structure that protects the internal battery space in a crash; and
- Vehicle floor reinforcements to distribute loads and maintain occupant space in a crash.

We have completed sufficient simulations and crash testing of our self-driving vehicle prototypes to show the effectiveness of the above requirements.

When we took out the items that the vehicle doesn't need — the steering wheel, brake pedal, accelerator pedal and other human driver controls — the left front seat became another forward-facing front passenger seat. Other than that, the self-driving vehicle seating arrangement is the same as the current NCAP five star Chevrolet Bolt EV. We designed the air bags and seat belts for the left front passenger seat to meet the same injury protection criteria, including those specified in Federal Motor Vehicle Safety Standards (FMVSS), as the right front passenger seat. And for systems beyond the left front passenger seat, the vehicle meets all federal crashworthiness standards.

The self-driving vehicle will accommodate customers installing FMVSS certified child seats for children in the rear.

Our all-electric self-driving vehicle also incorporates battery safety measures. It includes a reinforced structure for the battery compartment and is equipped with a crash-safety system that cuts power in the event of a collision, making it safer for first responders.

POST-CRASH BEHAVIOR

After a crash, the vehicle should return to a safe state.

Our requirements for post-crash behavior account for both physical safety and standard practices in the event of a crash.

In general, after a crash the vehicle will enter a safe state. Typically, the vehicle will automatically apply brakes to bring the vehicle to stop in a controlled manner after the initial impact. Built-in sensors will automatically alert an OnStar Advisor, who will be connected promptly to see if a passenger needs help and to communicate with first responders on the scene. If passengers don't respond, an OnStar Advisor uses GPS technology to pinpoint the exact location of the vehicle and request that emergency help be sent immediately. The self-driving vehicle crash response system will also unlock the doors and turn on the hazard lights (flashers) following the crash.

Our physical safety systems incorporate safety measures discussed above. In addition to the battery disconnect that cuts power in the event of a crash, the vehicle has a second battery disconnect. That disconnect is located underneath the rear seat and is intended for use by first responders or service technicians.

DATA RECORDING

Learning from crash data is a central component to the safety potential of self-driving vehicles.

Our self-driving vehicle has two data recording features — a conventional Event Data Recorder (EDR) and a second robust data logging system. The data logging system is highly reliable, has self-diagnostics, and stores data securely, protecting it against loss. The data logging system is designed to be fail-operational and to keep data intact even in the event of a crash. If a crash occurs, the data logging system stores predefined data from the vehicle. The collected data includes information on sensors, vehicle actions, any degraded behavior, malfunctions and other information useful for event reconstruction.

In addition to crashes, our vehicle's robust data recording capability provides information on vehicle performance during normal driving and avoided crash situations. We have IT teams in multiple states building computer systems to store and process data that we retrieve from our vehicles. With this retrieved data, we can evaluate design and driving performance during vehicle development and deployment, and for continuous improvement for future generations of self-driving vehicles.

CONSUMER EDUCATION AND TRAINING

Education and training are imperative for increased safety during the deployment of self-driving vehicles.

During development, we considered what consumers need to know to interact with our self-driving vehicle. The vehicle is designed for an intuitive and familiar user experience in a ride-sharing service. The mobile application, in-vehicle touch screens and other user interfaces will provide helpful information and safety reminders. Because we will deploy our vehicles in a self-driving ride-sharing service, consumers will not have a role in operating the vehicle itself. The intuitive interface, coupled with the ability to talk to remote support personnel, will provide all the information that customers need.

When the ride-share service is launched, we plan to publish material informing consumers about what to expect when using the service to obtain rides. This information will explain how to request rides, how to identify the self-driving vehicle that is assigned for the requested ride, what to expect during the ride, and what to expect when the ride ends.

FEDERAL, STATE AND LOCAL LAWS

Under our System Safety process, we develop requirements for compliance with federal, state and local laws and analyze the impact of those requirements within our safety development program.

Federal laws

Our self-driving vehicle will comply with federal laws. The vehicle will meet all applicable federal motor vehicle safety standards (FMVSS). Where FMVSS cannot be met because they are human-driver-based requirements, the vehicle will meet the safety purposes of those standards and we will petition for exemption (permission to meet the safety purpose of a standard through alternative means). We have filed such a petition for the Cruise AV.

We are also working with industry groups and NHTSA to advance the development of new FMVSS that will (a) remove unnecessary roadblocks to new safety technology, such as self-driving vehicles, and (b) advance the safety of self-driving vehicle technology.

The self-driving vehicle will also comply with federal laws and regulations relating to fuel economy, emissions, noise, hazardous materials and labelling requirements.

State and local laws

We designed our Cruise AV to be capable of complying with state and local laws applicable in its operational design domain.

In addition, we will comply with non-traffic-related state and local laws, such as insurance requirements, reporting requirements related to field incidents and interventions, and others. We will communicate with and educate first responders on how our self-driving vehicles implement local law requirements (like where to find the registration and insurance) and what first responders can expect when encountering our self-driving vehicles.

CONTINUING TO CREATE AND IMPROVE NEW TECHNOLOGY

And we're not stopping. We're adding to our roster of talent in California, Michigan and elsewhere, and we're expanding our capabilities with new components and systems technologies — all of which will advance safety and performance. We are developing new computer systems and sensor technologies, such as LiDAR, to make the technology more affordable and available for customers, and to continue to advance the safety performance abilities of our self-driving cars to levels far beyond human drivers. Our self-driving vehicles have the potential to reduce vehicle crashes and save lives, to reduce vehicle emissions, to reduce congestion and save people time, and to make transportation more accessible to more people — bringing our vision of a world of zero crashes, zero emissions and zero congestion closer to realization.

GENERAL MOTORS